

# AGRO PRODUCTIVIDAD

Foliar application  
of amino acids  
improves growth  
and productivity of  
**RADISH**  
(*Raphanus sativus* L.)

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**Agradecimientos:** Son opcionales y tendrán un máximo de tres renglones para expresar agradecimientos a personas e instituciones que hayan contribuido a la realización del trabajo.

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# Physiological quality and its relation to the maturity stages of maize seeds

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## ABSTRACT

**Objective:** To determine the physiological quality of maize seeds from the F6 (Yellow×V-54A) experimental variety and its relation to the maturation stages of the seeds, as well as its association with physiological maturity.

**Methodology:** Eight cob samples were assessed to determine the presence of milk line and black layer, moisture content, and dry matter accumulation during seed maturation. A germination test was used to establish physiological quality. The experiment included a completely randomized design with replicated measures at 5% significance.

**Results:** The milk line decreased (100 to 10%) and the black layer gradually appeared (0 to 99%) as seeds matured. Moisture content decreased (58.1 to 25.4%) as sampling progressed, resulting from the highest biomass accumulation (74.6%) and physiological quality (72.5%). The percentage of ungerminated seeds reached 94.3% when seeds were immature; however, this percentage decreased to 18.5% at physiological maturity. Seedling abnormalities ranged from 3.8 to 16.8%.

**Conclusions:** The physiological quality of maize seeds depended on their physical attributes rather than on their physiological maturity.

**Keywords:** *Zea mays* L., milk line, black layer, physiological maturity.

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## INTRODUCTION

Seed production largely depends on the environmental conditions that take place during the growth and development of the crops (Miya *et al.*, 2017). Some indicators of the physiological maturity of maize include moisture content, maximum dry matter accumulation, and presence of black layer. These parameters are used to determine the quality of the seeds (Ferreira *et al.*, 2013; Sripathy and Groot, 2023).

The maximum accumulation of dry matter takes place when the seed reaches its physiological maturity ( $\approx 35\%$  moisture) (Tadeo-Robledo *et al.*, 2010). Subsequently, several physiological processes take place, depending on environmental conditions.



These processes contribute to the deterioration of the seed. In this regard, Jacob *et al.* (2014) suggested that crops must be harvested as soon as possible after they reach their physiological maturity. Some morpho-physiological changes have been identified as indicators of physiological maturity: the presence of the black layer, the disappearance of the milk line, and the decrease of moisture content (Estrada-Urbina *et al.*, 2023a). Meanwhile, Bewley *et al.* (2013) and Dayal *et al.* (2014) indicate that harvest maturity occurs in a 7-10-day interval after the seeds have reached physiological maturity (<20% moisture content). Nevertheless, these characteristics depend on genotype and sowing date.

In other studies, the seed quality is related to their maturity. Consequently, the highest germination rate takes place when the seeds have a high moisture content, before they reach physiological maturity (Carvajal *et al.*, 2017; Mancera and Ramírez, 2018). In addition, the maximum seed quality potential is recorded when they accumulate the highest dry matter percentage and the lowest moisture level (Lozano-Pérez, 2021). Therefore, the objective of this study was to determine the physiological quality of maize seeds from the F6 (Yellow×V-54A) experimental variety and its relation to the maturation stages of the seeds, as well as its association with the morphological markers related to physiological maturity.

## **MATERIALS AND METHODS**

### **Location of the experiment and plant material**

The study was carried out in the Análisis de Semillas lab of the Colegio de Postgraduados - Campus Montecillo (19° 27' 54.7" N and 98° 54' 24.3" W). The F6 (Yellow×V-54A) experimental maize (*Zea mays* L.) variety was used in the experiment. This variety was grown and harvested during the spring-summer season (year 2022), in experimental fields of the Colegio de Postgraduados.

### **Seed sampling**

Eight samples were taken from five cobs. The first was at 20 days after flowering (daf) —*i.e.*, 106 days after sowing (das). Afterwards, the samples were collected in a seven-day interval until the seeds reached physiological maturity (PM). In order to guarantee the highest possible homogeneity and to prevent damages, harvesting was carried out only in phenotypically identical plants.

### **Milk line and black layer**

For each sampling, lengthwise sections were used to visually determine the presence of the milk line (ML) and the black layer (BL) in 100 seeds (Estrada-Urbina *et al.*, 2023a). In addition, the presence of the black layer was registered in eight repetitions of 25 seeds. PM was taken into account when 100% of the seeds had BL (Molina *et al.*, 2003).

### **Moisture content and dry matter**

Moisture content (MC) was determined according to the methodology of the International Seed Testing Association (ISTA, 2021a), by drying two replicates of 5 g of maize at  $130 \pm 2$  °C for 4h. Afterwards, MC was calculated with equation 1.

$$MC = \frac{(IWS - WDS)}{(IWS - WT)} * 100 \quad \text{Equation 1}$$

Where  $MC$ =moisture content (%);  $WT$ =weight of the metal tray (g);  $IWS$ =initial weight of the seed before the drying process (g);  $WDS$ =weight of the dried seed in the metal tray (g).

Seed dry matter (DM) was determined using a similar method than the one used for MC. The results were expressed as accumulated biomass percentages and were calculated with equation 2.

$$DMS = \frac{(WDS * 100)}{(IWS)} \quad \text{Equation 2}$$

Where:  $DMS$ =dry matter of the seed (%);  $IWS$ =initial weight of the seed in the metal tray before the drying process (g);  $WDS$ =weight of the dried seed in the metal tray (g).

### Physiological quality

Physiological quality was determined with the standard germination test (GER) in eight replications of 25 seeds, which were placed in Anchor<sup>®</sup> paper towels, previously soaked in distilled water. Subsequently, the paper towels were rolled up and placed inside a germination chamber at  $25 \pm 1$  °C for 7 days, with a 24 h white light photoperiod. After the incubation period, the seedlings were evaluated based on the criteria of the ISTA (2021b) regarding the number of normal (NNS) and abnormal seedlings (NAS), as well as ungerminated seeds (NUS). The following equations were used to determine physiological quality:

Equation 3 was used to determine the germination percentage.

$$GER = \frac{NNS}{25} * 100 \quad \text{Equation 3}$$

Where:  $GER$ =germination percentage and  $NNS$ =number of normal seedlings.

Equation 4 was used to calculate the percentage of abnormal seedlings.

$$ABNOR = \frac{NAS}{25} * 100 \quad \text{Equation 4}$$

Where:  $ABNOR$ =percentage of abnormal seedlings and  $NAS$ =number of abnormal seedlings.

Equation 5 was used to establish the percentage of ungerminated seeds.

$$NOGS = \frac{NUS}{25} * 100 \quad \text{Equation 5}$$

Where:  $NOGS$ =percentage of non-germinated seeds and  $NUS$ =number of ungerminated seeds.

### Experimental design and statistical analysis

A complete randomized design with repeated measures for the sampling factor was used for the experiment. The analyses of variance (ANOVA) were conducted at an  $\alpha=0.05$  significance with the first-order autoregressive matrix covariance, in order to obtain the lowest value of BIC (Bayesian Information Criterion). ANOVA were carried out with the following statistical model,

$$y_{ij} = \mu + Mue_i + \varepsilon_{ij}$$

where:  $y_{ij}$ = $i$ -th sampling response, in the  $j$ -th replication;  $\mu$ =overall mean;  $Mue_i$ =fixed effect of the  $i$ -th sampling;  $\varepsilon_{ij}$ =experimental error.

The data in percentage were transformed using the  $\arcsen\sqrt{(y/100)}$  equation, to homogenize the variances for their subsequent analysis. When the ANOVA showed statistical differences, the Tukey's test ( $\alpha=0.05$ ) was employed.

All data were analyzed in RStudio software (R Core Team, 2022).

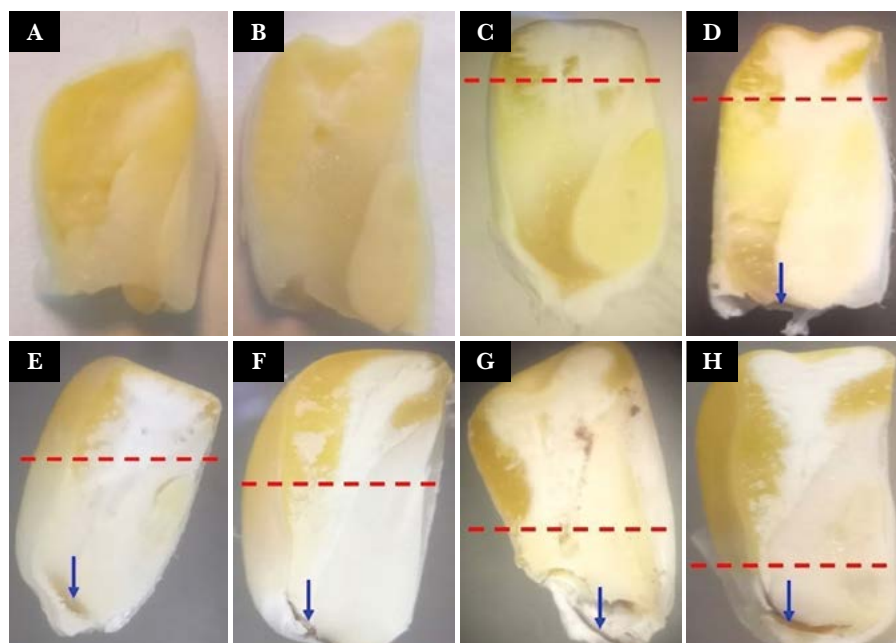
## RESULTS AND DISCUSSION

### Milk line and black layer

From 20 to 27 daf, the seeds were immature and the grains had a liquid endosperm (milky texture). At 27 daf, there was decrease of the ML of 15%, from the crown to the pedicel of the grain. At 34 daf, the ML recorded a 20% decrease. Regarding the harvests that took place between 48 and 69 daf (134-155 das), the ML decreased towards the pedicel around 50, 45, 25, and 10% (Figure 1).

At 20, 27, and 34 daf, the seeds were immature and, consequently, no visual proof about the presence of the BL was observed. Therefore, the ANOVA did not detect any significant difference ( $p>0.05$ ) during these development stages. During the 41-69 daf period, significant statistical differences ( $p<0.05$ ) were found. In addition, at 41 daf (127 das), a faint and greyish BL was detected in 27% of the seeds. Consequently, this period was identified as the beginning of physiological maturity (BPM).

The presence of the BL increased as the samplings progressed and, finally, it became totally dark. From 41 to 48 daf, the BL of the seeds increased 59%, while from 55 and 62 daf, it increased at a lower rate. The BL percentage for these periods reached 67.5 and 78.5%, respectively. Finally, a dark BL was completely visible in 100% of the seeds at 69 daf (Figure 2). Therefore, based on the visible black color of the BL (Figure 1), the seeds reached their PM at 69 daf —*i.e.*, 155 das. In this regard, Mancera and Ramírez (2018) pointed out that the BL is the best PM indicator. They estimated that the BL percentage in the seed should be  $>75\%$ . However, they also considered that the ML is a more practical parameter. Consequently, taking into account both morphological parameters is fundamental to draw a better inference of the PM. The visual evaluation of the F6 (Yellow  $\times$  V-54A) experimental variety showed that the plant material was immature during the first two samplings (20 and 27 daf), when the endosperm had a liquid texture (100% ML) and the seeds did not have the BL. As the samplings progressed, the endosperm started to solidify and the BL



**Figure 1.** Advance of the milk line and presence of the black layer as indicators of the physiological maturity of the F6 (Yellow×V-54A) experimental maize (*Zea mays* L.) variety. The red line shows the advance of the milk line from the crown to the pedicel of the seed. The blue arrow points out the presence of the black layer in the placenta area of the seed. A) 20 daf; B) 27 daf; C) 34 daf; D) 41 daf; E) 48 daf; F) 55 daf; G) 62 daf; and H) 69 daf.

became more noticeable as the seeds reached their PM. These results match the findings of Martínez-Álvarez (2015) and Lozano-Pérez (2021).

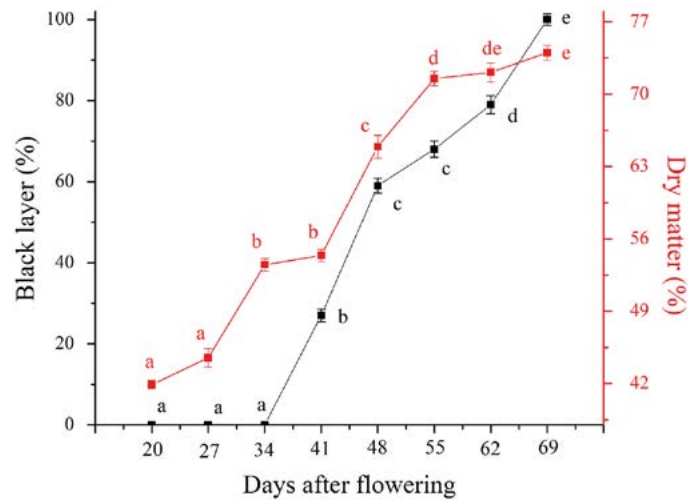
### Dry matter

The dry matter weight gain at 20 and 27 daf (41.9 and 44.5%, respectively) was not statistically significant ( $p > 0.05$ ). At 34 daf the DM increased 8.7% compared to the previous sampling, and 1.4% at 41 daf. Nevertheless, DM content did not registered statistically significant differences ( $p > 0.05$ ) between these two harvesting stages. At 48 daf, the behavior was similar than at 34 daf: DM was 10.5% higher than in the previous harvest. Finally, the grains accumulated the highest DM percentage (71.5%) at 55 daf. In addition, they continued recording a lower accumulation until they reached their physiological maturity (Figure 2).

Zavala-Hernández *et al.* (2015) reported that maximum dry matter accumulation is an indicator of the PM, while Ferreira *et al.* (2013) stated that PM is associated with the presence of the BL in all the seeds and the disappearance of the ML. In this study, the seeds reached the PM with a 74.6% dry matter accumulation and 100% BL. These results match the findings of Bewley *et al.* (2013), who linked dry matter content with the physiological maturity of the seeds.

### Moisture content

The seeds recorded 58.1% MC at 20 daf; however, this percentage decreased by 2.7% at 27 daf (Figure 3). No statistically significant difference was recorded in both cases ( $p > 0.05$ ).

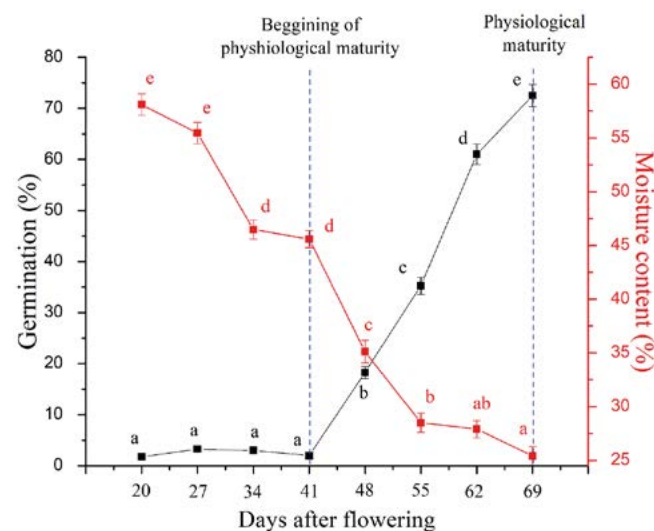


**Figure 2.** Dry weight gain and presence of the black layer (BL) during the maturation period of the seeds of the F6 (Yellow×V-54A) experimental maize (*Zea mays* L.) variety. Mean value ± standard error. Means with different letters in each sampling are statistically different (Tukey,  $\alpha=0.05$ ).

From 34 to 41 daf, MC decreased by 0.9%, recording 46.5 and 45.6%, respectively. Likewise, no statistically significant differences ( $p>0.05$ ) were recorded between them.

From 20 to 41 daf, MC decreased 12.5%. This last period was established as the BPM of the seed, given the appearance of a faint BL (27%) (Figures 1 and 2). From 48 to 69 daf, MC decreased 10.4, 17.1, 17.7, and 20.2% in relation to the BPM. Consequently, the F6 (Yellow×V-54A) experimental variety reached its PM when the seeds recorded a 25.4% MC (Figure 3), 100% BL, 10% ML, and 74.6% DM.

MC could be one of the main causes of seed deterioration: as it increases, a significant germination decrease takes place, as a result of the increase of cellular respiration (Estrada-



**Figure 3.** Relation between the germination percentage and moisture content during the maturation process of F6 (Yellow×V-54A) experimental maize (*Zea mays* L.) variety. Mean value ± standard error. Means with different letters in the eight samplings are statistically different (Tukey;  $\alpha=0.05$ ).

Urbina, 2022). Magdaleno-Hernández *et al.* (2020) pointed out that, during the formation and maturation processes, maize seeds undergo physiological, chemical, and physical changes (such as the increase of cellular respiration), which directly impact germination. For their part, Ghassemi-Golezani *et al.* (2011) mentioned that the maximum physiological quality of maize seeds is related to their maximum dry matter accumulation and their lower moisture content. Consequently, the lack of germination during the first four samplings (from 20 to 41 daf) could be the result of a high MC (58.1-45.6%), a doughy-liquid endosperm (100-50% ML), and a low BL presence (0-27%).

Likewise, this study recorded that germination reached 72.5% when MC decreased to 25.4%. These results match the reports of Mishra *et al.* (2023), who linked the physical with the physiological elements, because moisture content highly impacts seed maturity degree and quality. According to Sripathy and Groot (2023), dry matter accumulation—an indicator of physiological maturity—is the best sign of maximum quality seeds.

### Physiological quality

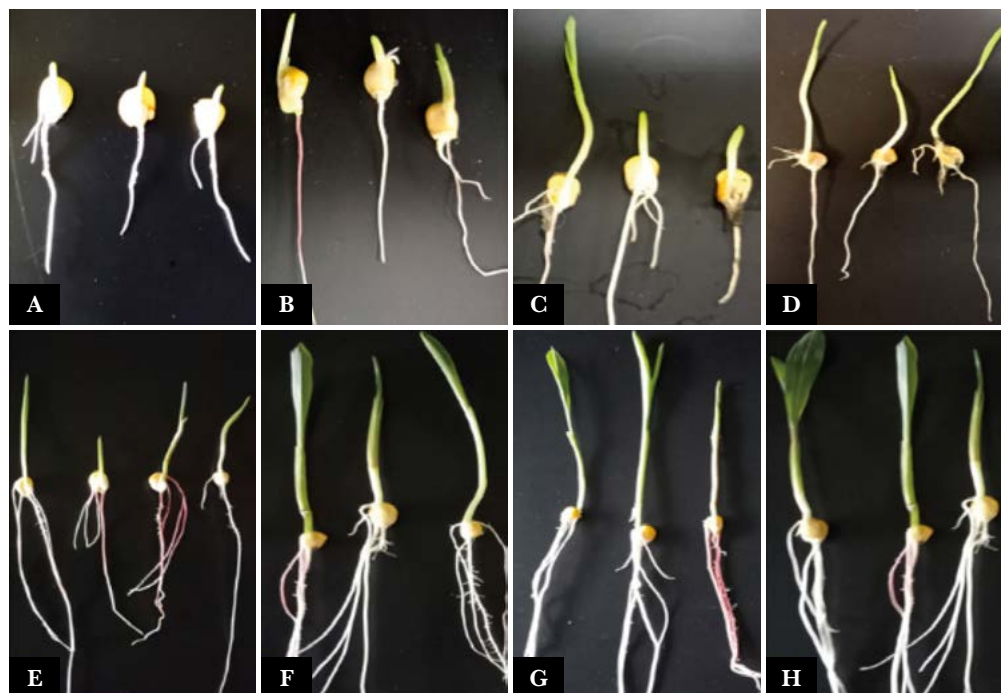
Germination was not statistically different at 20 (1.8%), 27 (3.3%), 34 (3.0%), and 41 daf (2.0%). However, it increased by 16.3% at 48 daf (Figure 3). The 41 daf harvest was established as the BPM, recording a 27% BL and a 50% decrease of the ML in the seeds. Meanwhile, germination increased 70.5% from the BPM to the PM of the seed (69 daf). Consequently, the seeds of the plant material used in this study reached their PM with a 72.5% maximum germination. In this regard, the physiological quality of maize seeds depends on their maturation degree. Therefore, in contrast with immature seeds, a higher germination is achieved when the seeds reach their PM (Escobar-Álvarez *et al.*, 2024b).

However, MC affected germination percentage of the F6 (Yellow×V-54A) experimental variety (Figure 3). This situation was the result of the maturation process of the seeds, which is highly influenced (88%) by their moisture content (Estrada-Urbina *et al.*, 2023b). Consequently, the high MC of the seeds diminished their germination. Likewise, Rosabal-Ayan *et al.* (2014) mentioned that germination involves cellular (enzymatic activation) and genetic changes (protein hydration, respiration, cell proliferation, or gene activation). Immature seeds cannot produce new plants, because they are not fully developed; meanwhile, the food material translocation to the seed stops during its physiological maturity, reaching its highest quality level. However, the moisture content is still too high (20%) to store the seeds (Dayal *et al.*, 2014).

### Normal seedlings

Figure 4 shows the growth and development evolution of the normal seedlings, from their earliest stages to their PM. Figures 4A and 4B show that the seedlings were underdeveloped when the seed was immature. In the case of the first and second samplings, the coleoptile had a <20.0 mm development, growing longer as the subsequent harvests took place. Figures 4C and 4D show a better coleoptile development. The emergence of the cotyledonary leaf is evident.

The coleoptile of some seedlings had a slight malformation (Figures 4C and 4D). This situation is the consequence of the position of the seeds in the Anchor<sup>®</sup> paper towels: adjacent

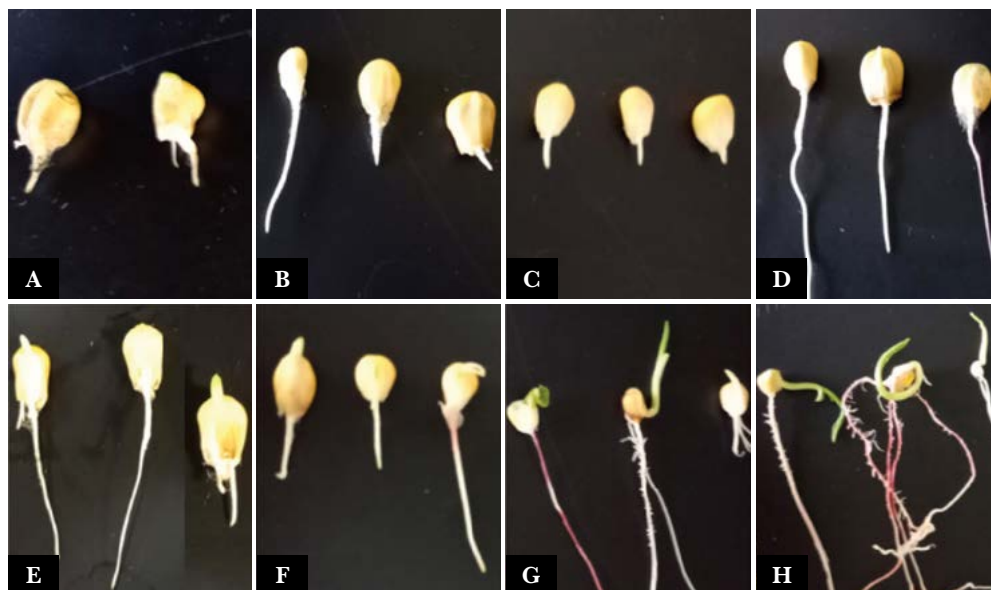


**Figure 4.** Growth and development of normal seedlings from the germination test of the F6 (Yellow×V-54A) experimental maize (*Zea mays* L.) variety. A) 20 daf; B) 27 daf; C) 34 daf; D) 41 daf; E) 48 daf; F) 55 daf; G) 62 daf; and H) 69 daf.

seeds served as a barrier for the upright growth of the seedlings and, consequently, these seedlings were not classified as abnormal (ISTA, 2021b). In addition, the secondary roots grew gradually. In the samplings carried out after the BPM (48 daf), the seedlings showed a better development of the secondary roots and primary leaves (Figures 4E and 4H). The cotyledonary leaf and the first true leaf appeared at 55 and 62 daf, respectively. Once the seeds reached their PM, the seedlings showed their maximum growth and development potential, in comparison to the previous stages when the seeds were both immature and starting to mature. Escobar-Álvarez and Estrada-Urbina (2024a) visually detected the differences regarding the quality of the seedlings from maize seeds with two degrees of maturation. The seedlings from PM seeds were more vigorous, since the development of the cotyledonary leaf and the secondary (coronary and seminal) roots were fundamental to determine their quality.

### Abnormal seedlings

Figure 5 shows that the coleoptile growth and development were inhibited from 20 to 34 daf. The Figure also includes the emergence of a 3.0-12.0 mm primary root (with a damaged root cap) and the lack of development of secondary roots (Figures 5A, 5B, and 5C). Regarding the BPM (41 daf), the main root was approximately eight times bigger than in the previous sampling. The root system was damaged and no secondary root development was recorded. The coleoptile development remained difficult until 55 daf and, in this same structure, the filling of leaf primordia never exceeded 50% (Figures 5D, 5E, and 5F).



**Figure 5.** Growth and development of abnormal seedlings from the germination test of the F6 (Yellow X V-54A) experimental maize (*Zea mays* L.) variety. A) 20 daf; B) 27 daf; C) 34 daf; D) 41 daf; E) 48 daf; F) 55 daf; G) 62 daf; and H) 69 daf.

Foliar structures grew in the coleoptile when the seeds reached a more advanced maturity (62 daf). Even during this stage and until their PM, the coleoptile of some seedlings was deformed (rolled-up shape), while other seedlings grew laterally or with a positive geotropism.

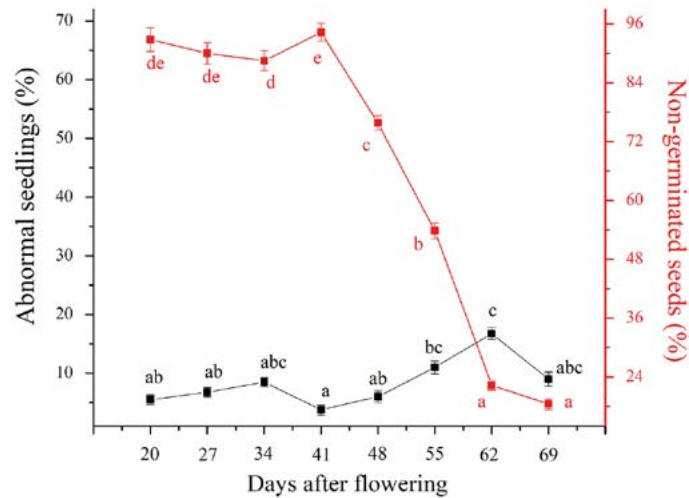
In addition, malformations and maldevelopment of the primary and secondary roots (Figures 5G and 5H) were identified. All these malformations are included in the ISTA (2021b) rules for the germination test. Clear malformations, deficiencies, and weakness in the root system and foliar structures were observed. These seedlings were classified as abnormal, because their main structures were deformed and prevented their optimal development, from the beginning of their maturity to their PM (Guillén-de la Cruz *et al.*, 2018).

During the germination test, all seedlings without main structures, malformed, badly damaged, sick, or rotten, were classified as abnormal and were not taken into account for the germination percentage. These seedlings were not expected to become normal plants, impacting their growth in the fields (Vujosevic *et al.*, 2018).

The ABNOR variation recorded statistically significant differences ( $p < 0.05$ ) throughout the evaluation period. The highest percentages of abnormalities were recorded at 55 and 62 daf: 8.5 and 16.8%, respectively (Figure 6). The abnormal seedlings recorded the same behavior pattern during the experiment. This pattern was divided into two periods: i) 20-41 daf and ii) 48-69 daf. The percentage of ABNOR was lower during the first period and it increased during the BPM.

### Non-germinated seeds

The percentage of non-germinated seeds (NOGS) fluctuated between 88.5 and 94.3% from 20 daf to the BPM. However, from 48 to 62 daf, NOGS decreased  $\approx 72\%$ . Therefore,



**Figure 6.** Morphological alteration of the maize seeds maturation of the F6 (Yellow×V-54A) experimental maize (*Zea mays* L.) variety alteration recorded in the germination test. Mean value  $\pm$  standard error. Means with different letters in the eight samplings are statistically different (Tukey,  $\alpha=0.05$ ).

NOGS at 48, 55, and 62 daf were statistically significant between each period ( $p<0.05$ ), recording 75.8, 53.8, and 22.3%, respectively. Finally, NOGS recorded 19% when the seeds reached their PM (Figure 6). In this regard, immature seeds reached the highest ABNOR and NOGS percentages in this study, as a result of the lack of the nutrients required to complete the development process. Consequently, the embryo could not reach a satisfactory growth (Alves *et al.*, 2018). Likewise, the high MC could promote a high metabolic activity (cellular respiration) that resulted in seed deterioration —*i.e.*, a low physiological quality (Pardo-Varela, 2016). One of the factors that contribute to a high physiological quality of the seeds is a timely harvest. There are several adverse environmental conditions, which accelerates the deterioration process of the seeds during their maturation; consequently, it is important to identify the right moment of the harvest of seeds. This activity (harvest) is usually associated to the physiological maturity of the seeds. However, seeds have their highest moisture content in that stage, hindering the harvesting process (Sripathy and Groot, 2023). This research suggests that the best time to the seed harvest is when they reach the physiological maturity. On the other hand, Estrada-Urbina *et al.* (2023b) indicate that maturity does not match maximum physiological quality and that the high seed quality is highly dependent on moisture content.

## CONCLUSIONS

As moisture content decreased, the seeds of the F6 (Yellow×V-54A) experimental variety recorded a higher physiological quality. The maximum quality of the product depended on the moisture content of the seed and, consequently, the germination percentage was not associated with physiological maturity. Finally, depending on seed maturity, a higher percentage of normal seedlings was recorded.

## REFERENCES

- Alves, M., Pinho, É.V.D.R.V., Santos, H.O.D., Alves, G.C.P., Carvalho, M.L.M.D., & Bustamante, F. D. O. (2018). Análisis de imágenes, calidad y maduración de semillas de jiló (*Solanum gilo*). *Agrociencia*, 52(2), 267-278. <https://agrociencia-colpos.org/index.php/agrociencia/article/view/1668>
- Bewley, J.D., Bradford, K.J., Hilhorst, H.W.M., & Nonogaki, H. (2013). *Seeds, Physiology of Development, Germination and Dormancy*, 3ra ed. Springer, New York, NY. 399 p. <https://doi.org/10.1007/978-1-4614-4693-4>
- Carvajal, C., Márquez, M., Gutiérrez, B., González-Vera, A., Arellano, J., & Ávila, M. (2018). Aspectos de fisiología, deterioro y calidad en semilla de soya. *Revista de la Facultad de Agronomía*, 73, 76-92. [http://saber.ucv.ve/ojs/index.php/rev\\_agro/article/view/15258/144814481921](http://saber.ucv.ve/ojs/index.php/rev_agro/article/view/15258/144814481921)
- Dayal, A., Rangare, N.R., Kumar, A., & Kumari, M. (2014). Effect of physiological maturity on seed quality of maize (*Zea mays* L.). *Forage Research*, 40(1), 1-6.
- Escobar-Álvarez, J.L., & Estrada-Urbina, J. (2024a). Influencia del grado de madurez de semillas de maíz sobre la calidad de plántula y producción de biomasa. En: Memorias de la XXXVI Semana Internacional de Agronomía, 383-389.
- Escobar-Álvarez, J.L., Pérez-Heredia, O.S., Canales-Sosa, E., Molina-Moreno, J.C., Estrada-Gómez, J.A., & Estrada-Urbina, J. (2024b). Influencia de la época de cosecha y desgrane sobre la calidad fisiológica de semillas de maíz. *Revista Tecnológica CEA*, 26(2), 1179-1186.
- Estrada-Urbina, J. (2022). Calidad física y fisiológica en semillas de maíz raza Pepitilla de la montaña baja de Guerrero. Tesis de Maestría en Ciencias. Colegio de Postgraduados. Estado de México, México. 141 p. Disponible en: <http://colposdigital.colpos.mx:8080/xmlui/handle/10521/4914>
- Estrada-Urbina, J., Cantú-López, E., Molina-Moreno, J.C. y Estrada-Gómez, J.A. (2023a). Madurez fisiológica en semillas de maíz (*Zea mays* L.) mediante marcadores morfológicos y el contenido de humedad. *Agronomía Mesoamericana*, 34(3), 53269. <https://doi.org/10.15517/am.2023.53269>
- Estrada-Urbina, J., Molina-Moreno, J.C. y Estrada-Gómez, J.A. (2023b). Comportamiento de componentes físicos y fisiológicos durante la maduración de las semillas de maíz. En: Memorias de la X Reunión Nacional de Investigación Agrícola, 562-564 p.
- Ferreira, V.F., Oliveira, J.A., Ferreira, T.F., Reis, L.V., De A.V., & Neto, J.C. (2013). Quality of maize seeds harvested and husked at high moisture levels. *Journal of Seed Science*, 35(3), 276-283. <http://doi.org/10.1590/S2317-15372013000300001>
- Ghassemi-Golezani, K., Tajbakhsh, Z., & Yaeghoob, R.A.E.Y. (2011). Seed development and quality in maize cultivars. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 39(1), 178-182. <https://doi.org/10.15835/nbha3915713>
- Guillén-de la Cruz, P., Velázquez-Morales, R., de la Cruz-Lázaro, E., Márquez-Quiroz, C., & Osorio-Osorio, R. (2018). Germinación y vigor de semillas de poblaciones de maíz con diferente proporción de endospermo víteo. *Chilean Journal of Agricultural & Animal Sciences*, 34(2), 108-117. <https://doi.org/10.4067/S0719-38902018005000304>
- Gil, M. C. (2018). Técnicas de regularización y de selección del mejor modelo. Disponible en: [https://rpubs.com/Cristina\\_Gil/Regularizacion\\_Seleccion](https://rpubs.com/Cristina_Gil/Regularizacion_Seleccion).
- ISTA. (2021a). Determination of moisture content. In: International rules for seed testing. International Seed Testing Association, i-9-12-20 p.
- ISTA. (2021b). The germination test. In: International rules for seed testing. In: International Seed Testing Association, i-5-56-64 p.
- Jacob, J.E.A., Marcia, M.L., Augusto, H.F., Teichert, P.S., Amaral, V.F., & Baudet, L.L.P. (2014). Ideal seeds harvest moment of different maize hybrids. *Ciência Rural, Santa Maria*, 44(2), 253-260. <http://doi.org/10.1590/S0103-84782014000200010>
- Lozano-Pérez, G.A. (2021). Determinación del momento oportuno de cosecha de maíz (*Zea mays* L.) para la producción de semilla. Tesis de Maestría en Ciencias. Colegio de Postgraduados, Campus Montecillo. Estado de México, México. 158 p. Disponible en: <http://colposdigital.colpos.mx:8080/handle/10521/4945>
- Magdaleno-Hernández, E., Magdaleno-Hernández, A., Mejía-Contreras, A., Martínez-Saldaña, T., Jiménez-Velázquez, M. A., Sánchez-Escudero, J. y García-Cué, J. L. (2020). Evaluación de la calidad física y fisiológica de semilla de maíz nativo. *Agricultura, Sociedad y Desarrollo*, 17, 569-581. <https://doi.org/10.22231/asyd.v17i3.1372>
- Mancera, R.A. y Ramírez, J.A. (2018). Determinación de la madurez fisiológica en semilla de maíz mediante ganancia de peso seco y métodos alternos (*Zea mays* L.). *Agroproductividad*, 7(1): 50-57. <https://revista-agroproductividad.org/index.php/agroproductividad/article/view/504>
- Martínez-Álvarez, D. (2015). Ecofisiología del cultivo de maíz. En J.A. Garay, & J. Cruz-Colazo (Eds.), El

- Cultivo de Maíz en San Luis. INTA Ediciones, 7-31 p.
- Mishra, U., Goswami, S.P., Chauhan, S., & Kumar, M.P. (2023). Principles of Quality Seed Production. In H.R. Archana, A. Akash, K.A. Asha, & M. Sanjay (Eds.). *Recent Advances in Seed Science and Technology, volume 1. Stella International*, 118-134 p.
- Miya, S.P., Modi, A.T., & Mabhaudhi, T. (2017). Interactive effects of simulated hail damage and plant density on maize seed quality. *Seed Science and Technology*, 45(1), 100-111. <https://doi.org/10.15258/sst.2017.45.1.02>
- Molina, M.J.C., González, H.V.A., Carballo, C.A., Livera, M.M., Castillo, G.F., & Ortega, D.M.L. (2003). Cambios en la calidad fisiológica y su asociación con la madurez de la semilla de maíz durante su formación. *Revista Fitotecnia Mexicana*, 26(4), 271-277. <https://doi.org/10.35196/rfm.2003.4.271>
- Pardo-Varela, M.I. (2016). Calidad fisiológica de la semilla de soja (*Glycine max* L. Merr.), bajo diferentes condiciones de almacenamiento y envasado. Universidad Nacional de Rosario, Facultad de Ciencias Agrarias. Santa Fe, Argentina. 42 p. Disponible en: <https://rephip.unr.edu.ar/server/api/core/bitstreams/5b61b01d-9ca7-490b-962b-9581bc743bd5/content>
- R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>
- Rosabal-Ayan, L., Martínez-González, L., Reyes-Guerrero, Y., Amico-Rodríguez, J. D., & Núñez-Vázquez, M. (2014). Aspectos fisiológicos, bioquímicos y expresión de genes en condiciones de déficit hídrico. Influencia en el proceso de germinación. *Cultivos Tropicales*, 35(3), 24-35.
- Sripathy, K.V., & Groot, S.P. (2023). Seed development and maturation. In M. Dadlan & D. K. (Eds.), *Yadava Seed Science and Technology: Biology, Production, Quality*. Springer Nature, Singapore. 17-38 p.
- Tadeo-Robledo, M., Espinosa-Calderón, A., Valdivia-Bernal, R., Gómez-Montiel, N., Sierra-Macías, M., & Zamudio-González, B. (2010). Vigor de las semillas y productividad de variedades de maíz. *Agronomía Mesoamericana*, 21(1), 31-38. <https://doi.org/10.15517/am.v21i1.4909>
- Vujosevic, B., Canak, P., Babic, M., Mirosavljevic, M., Mitrovic, B., Stanisavljevic, D.; & Tatic, M. (2018). Field performance of abnormal maize seedlings. *Ratarstvo i Povrtarstvo*, 55(1), 34-38. <http://doi.org/10.5937/ratpov55-15198>
- Zavala-Hernández, J., Córdova-Téllez, L., Martínez-Herrera, J., & Molina-Moreno, J. C. (2015). Desarrollo del fruto y semilla de *Jatropha curcas* L. e indicadores de madurez fisiológica de la semilla. *Revista Fitotecnia Mexicana*, 38(3), 275-284. <https://doi.org/10.35196/rfm.2015.3.275>

# Spatiotemporal dynamics of crime in Mexican agroecosystems and socioeconomic performance (2006-2022)

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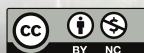
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## ABSTRACT

**Objective:** To identify the spatiotemporal dynamics of the types of crime committed in Mexican agroecosystems and their relationship with the economic performance of Mexican states from 2006 to 2022.

**Design/Methodology/Approach:** The study consisted of the following stages: 1) documentary research; 2) collection of data from official indicators and a hemerographic review of 292 newspaper articles; and 3) a statistical analysis for the evaluation of the information collected.

**Results:** The most frequent crimes in agroecosystems from 2006 to 2022 were homicide, kidnapping, and extortion. The most impacted productive components were livestock, avocado, and seed trade. The states with the highest criminal rates were Guerrero, Michoacán, and Sinaloa. Likewise, according to the statistical analysis, a decrease in socioeconomic indicators causes an increase in crime in the agroecosystems and vice versa.

**Study Limitations/Implications:** The information analyzed was obtained from newspaper reports, given the lack of statements or documents with official figures on the incidence of crime in Mexican agroecosystems.

**Findings/Conclusions:** According to theoretical approaches that consider crime as a fundamentally rational act (based on benefits and costs), crimes in agroecosystems increase as the indicators of economic development decline, and diminish as the economy grows. This phenomenon can be analyzed from a social and economic approach.

**Keywords:** Mexican agroecosystem, crime, rural crimes, economy.

## INTRODUCTION

Agriculture is the most important economic activity both for the biological maintenance of humanity and its social reproduction, as well as for the employment and income it generates for rural areas (FAO, 2009). Likewise, agriculture makes a major contribution to the Mexican economy, because it creates jobs, preserves natural environments, and promotes progress in rural areas. However, given that agriculture produces wealth, agricultural producers are continuously exposed to crime.



Although the reasons that motivate a person to commit crimes are diverse, they can be divided into two main categories: irrational criminal conduct and the rational behavior of a subject who seeks a benefit (Becker, 1974). This research focuses on the latter, since rational individuals who decide to commit a crime expect to obtain greater benefits than they would obtain by legal means; on the contrary, if individuals consider that they will have better opportunities in legal activities, they will be less likely to commit a crime. Therefore, before engaging in illicit activities, people evaluate their profitability; however, faced with the opportunity to obtain a higher income through legal means, their motive to commit a crime disappears. In conclusion, the level of crime increases when economic recessions cause high unemployment rates (Lozano *et al.*, 2018).

Quiroz *et al.* (2015) explain that the global indicators of economic activity and crime have a non-monotonic relationship, because crime diminishes when economic performance is high and increases when the economy declines.

In this sense, crime is a consequence of social disintegration —which is characterized by deep economic polarization, lack of opportunities, and loss of values (Calvillo, 2014). It is a maladjustment that challenges society through non-compliance with the rules of coexistence. It can be found throughout the world, without distinction of social strata and it results in violence, robberies, terrorism, drug trafficking, rape, murder, etc. (Jimenez, 2005).

Criminal violence is one of the problems with the greatest repercussions in Mexico, because it generates human losses, impacts economic activities, causes school absenteeism, and leads to forced migration (Quiroz *et al.*, 2015). Romero *et al.* (2013) point out that the violent criminal conduct that impacts the Mexican economy consist of operations with resources of illicit origin, such as extortion, robbery, kidnapping, human trafficking, drug trafficking, threats, attacks, home invasion, collusion of authorities with criminals, smuggling, forgery, identity theft, burglary, obstruction of the transport system, and homicide. These authors indicate that agriculture is among the most affected economic sectors, since some crimes occur specifically in rural areas, such as the theft of tractors or livestock. Meanwhile, Ceccato (2016) also includes crimes against nature and wildlife among criminal activities committed in rural areas.

In addition to the loss of human lives, crime deeply affects the economic activities of the agricultural and rural sector (Cornejo and Rojas, 2017; Aguirre and Gómez, 2020), since productivity and the ability to provide jobs are reduced by bribery, theft of machinery, livestock, and merchandise, and kidnappings. Some people even stop their economic activities, afraid of becoming victims of violent acts (Díaz and Díaz, 2016).

Smith (2020) highlights that agricultural producers distrust the authorities, because the authorities do not intervene in a third of the crimes that occur in agroecosystems, either due to the lack of complaints or because many of the reported cases are not solved, generating a feeling of rejection. According to Díaz and Díaz (2016), the lack of complaints is related to the potential collusion of rural authorities with criminal groups, generating fear of repercussions if a victim files a report. Therefore, rural population distrusts the authorities, as well as each other. For example, just like the police, some members of the

community associate with criminal organizations to guarantee their well-being, attacking their communities and causing social disintegration.

Although the way in which crime threatens the integrity of rural producers, causes displacement, encourages the abandonment of land, harms production, and violates the quality of life has been documented, the dynamics between crime in Mexican agroecosystems and economic activity has not been analyzed. Consequently, the objective of this research was to identify the spatiotemporal dynamics of the types of crime committed in Mexican agroecosystems and their relationship with the economic performance of the Mexican states from 2006 to 2022.

## MATERIALS AND METHODS

The research mainly consisted of the collection of documentary information and the processing and analysis of the data.

Data was obtained through a hemerographic review and through official indicators. For this purpose, a compilation of newspaper articles about the impact of criminal activities in the agriculture and the rural areas of Mexico was carried out. The said articles had been published in two national circulation newspapers, *La Jornada* and *Reforma*, between December 1, 2006 and November 30, 2022. To address the relationship between crime and the economic performance of Mexico, variables that provided valuable information were established to better understand this dynamic. The variables are described in Table 1.

The information on these variables was captured per year and per state. These data were retrieved from the INEGI consultation portal and the reports published by each state government.

**Table 1.** Variable description.

| Variable | Variable Name                                | Description  | Unit of measurement |
|----------|--|--|---------------------|
| GDP      | Gross Domestic Product                       | Indicator of a country's economic performance. It can be used to assess economic prosperity and growth over time.  | Millions of pesos   |
| GDP PA   | Gross Domestic Product by Primary Activities | This indicator specifically focuses on the contribution of agricultural and rural activities to GDP.   | Millions of pesos   |
| UR       | Unemployment Rate                            | Indicates the proportion of unemployed people in the active population. Unemployment is related to crime as unemployed individuals facing economic hardships may be more inclined to engage in criminal activities out of necessity.                         | Percentage          |
| PC       | Perception of Corruption                     | Measures the public perception of corruption. High corruption indices may indicate that it contributes to crime by reducing the effectiveness of institutions that provide security and justice.   | Percentage          |
| CIR      | Crime Incidence Rate                         | Indicates the frequency of crimes in specific geographic areas. It helps to understand the magnitude of the crime problem and how it changes over time.  | Absolute numbers    |
| CI       | Crime Incidents (according to news reports)  | Indicates the number of crimes occurring in rural areas. Since there is no source that registers crimes affecting the countryside, news reports can provide useful information to understand this problem, its implications, and the most recurrent regions. | Absolute numbers    |

The analysis was carried out in two stages: 1) review of newspaper articles; and 2) statistical analysis of the variables.

The hemerographic review was made up of 292 newspaper articles. The variables used for the text analysis were: productive component of the impacted agroecosystem (activity), location (state), date, and crime classification. Table 2 describes the crimes identified in the articles.

Given the extensive amount of data, a six-year average was developed. Consequently, two six-year and one four-year sets with six variables per state were calculated.

Descriptive analysis was carried out with STATISTICA (v. 8.0) to obtain the mean and standard deviation of the variables. Subsequently, diagrams were developed to graph the behavior of the variables throughout the study period. The same exercise was repeated, taking into account only the last year of each period, to obtain a perspective related to the exchange rate between them. However, due to the lack of information before the first period, 2007 was used as a reference year.

## RESULTS AND DISCUSSION

The crimes with the highest rates are homicide, kidnapping, and extortion, which are not necessarily typical of agricultural contexts and, on the contrary, are more frequent in

**Table 2.** Description of crime types.

| Crime classification | Description  |
|----------------------|--|
| Cattle Rustling      | Involves the theft of animals, mainly horses or cattle, and is characterized by its rural nature (Norza <i>et al.</i> , 2012). It is considered an act against property and is stipulated in most penal codes of livestock-rearing countries, as it affects the growth of the sector (Cornejo and Rojas, 2017).                          |
| Extortion            | Article 390 of the Federal Penal Code defines extortion as the act of forcing another to give, do, refrain from doing, or tolerate something, with the purpose of obtaining a benefit for oneself or for someone else and/or causing harm to another's property. This includes the collection of fees for protection or "floor rights".  |
| Homicide             | A violent act that disrupts the victim's body and causes death, either immediately or due to complications that cannot be treated because they are incurable or because of lack of access to necessary resources (Padrón and García, 2018).  |
| Theft                | Taking someone else's property without the owner's consent. It is a crime against economic property that is situational and opportunistic, as its execution depends on three elements: object, person, and place, where accessibility, vulnerability, potential gain, and chances of success are evaluated (Norza <i>et al.</i> , 2012). |
| Kidnapping           | Physical and movable deprivation of a person's freedom, meaning that victims cannot move from one place to another. Its motivations attack the victims' property, as they are forced to deliver money, information, or some goods in exchange for their freedom (Muñoz, 2019).   |
| Piracy               | A crime related to copyright, such as the production, reproduction, importation, storage, transportation, distribution, sale, or rental of copies of works, phonograms, videograms, or books protected by the Federal Copyright Law for profit and without the authorization of the copyright holder.                                    |
| Illegal Logging      | Activities that involve dismantling or destroying natural vegetation, cutting down, uprooting, toppling, or felling trees.   |

urban areas. The most characteristic crimes of the countryside, such as cattle rustling and illegal logging, have a lower incidence (Figure 1).

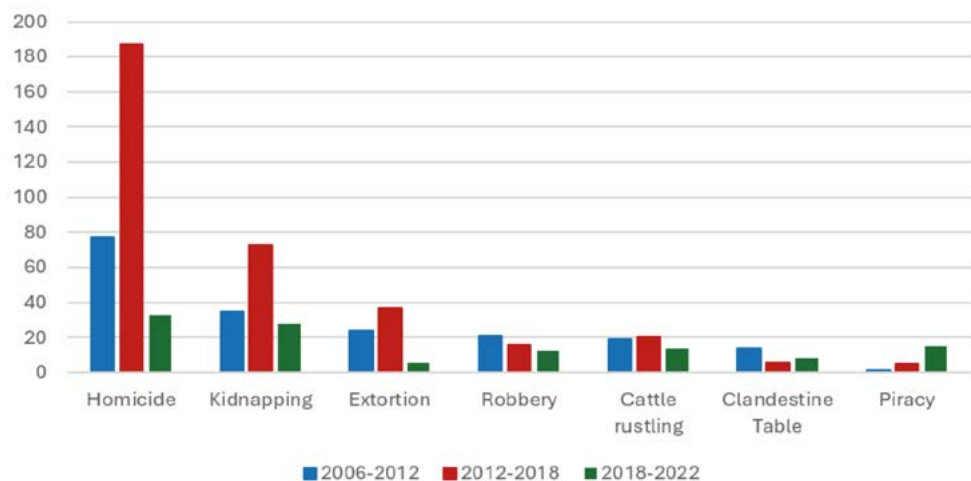
In this study, homicide was the most common crime. The victims belong to any productive component without distinction. Nevertheless, most homicide victims are ranchers, agricultural business owners, and producers who had been previously kidnapped or who refused to pay protection rackets. Other regular victims are the leaders of rural organizations and environmental activists, who pose a threat to the development of the illicit activities of organized crime groups.

Kidnapping was the second most frequent crime and mainly affects livestock producers, avocado growers, and owners of agricultural trading companies or their relatives, who have a greater chance of paying a ransom due to their high level of income. However, income is not a limiting factor, because although the percentage is lower, small producers were also kidnapped. Agrarian organization leaders and environmental activists were likewise targets of kidnappings, for the same reasons mentioned in the paragraph about homicides.

In rural areas, extortion can be observed mainly in the so-called *derechos de piso*, a protection racket system where producers are forced to pay bribe to criminal groups in exchange for permission to work their own land, as well as payments per ton received, and for the use of transportation. Producers are also forced to plant narcotic plants on their plots; refusals to cooperate with criminals results in reprisals. Some agricultural companies are also victims of extortion. They are forced to fine and reduce the payments to the producers, arguing that humidity has damaged the crops. The resulting difference goes to the criminals, who sometimes demand one-time payments to refrain from kidnapping company members.

Information about robberies is scarce and, in most cases, the stolen goods are vehicles, machinery, and agricultural equipment.

Cattle rustling is a major rural crime, with two major modus operandi: 1) the violent robbery of producers, who are subdued while the criminals take away the livestock; and 2) the theft of livestock transport vehicles on the road. In addition to economic losses, cattle



**Figure 1.** Six-year crime incidence, according to newspaper articles.

rustling has repercussions on final consumers, due to the loss of health control, which can trigger an epidemiological problem (Lago *et al.*, 2019).

The articles consulted mention that illegal logging allows organized crime to generate profits from the commercialization of wood and resin, which is a problem for some producers since criminal groups invade their land to cut down trees.

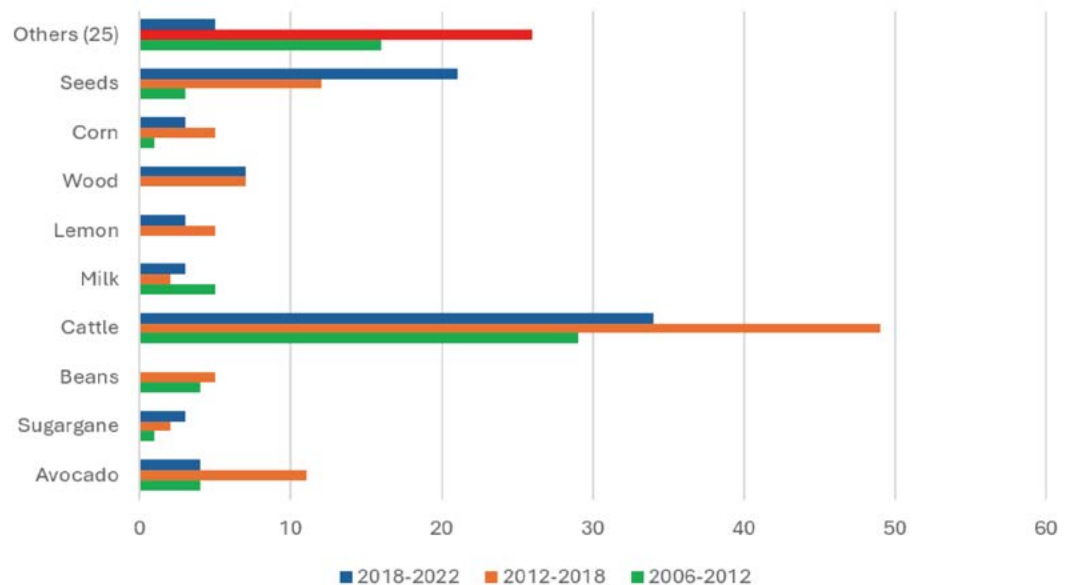
Finally, an unprecedented crime was identified in the agricultural context: the impact of piracy in the seed trade. Criminal groups often steal, reproduce, and market patent seeds. Others collect empty packages of original seeds and fill them with fake product to pass it off as authentic. This situation impacts, on the one hand, the seed companies (which do not obtain profits), and on the other hand, the farmer (who does not obtain the expected productive results).

The state with the highest criminal rates in Mexico was Guerrero, followed by Michoacán and Sinaloa. Figure 3 shows the matches for each state in the newspaper articles consulted.

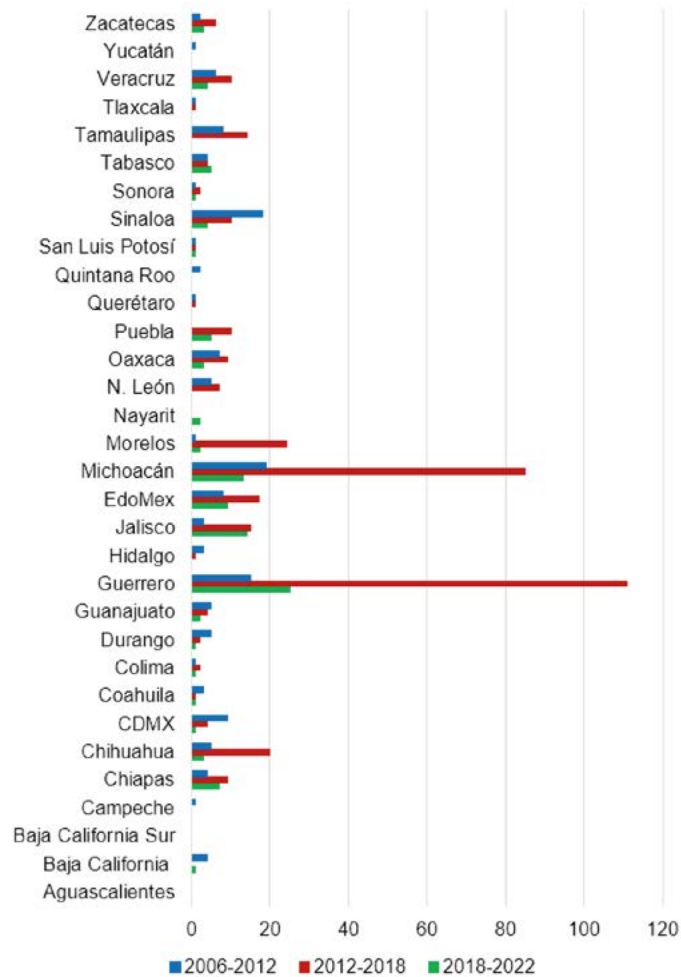
A decrease in the reporting rate of the crimes was recorded, indicating that the authorities are not always aware of the magnitude of the problem. Only 292 articles about the said crimes were found —a small figure, considering that sixteen-year period under study.

One of the major features of criminal violence in agroecosystems is the failure to meet the demand, caused by the reduction and delay in production. This phenomenon is attributed to the loss of producers, either due to homicides or land abandonment, driven by threats or the need to escape the violence that impacts the region. This situation led to a decrease in cultivated areas and the closure of numerous farms.

An additional consequence of the insecurity and violence is the withdrawal of foreign investors, who used to rent land for vegetable production. This withdrawal has a negative



**Figure 2.** Impact of crime on the productive components of agroecosystems, between 2006 and 2022 (six-year periods).



**Figure 3.** Criminal rate in agroecosystems per state (six-year periods).

impact on the local economy and increases the probability that unemployed laborers turn to criminal activities as a source of livelihood.

Furthermore, this low supply increases the cost of agricultural products above their usual prices for final consumers.

Homicide, kidnapping, and extortion were the most frequent crimes found in the study. Based on the Programa Nacional de Seguridad, Samano and Leal (2020) classify them as high-impact crimes and suggest that their high rates have a deep and negative relationship with the displacement of agricultural producers from the state of Tamaulipas. Interestingly, migration and forced displacements are some of the most marked consequences of crime in agroecosystems.

The analysis found that cattle rustling is carried out with violence within the producers' property or through the theft of livestock transport vehicles. However, other research record different modus operandi. For example, Donnermeyer and Barclay (2005) mention that it is common for lost livestock to end up in neighboring herds and not be returned to their owner. They also suggest that some criminals hire local herders who have the necessary equipment and local knowledge.

Articles mentioned that most crimes in agroecosystems are not reported. Donnermeyer and Barclay (2005) indicated that very few cases end in a conviction, because a long time passes between the crime and the moment in which the producers realize that something happened. In other cases, they consider that the authorities are not prepared or aware of the rural context and are therefore unable to address their problems. For their part, Díaz and Díaz (2016) and Aguirre and Gómez (2020) highlighted the inefficiency of the rule of law in Mexico, explaining that agricultural producers do not report crimes due to the corruption of the authorities and their connection with organized crime.

The various economic consequences of rural crimes leave producers vulnerable, because it is easier to engage in criminal behavior as a means of subsistence. This situation further contributes to the deterioration of the social fabric. Arisukwu *et al.* (2020) mention that most of the crimes in the rural areas of Nigeria are committed by unemployed youths. Likewise, Díaz and Díaz (2016) indicate that some rural inhabitants in Mexico first participate in drug trafficking through drug production or working as informers for criminal groups, reporting on every movement that occurs in their communities.

The statistical analysis shows the dynamics of the variables in the three established periods (Table 3 and Figure 4).

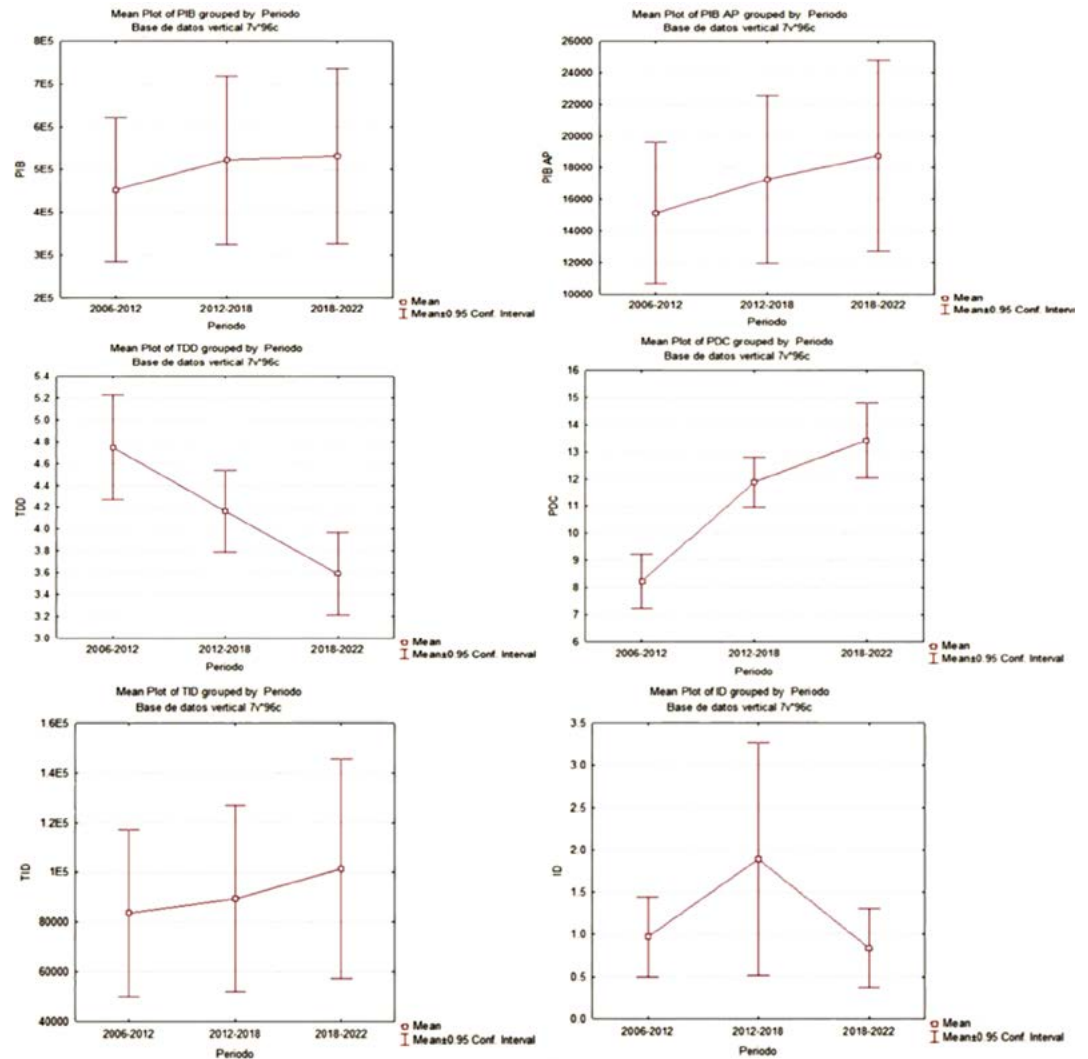
The analysis of the socioeconomic variables in the three periods identified a constant increase in GDP, which indicates a sustained economic growth. Similarly, primary sector GDP (PS-GDP) shows an increase throughout the periods, which suggests growth in the primary sector of the economy.

The unemployment rates (UR) variable shows a constant decrease throughout the periods, indicating an improvement in economic activities and a reduction in unemployment. Meanwhile, an increase in corruption perception was observed throughout the periods, which could indicate a worsening in the perception of institutional integrity. For its part, there was an increase in the crime incidence rate throughout the periods, which suggests an increase in criminal activity. In the case of criminal incidents recorded in newspaper articles, the values fluctuate significantly throughout the periods, increasing from the first to the second and then dropping drastically in the third.

Table 4 shows the values resulting from the repetition of the same exercise, carried out to determine the exchange rate between periods.

**Table 3.** Six-year behavior of socioeconomic variables in Mexico (2006-2022).

| Variable  | Period    |           |           | Standard deviation |
|---|-----------|-----------|-----------|--------------------|
|   | 2006-2012 | 2012-2018 | 2018-2022 |                    |
| Gross Domestic Product (GDP)                          | 452942.5  | 522410.5  | 531284.2  | 522921.6           |
| Gross Domestic Product by Primary Activities (GDP PA) | 15138.0   | 17266.0   | 18761.4   | 14683.4            |
| Unemployment Rate (UR)                                | 4.7%      | 4.2%      | 3.6%      | 1.2%               |
| Perception of Corruption (PC)                         | 8.2%      | 11.88875% | 13.43125% | 3.8%               |
| Crime Incidence Rate (CIR)                            | 83590.0   | 89298.7   | 101528.2  | 106433.0           |
| Crime Incidents (CI)                                  | 0.968750  | 1.890625  | 0.835938  | 2.5                |



**Figure 4.** Behavior of the variables in the analyzed periods.

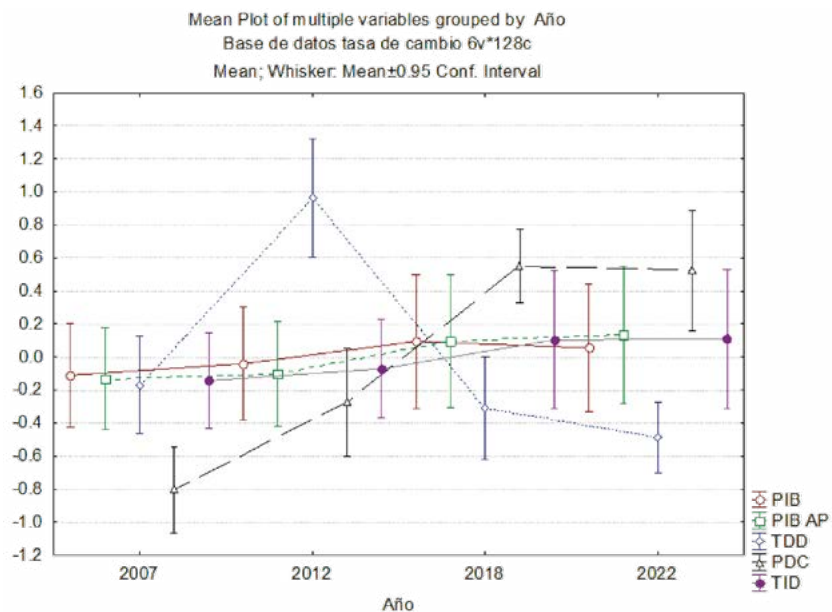
The table shows an increase in GDP except in the last period, but this reduction is barely perceptible. Likewise, the PS-GDP maintained a constant growing trend over the years. The unemployment rate (UR) showed an exponential increase in the first two years, but in

**Table 4.** Exchange rate of the variables between periods.

| Variable  | Year     |          |          |          | Standard deviation |
|---|----------|----------|----------|----------|--------------------|
|   | 2007     | 2012     | 2018     | 2022     |                    |
| Gross Domestic Product (GDP)                          | 445452.0 | 482218.5 | 553164.6 | 532521.7 | 525077.2           |
| Gross Domestic Product by Primary Activities (GDP PA) | 15208.78 | 15609.84 | 18563.78 | 19120.78 | 14803.1            |
| Unemployment Rate (UR)                                | 3.365313 | 4.943594 | 3.170313 | 2.919375 | 1.4                |
| Perception of Corruption (PC)                         | 7.975    | 10.08    | 13.38    | 13.27    | 4.0                |
| Crime Incidence Rate (CIR)                            | 77231.4  | 85022.5  | 104135.0 | 104682.6 | 109077.9           |

2018 it fell below the initial point and continued decreasing in 2022. The initial perception of corruption (POC) had high values and increased until 2018, when it began to slowly decrease. The crime rate (CR) grew slowly but steadily until 2018, when it apparently stagnated.

According to the variables of the comprehensive socioeconomic analysis, an inverse trend is observed between the indicators of the economic sector and the factors that favor crime. Therefore, as economic indicators grow, critical variables (such as unemployment and the perception of corruption) decrease, causing a slowdown in crime. This phenomenon established an inverse connection between economic development and the factors that lead to crime (Figure 5).



**Figure 5.** Exchange rate of the GDP (PIB), PS-GDP (PIB PA), UR (TDD), POC (PDC), and CR (TID) variables during 2007, 2012, 2018, and 2022.

## CONCLUSIONS

Crime was present in Mexican agroecosystems and rural life during the 2006-2022 period. The most common crimes were homicide, kidnapping, and extortion. In addition, a new form of crime was found in rural areas: seed piracy. Crime was more frequent in agroecosystems which mainly produce livestock and avocado, but also include seed trade. Agricultural organizations leaders and environmental activists are frequently the victims of crime. The states with the highest criminal rates in rural areas were Guerrero, Michoacán, and Sinaloa.

Crime reached its highest peak during the second period (2012-2018), and decreased considerably in the third period (2018-2022), following the dynamics of socioeconomic development indicators.

This research highlights the inverse relationship between socioeconomic development and crime: when the economy declined, rural crimes tended to increase and, on the






contrary, rural crimes decreased when socioeconomic indicators increased. This research is based on a theoretical current that suggests that crime is fundamentally a rational act and, overall, it should be analyzed from a social and economic point of view.

## REFERENCES

- Aguirre, J., Gómez, M. 2020. Competitive Strategies in Contexts of Organized Crime: The Case of the Avocado Industry in Mexico. *Int. Jour. Crim. Just. Sci.*, 15. 114-126. <https://doi.org/10.5281/zenodo.3822110/IJCJS>
- Arisukwu, O., Igbokwu, C., Oye, J., Oyeyipo, E., Asamu, F., Rasak, B., Oyekola, I. 2020. Community participation in crime prevention and control in rural Nigeria. *Heliyon*. 6(9). <https://doi.org/10.1016/j.heliyon.2020.e05015>
- Becker, G. S. 1974. Crime and Punishment: An Economic Approach. *Jour. Pol. Eco.* 72(2). 169-217.
- Calvillo S., Y. 2014. Espacio y delincuencia: un caso de estudio del robo a transeúnte en el Centro Histórico de la ciudad de México. *Esp. Rev. Tem. Cont. Lug. Pol. Cul.* 4(2). 110-151.
- Ceccato, V. A. 2016. Rural Crime and Community Safety. Routledge.
- Cornejo E., S. E., Rojas R., J. C. 2017. Abigeato: estrategia para su prevención y control. *Lid. Pol. Paz.* 155-162.
- Díaz V., R., Díaz V., M. C. 2016. El impacto de la violencia en la vida cotidiana de los pueblos nahuas del estado de Guerrero, México. *Cuad. Inter. Cent. Car.* 13(2). 37-53.
- Donnermeyer, J. F., Barclay, E. 2005. The policing of farm crime. *Pol. Prac. Res.* 6(1). 3-17. <https://doi.org/10.1080/15614260500046913>
- FAO (Organización de las Naciones Unidas para la Alimentación y la Agricultura). 2009. La FAO en México. Más de 60 años de cooperación 1945-2009.
- Jiménez O., R. A. 2005. La delincuencia juvenil: fenómeno de la sociedad actual. *Pap. Pob.* 11(43). 215-261.
- Lozano C., R. L., Cabrera C., L. F., Lozano C., M. 2018. Causas sociales y económicas de los delitos en México. *Bol. Crim.* 176.
- Muñoz A., C. E. 2019. El delito del secuestro. *Anua. Der.* 48. 178-186.
- Norza C., E., López G., W. A., Peñaloso O., M. X. 2012. Exégesis de los delitos en Colombia, 2011. *Rev. Crim.* 54(1). 17-54.
- Padrón G., C. X., García P., T. 2018. Trastornos mentales y homicidio. *Rev. Cub. Med. Gral. Int.* 34(1). 4-13.
- Quiroz F., J., Castillo P., R. A., Ocegueda H., J. M., Varela L., R. 2015. Delincuencia y actividad económica en México. *Norteamérica.* 10(2). 187-209.
- Romero O., M. V., Loza L., J., Machorro R., F. 2013. Violencia del crimen organizado relacionada a los sectores económicos en México. Una propuesta de categorización. *Polis. Rev. Lat.* 36.
- Samano G., M. H., Leal R., R. G. 2020. Efecto de los delitos de alto impacto en el desplazamiento de productores agrícolas: un estudio longitudinal en Tamaulipas, México. *Rev. Esp.* 43(3). 14-23.
- Smith, K. 2020. Desolation in the countryside: How agricultural crime impacts the mental health of British farmers. *Jour. Rur. Stu.* 80. 522-531. <https://doi.org/10.1016/j.jrurstud.2020.10.037>



# Income optimization of a biodiesel, glycerin and soap company using waste cooking oil

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## ABSTRACT

**Objective:** Optimize a production unit for biodiesel, glycerin, and soap using a mathematical programming model (MPM). Determine the optimal quantities of waste cooking oil from different sources ( $ACD_1$ =glycerin and biodiesel;  $ACD_2$ =soap) to maximize the income of a biodiesel production company.

**Design/methodology/approach:** To assess the availability of ACD inputs, stratified sampling was conducted from February 8 to 19, 2021, measuring the ACD generation of restaurants in downtown Texcoco, State of Mexico. The analysis was conducted using an economic approach for a biofuel-producing company, considering 10 decision variables in the objective function (OF), subject to 18 constraints. These variables were based on the technical requirements to produce 1 liter of biodiesel and a 400 g bar of soap, using technical coefficients (input-product). Excel<sup>®</sup> Solver<sup>®</sup> was used to generate a sensitivity report and analyze shadow prices (SP) and reduced costs (RC).

**Results:** Monthly revenues exceeding \$140,000 MXN were obtained.  $ACD_2$  emerged as the scarcest and most valuable input within the model.

**Limitations on study/implications:** Proper management of ACD disposal can generate income through the production of biodiesel, glycerin, and soap.

**Findings/conclusions:** MPM proves to be the most efficient method for utilizing kitchen waste and converting it into valuable products.

**Keywords:** Waste cooking oil, biodiesel, mathematical programming, optimization.

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## INTRODUCTION

Edible vegetable or animal oils are a fundamental dietary component in the Mexican diet. After frying and cooking processes, waste cooking oil (ACD) is generated (Banerji *et al.*, 2022). At high temperatures (160-200 °C), vegetable oils composed of triacylglycerols undergo physical and chemical modifications, resulting in toxic compounds formed through oxidation, hydrolysis, and polymerization of triglycerides (Tsoutsos *et al.*, 2016). According to González and González (2023), 1 liter of used cooking oil can contaminate approximately 40,000 liters of drinking water. Furthermore, once cooled, the oil solidifies and can clog pipes and drains. Improper disposal of ACD poses serious environmental issues. The compounds produced from the degradation of cooking oils have harmful effects on

human health and are known to be mutagenic, carcinogenic, neurotoxic, and hepatotoxic, among others (Tsoutsos *et al.*, 2016). This highlights that improper ACD disposal can lead to environmental pollution and public health problems (Lopes *et al.*, 2020). There is a pressing need to implement alternatives for the reuse and final disposal of these residues in order to give new life to what is typically considered single-use waste (Tsoutsos *et al.*, 2016). ACD can be repurposed through transformation, for which the simplex method an algorithm used to optimize the value of the objective function (OF) while considering defined constraints proves useful. This is an iterative process that improves the OF in each step until reaching the optimal solution (Alvarado-Boirivant, 2011). In this research, an MPM was developed to maximize the net income of a company producing biodiesel, glycerin, and soap, making efficient use of ACD as a limited resource.

**MATERIALS AND METHODS**

The ACD was classified into two types based on its origin and quality, according to culinary practices. The quantity of ACD generated was estimated by production strata in the central area of the municipality of Texcoco, State of Mexico, Mexico, located at coordinates 19° 30’ 42.98” N, 98° 52’ 58.55” W.

A stratified sampling was conducted from February 8 to February 19, 2021: ACD<sub>1</sub> was obtained from restaurants (n=16), taco stands and Mexican snacks vendors (n=12), and local diners (n=5) to produce biodiesel and glycerin; ACD<sub>2</sub> was collected from fast food establishments and bars (n=13), as well as donut and churro vendors (n=5) for soap production. The sample size was based on Santoyo *et al.* (2002), totaling 51 units (22% of the total population). The model includes percentage-based constraints on the availability of ACD types, according to their participation in final production. A total of ACD<sub>1</sub>=18,833 L/month was recorded, of which 82% came from restaurants, 15% from taco stands, and 3% from local diners. ACD<sub>2</sub>=14,147 L/month was primarily sourced from fast food vendors, contributing 46.3%. Using a mathematical programming model (MPM), an optimal profit-maximizing solution was sought through the Simplex method via Microsoft Excel<sup>®</sup> and Solver<sup>®</sup>. The model design required a literature review to obtain technical coefficients that identified the necessary inputs for producing biodiesel, glycerin, and soap. The general form of the objective function (OF) is mathematically expressed as described by Anderson *et al.* (2013) and Alvarado-Boirivant (2011):

$$\text{Maximize } Z = \sum_{j=1}^n c_j * x_j \quad \text{where } j=1 \text{ up to } n \tag{1}$$

Subject to 18 constraints and 10 decision variables:

$$\begin{aligned} a_{11} X_1 + a_{12} x_2 + a_{13} x_3 + \dots + a_{1\ 10} x_{10} &\leq \geq b_1 \\ a_{21} X_1 + a_{22} x_2 + a_{23} x_3 + \dots + a_{2\ 10} x_{10} &\leq \geq b_2 \\ a_{31} X_1 + a_{32} x_2 + a_{33} x_3 + \dots + a_{3\ 10} x_{10} &\leq \geq b_3 \\ \cdot &\cdot \\ \cdot &\cdot \\ a_{18\ 1} X_1 + a_{18\ 2} x_2 + a_{18\ 3} x_3 + \dots + a_{18\ 10} x_{10} &\leq \geq b_{18} \end{aligned} \tag{2}$$

$$\text{And non-negativity restrictions } x_j \geq 0 \tag{3}$$

Where  $c$ =net price coefficient of OF,  $a$ =technical coefficient,  $x$ =decision variable,  $b$ =available resource. Using the sensitivity report in Excel<sup>®</sup> Solver<sup>®</sup>, shadow prices (SP) and reduced costs (RC) were analyzed. Optimized production and sales of biodiesel, glycerin, and soaps were considered (Table 1).

In this way the OF is:

$$\begin{aligned} \text{MAX } Z = & ACD_{1r} * (-8) + ACD_{1t} * (-8) + ACD_{1ce} * (-8) + ACD_{2cr} * (-8) + ACD_{2p} \\ & * (-8) + BIO * (-13.48) + JB * (-11.1) + Gl * 30 + J * 50 + B * 24 \end{aligned} \tag{4}$$

The technical coefficients were obtained from Tacias *et al.* (2016). Through the transesterification of fats and oils, 1 L of ACD reacting with 0.376 mL of methanol (CH<sub>3</sub>OH) in a basic environment and under the action of a catalyst such as 0.09 g of potassium hydroxide (KOH), produces 1 L of biodiesel and 0.361 mL of glycerin. For the production of a 400 g bar of soap, 253 mL of ACD, 139 g of sodium hydroxide (NaOH), 4 g of colorant, and 4 g of fragrance are required. The study also notes that the acid index (AI) and the content of free fatty acids in the oil are key parameters that determine the feasibility of ACD for biodiesel production. The AI was measured based on the Mexican standard for determining free fatty acids (NMX-F-101-SCFI2012, S.E. 2012), calculating the free fatty acids as oleic acid (%) using the following formula:

$$\text{Free fatty acids such as oleic, in \%} = \frac{V \times N \times 28.2}{pm} \tag{5}$$

Where:  $V$ =milliliters of sodium hydroxide solution used to titrate the sample.  $N$ =normality of the sodium hydroxide solution.  $pm$ =mass of the sample in grams.

**Table 1.** OF decision variables.

| Variable  | Abbreviation       | Notation        | Coefficient     | Element in OF                    |
|---|--------------------|-----------------|-----------------|----------------------------------|
| Waste Cooking Oil from Restaurants                      | ACD <sub>1r</sub>  | X <sub>1</sub>  | c <sub>1</sub>  | c <sub>1</sub> *X <sub>1</sub>   |
| Waste Cooking Oil from Mexican taquerias and snack bars | ACD <sub>1t</sub>  | X <sub>2</sub>  | c <sub>2</sub>  | c <sub>2</sub> *X <sub>2</sub>   |
| Waste Cooking Oil from Commercial Kitchens              | ACD <sub>1ce</sub> | X <sub>3</sub>  | c <sub>3</sub>  | c <sub>3</sub> *X <sub>3</sub>   |
| Waste Cooking Oil from Fast Food and Snack Bars         | ACD <sub>2cr</sub> | X <sub>4</sub>  | c <sub>4</sub>  | c <sub>4</sub> *X <sub>4</sub>   |
| Waste Cooking Oil from Potatoes and Donuts              | ACD <sub>2p</sub>  | X <sub>5</sub>  | c <sub>5</sub>  | c <sub>5</sub> *X <sub>5</sub>   |
| Biodiesel Production                                    | BIO                | X <sub>6</sub>  | c <sub>6</sub>  | c <sub>6</sub> *X <sub>6</sub>   |
| Bar Soap Production                                     | JB                 | X <sub>7</sub>  | c <sub>7</sub>  | c <sub>7</sub> *X <sub>7</sub>   |
| Glycerin Sales  | Gl                 | X <sub>8</sub>  | c <sub>8</sub>  | c <sub>8</sub> *X <sub>8</sub>   |
| Kg of Soap Sales  | J                  | X <sub>9</sub>  | c <sub>9</sub>  | c <sub>9</sub> *X <sub>9</sub>   |
| Biodiesel Sales from All Levels                         | B                  | X <sub>10</sub> | c <sub>10</sub> | c <sub>10</sub> *X <sub>10</sub> |

Source: Prepared by the authors.  $c_i$ =net price=product price<sub>*i*</sub>\* quantity produced<sub>*i*</sub>-variable cost<sub>*i*</sub>

To measure the acid index (AI), the following materials were used: a) accurately standardized sodium hydroxide solution; b) 95% (v/v) ethyl alcohol, neutralized at the time of use with 0.1 N sodium hydroxide using phenolphthalein as an indicator; c) 1.0% alcoholic phenolphthalein indicator solution; d) 500 mL Erlenmeyer flask; e) 20 cm<sup>3</sup> volumetric pipette; f) 50 cm<sup>3</sup> burette graduated in 0.1 cm<sup>3</sup>; g) electromagnetic stirrer; h) beaker; i) graduated cylinder; and j) 30-gauge stainless steel mesh. ACD<sub>1</sub> with an AI < 2 was used for biodiesel and glycerin production, while ACD<sub>2</sub> with an AI > 2 was used for soap production (Table 2).

The MPM was constrained with the following algorithms:

$$\text{Liters of ACD}_1: (1X_1 + 1X_2 + 1X_3) \leq 18833$$

$$\text{Liters of ACD}_2: (1X_4 + 1X_5) \leq 14047$$

$$\text{Liters of methanol: } (0.376X_6) \leq 12362.88$$

$$\text{Potassium hydroxide catalyst (KOH) kg: } (0.09X_6) \leq 295.2$$

$$\text{Sodium hydroxide catalyst (NaOH) kg: } (0.139X_7) \leq 18281$$

$$\text{Soap coloring g: } (0.04X_7) \leq 5260.8$$

$$\text{Fragrance soaps g: } (0.04X_7) \leq 5260.8$$

$$\text{Labor hours: } (1X_6 + 1X_7) \leq 10000$$

$$\text{Energy Kilowatts: } (0.0185X_6 + 0.0041X_7) \leq 32880.368$$

$$\text{Distilled water liters: } (0.05X_6) \leq 274$$

$$\text{ACD}_1 \text{ biodiesel restaurant L: } (0.188X_1 - 0.812X_2 - 0.1821X_3) \leq 0$$

$$\text{ACD}_1 \text{ taco shop for biodiesel L: } (-0.1581X_1 - 0.8419X_2 - 0.1581X_3) \leq 0$$

$$\text{ACD}_2 \text{ fast food and bars L: } (0.5375X_4 - 0.4625X_5) \leq 0$$

$$\text{Biodiesel transfer L: } (-1X_1 - 1X_2 - 1X_3 - 1X_6) \leq 0$$

$$\text{Soap transfer L: } (-1X_4 - 1X_5 + 2.5X_7) \leq 0$$

$$\text{Biodiesel for sale L: } (-1X_6 - 1X_{10}) \leq 0$$

$$\text{Glycerin for sale L: } (-0.3661X_6 - 1X_8) \leq 0$$

$$\text{Wind soap L: } (-1X_7 + 1X_9) \leq 0$$

**Table 2.** Average annual acidity index by stratum.

| Stratum                      | Density Kg/m <sup>3</sup> | Goo mm <sup>2</sup> /s | Free Fatty Acids % | Acid number mg KOH/g |
|------------------------------|---------------------------|------------------------|--------------------|----------------------|
| Formal Restaurants           | 912                       | 41.5                   | 0.9                | 1.78                 |
| Taquerias and Mexican Snacks | 860                       | 46.1                   | 1.57               | 1.16                 |
| Cheap Kitchens               | 909                       | 34.9                   | 0.99               | 1.98                 |
| Fast Food and Bars           | 890                       | 44.6                   | 1.72               | 5.42                 |
| Potatoes and Churros         | 918                       | 56.9                   | 0.58               | 3.13                 |
| Average                      | 897.8                     | 44.81                  | 1.35               | 2.7                  |

Source: Prepared by the authors.

## RESULTS AND DISCUSSION

From the MPM, the total Net Income obtained was \$149,983.32 MXN per month from the activities of the biodiesel, glycerin, and soap production company. All variables were selected by the model; therefore, each had a Reduced Cost (RC) of 0 (Table 3).

When the objective is maximization, the opportunity cost or shadow price (SP) represents the benefit forgone by not having an additional unit of a resource, and thus this result can be interpreted as a market price (Anderson *et al.*, 2013). The catalyst KOH has an SP of \$148.33 MXN/L, as this input is essential for the production of biodiesel and glycerin. The SPs corresponding to transfers match the market price in the MPM, while the remaining inputs have an SP=0, indicating they are still available (Table 4).

Bierkens *et al.* (2019) mention that market prices rarely constitute a valid indicator of the social value of resources, due to the various reasons that cause such markets to not operate under perfect competition. One alternative is the so-called shadow prices (SP), which indicate the marginal cost of production. The model yielded an SP of \$7.56 MXN/L for ACD<sub>2</sub>, a figure close to its market price, which according to the surveys conducted was \$8.00 MXN; for ACD<sub>1</sub>, its SP=0. According to Ortiz and Caicedo (2015), constraints with an SP=0 indicate that having a greater quantity of these resources will not result in an increase in total net income. Therefore, the model indicates that ACD<sub>2</sub> is more valuable than ACD<sub>1</sub>, and it is more feasible for the company to focus on soap production rather than biodiesel production.

**Table 3.** Optimal value of activities that maximize the objective function.

| Variable           | Optimized quantity | RC |
|--------------------|--------------------|----|
| ACD <sub>1r</sub>  | 2663.36            | 0  |
| ACD <sub>2t</sub>  | 518.57             | 0  |
| ACD <sub>1ce</sub> | 98.07              | 0  |
| ACD <sub>2cr</sub> | 6496.74            | 0  |
| ACD <sub>2p</sub>  | 7550.26            | 0  |
| BIO                | 3280               | 0  |
| JB                 | 5618.8             | 0  |
| Gl                 | 1184.08            | 0  |
| Jk                 | 5618.8             | 0  |
| B                  | 3280               | 0  |

Source: Data obtained directly from the MPM.

## CONCLUSIONS

The model maximized its profits and a monthly profitability exceeding \$140,000 MXN was determined. This income increases based on the addition of scarce resources, such as ACD<sub>2</sub> and KOH. Therefore, it is concluded that ACD<sub>2</sub> is more important for this model, as its availability allows for soap production. The obtained shadow prices (SP) reflect the scarcity of resources the higher the value, the scarcer the resource is considered, and thus it holds a higher value as an alternative for resource valuation.

**Table 4.** Shadow prices of the MPM.

| Restriction | Resource (inputs)                       | SP     |
|-------------|---|--------|
| 1           | ACD <sub>1</sub>                        | 0      |
| 2           | ACD <sub>2</sub>                        | 7.56   |
| 3           | Biodiesel Transfer                      | 8      |
| 4           | Soap Transfer                           | 15.56  |
| 5           | Methanol                                | 0      |
| 6           | Catalyst (KOH)                          | 148.33 |
| 7           | Catalyst (NaOH)                         | 0      |
| 8           | Dye                                     | 0      |
| 9           | Fragrance                               | 0      |
| 10          | Labor                                   | 0      |
| 11          | Electricity                             | 0      |
| 12          | Distilled Water                         | 0      |
| 13          | Transfer of Produced Biodiesel for Sale | 24     |
| 14          | Transfer of Glycerin for Sale           | 30     |
| 15          | Transfer of Soap for Sale               | 50     |
| 16          | Restriction on Restaurant ACD           | 0      |
| 17          | Restriction on Taco Shops               | 0      |
| 18          | ACD food bar restriction                | 0      |

Source: Data obtained directly from the MPM.

## REFERENCES

- Alvarado-Boirivant, J. 2011. El análisis post-optimal en programación lineal aplicada a la agricultura. *Reflexiones*, vol. 90, núm. 1. pp. 161-173. [consulta 15 noviembre 2023]. <https://www.redalyc.org/articulo.oa?id=72918776010>
- Anderson, D.R., Sweeney, D.R., Williams, T.A., Camm, J.D., Cochran, J.J., Fry, M.J. y Ohlmann, J.W. 2013. *Quantitative Methods for business*. South-Western, Cengage Learning. 12 edition. 910 pp.
- Bierkens, M., Reinhard, S., de Bruijn, J. A., Veninga, W., & Wada, Y. 2019. The shadow price of irrigation water in major groundwater depleting countries. *Water Resources Research*, 55, 4266-4287. <https://doi.org/10.1029/2018WR023086>
- Benerji, A., Chakraborty, D., Mudi, A., Chauhan, P. 2022. Characterization of waste cooking oil and waste engine oil on physical properties of aged bitumen. *Materials Today: Proceedings*. Volumen 59. Páginas 1694-1699. [doi.org/10.1016/j.matpr.2022.03.401\\_](https://doi.org/10.1016/j.matpr.2022.03.401_)
- González, I. y J. González. 2023. Aceites usados de cocina. Problemática ambiental, incidencias en redes de saneamiento y coste del tratamiento en depuradoras. Consorcio de aguas Bilbao Bizkaia (Consultado el 8 de septiembre del 2023): <https://studylib.es/doc/4595302/aceites-usados-de-cocina-problem%C3%A1tica-ambiental>
- Lopes, M., Miranda, I., Belo, I. 2020. Microbial valorization of waste cooking oils for valuable compounds production—a review, *Crit. Rev. Environ. Sci. Technol.* Volumen 50. Páginas 2583-2616. [doi.org/10.1080/10643389.2019.1704602](https://doi.org/10.1080/10643389.2019.1704602)
- Ortiz, V., Caicedo, R. 2015. Procedimiento para la programación y control de la producción de una pequeña empresa. *Revista Ingeniería Industrial*. Vol. 14. Núm. 1. Páginas 89-104.
- Secretaría de Economía. (2012). NMX-F-101-SCFI-2012. Industria del plástico - Envases y embalajes plásticos - Criterios de sustentabilidad - Clasificación y especificaciones. México.
- Santoyo, H., Ramírez, P. y Suvedi, M. 2002. Manual para la evaluación de programas de desarrollo rural. 2ª edición. Gpo. Mundi Prensa. 241 p. ISBN: 968-7462-31-0
- Tacias, V., Rosales, A., Torrestiana, B. 2016. Evaluación y caracterización de grasas y aceites residuales de cocina para la producción de biodiesel: un caso de estudio. *Revista int. Contam. Abie.* Volumen 32. Páginas 303-313. [doi.org/10.20937/RICA.2016.32.03.05](https://doi.org/10.20937/RICA.2016.32.03.05)

Tsoutsos, T., Tournaki, S., Paraiba, O., Kaminaris, S. 2016. La cadena del aceite de cocina usado a biodiesel en Europa, evaluación de mejores prácticas y desempeño ambiental. *Revisiones de energía renovable y sostenible*. Volumen 54. páginas 74-83. [doi.org/ 10.1016/j.rser.2015.09.039](https://doi.org/10.1016/j.rser.2015.09.039)





# Specialization and Competitiveness in Blueberry (*Vaccinium* spp.) Production in Mexico

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## ABSTRACT

**Objective:** Assess national competitiveness in the global blueberry market from 2011 to 2021.

**Methodology:** Five indicators were estimated to analyze production specialization and the commercial competitiveness of Mexican blueberries in the three leading producing states.

**Results:** Specialization in blueberry production has increased; both planted and harvested areas expanded in recent years due to agricultural and sectoral strategies implemented by the governments of the main producing states. As a result, Michoacán and Baja California emerged as the most specialized states in this production.

**Conclusions:** The commercial competitiveness of blueberries has risen and continues to grow. Mexican blueberries are profitable due to strong demand, with national production meeting both domestic and international consumption. It remains one of the least affected products during the COVID-19 pandemic.

**Keywords:** competitiveness, blueberry, production, specialization, growing.

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## INTRODUCTION

Berries are a category of small, wild, reddish or purplish fruits with a pleasantly tangy-sweet flavor, including blueberries, raspberries (*Rubus idaeus*), strawberries (*Fragaria*), and blackberries (*Rubus ulmifolius*) (Palacio, 2018). These fruits are rich in antioxidants, vitamin C, iron, and tannins plant-based polyphenols used medicinally to promote healing due to their anti-inflammatory and restorative properties (Quiñones *et al.*, 2012). The blueberry (*Vaccinium* spp.), commonly known as “blueberry,” and the cranberry (*Vaccinium macrocarpon*) are deciduous shrubs from the *Vaccinium* genus, part of the Ericaceae family, and are native to the Northern Hemisphere, primarily the United States and Canada (Bustillo, 2018). These berries are spherical, measuring between 1 and 2 cm in diameter, and range in color from deep to light blue hence the name “blueberry” or red in the case of cranberries (SAGARPA, 2017). They are consumed fresh or used in products such as jams, purées, juices, wines, pastries, and cereals. In some areas, they are also sold frozen or dehydrated; however, most of Mexico’s domestic production is exported immediately (Undurraga,



2013). In recent years, blueberry production has increased at an average annual growth rate of 28%, with more than 26% of cultivated land dedicated to the crop, resulting in improved yields and a 4.5% increase compared to 2020 (SIAP, 2022). Blueberries are grown in central, western, and northwestern Mexico; *per capita* annual consumption is 71 grams, and the fruit represents 0.3% of the country's total fruit production (Secretaría de Agricultura y Desarrollo Rural, 2023). In 2021, Jalisco led production, accounting for half of Mexico's blueberry output. However, Michoacán recorded the highest market prices, where producers earned an average of over 82,000 pesos per ton, generating 1.278 billion pesos from 15,490 tons harvested (SIAP, 2022). There are several blueberry varieties, though most consumption still comes from wild sources. The most widely cultivated type in Europe and the Americas is the highbush blueberry (*Vaccinium corymbosum*), representing 80% of cultivated species, due to a breeding program initiated in 1906 (González *et al.*, 2017). This variety produces the highest quality fruit in terms of size and flavor. The rabbiteye blueberry (*Vaccinium ashei*) is less commonly grown, as are cranberries (*Vaccinium macrocarpon*) and sour cranberries (*Vaccinium oxycoccos*) (González *et al.*, 2017). Mexico contributes 5.97% of global blueberry production, harvesting approximately 66,000 tons, placing the country fifth worldwide (FAOSTAT, 2023). From 2011 to 2021, the planted area and production increased by 451% and 650%, respectively the period for which consistent statistical records are available. Therefore, evaluating Mexico's competitiveness in the global blueberry market is essential to offer a clear analysis of its production and to assess competitiveness, which is defined as the agri-food chain's dynamic ability to continuously and sustainably maintain, expand, and enhance its market share (Gómez *et al.*, 2023).

## MATERIALS AND METHODS

Blueberries are identified under tariff code 0810.40.01. This falls under Chapter 08, which covers edible fruits and nuts; peel of citrus fruits, melons, or watermelons. Heading 08.10 includes other fresh fruits; subheading 40 groups cranberries, blueberries, and other fruits of the *Vaccinium* genus (SNICE, 2023). The research was conducted using databases from FAO, SIAVI, and SIAP. Global and national data were collected for the period 2011-2021 to measure five indicators aimed at analyzing production specialization and commercial competitiveness in Mexico.

### Location quotient

It is a static measure that reflects the current state of an activity within a specific sector. This ratio compares the relative size of a sector in a region to the relative size of the same sector at the national level (Boisier, 1980). It can be determined in terms of activities, meaning the agricultural sector and blueberry production will be compared at both the national and state levels using the following formula:

$$Q_{ij} = \frac{V_{ij}}{\sum_i V_{ij}} \div \frac{\sum_j V_{ij}}{\sum_i \sum_j V_{ij}}$$

Where:  $Q_{ij}$ =Value of the location quotient for sector  $i$  in region  $j$ .  $V_{ij}$ =Value of variable  $V$  corresponding to sector  $i$  in region  $j$ .  $\sum_i V_{ij}$  =Value of  $V$  corresponding to the regional total.  $\sum_j V_{ij}$  =Value of  $V$  corresponding to the sectoral total.  $\sum_i \sum_j V_{ij}$  =Value of  $V$  corresponding to the national total.

In this research, the value of “V” refers to the production value, in thousands of Mexican pesos, of an activity “i”, which is blueberry production, for region “j”, which includes the three main blueberry-producing states in Mexico.

The calculation of this quotient yields three results:

- If  $Q_{ij} < 1$ , the relative size of the region is smaller than that of the country; therefore, there is no specialization.
- If  $Q_{ij} = 1$ , the relative size of the sector in the region is identical to the relative size of the same sector nationwide; therefore, there is no specialization in the activity within the region.
- If  $Q_{ij} > 1$ , the relative size of the region is greater than the national size; therefore, there is regional specialization in the activity or sector under study (Boisier, 1980).

### Lafay International Specialization Indicator

This refers to specialization and measures the degree to which a country has a comparative advantage in a particular area, allowing it to be a natural exporter (Durán & Alvarez, 2018). This indicator is obtained as follows:

$$IL^k = \frac{Pd_{ij}}{|Pd_{ij} + M_{ij} - X_{ij}|}$$

Where:  $IL^k$ =Lafay’s International Specialization Index.  $Pd$ =It is the production of a good  $i$  in region  $j$ .  $M$ =Imports of said good in region  $j$ .  $X$ =Exports of good  $i$  in region  $j$ .

The interpretation of the results following the calculation of the Lafay index reveals the following scenarios:

- If  $IL > 1$ , the country is a net exporter of the good; therefore, this situation improves as exports become the main destination of production.
- If  $IL < 1$ , the country is not a net exporter of the good; therefore, its production should focus more on exports (Durán & Alvarez, 2018).

In this study, only the volume of production in tons, as well as the value of imports and exports (in thousands of pesos) of blueberries in Mexico and the main producing states during the 2011-2021 period, are considered.

### Relative trade balance

The Relative Trade Balance (RTB) measures the relationship between the trade balance—defined as exports minus imports of a product—and the total sum of a country's exports and imports (Nazif Astorga, 1977).

$$BCR_{ij} = \frac{X_{ij} - M_{ij}}{X_{ij} + M_{ij}}$$

Where, according to the period from 2011 to 2021:  $X_{ij}$ =Value of exports in tons of product  $i$  in  $j$  which is Mexico and  $M_{ij}$ =Value of imports in tons of product  $i$  in Mexico.

In general, when this indicator is greater than 1, the country is a net exporter; when it is less than 1, the country is a net importer.

### Commercial Dependency Index

This index calculates the ratio between the value of imports (M) and the value of apparent consumption (AC) over the same period. It reflects the extent of international competition for domestic demand (Ramírez *et al.*, 2016). Commercial dependency can be defined as the economic condition of a country that is largely influenced or determined by a stronger country. The dependency index is obtained by replacing exports with imports in the formula for the export specialization index (Placer, J. L., 2015b). This index is measured using the following formula:

$$IDC_{ij} = \frac{M_{ij}}{P_{ij} + M_{ij} - X_{ij}}$$

Where:  $IDC_{ij}$ =Trade dependency index of product  $i$  in country  $j$ ;  $M_{ij}$ =Imports of product  $i$  from country  $j$ ;  $P_{ij}$ =Domestic production of product  $i$  of country  $j$ ;  $X_{ij}$ =Exports of product  $i$  from country  $j$ .

These values will be analyzed using tons as the unit of measurement. A country or region is considered to have relative dependency in a specific sector when the relative weight of that sector in its imports is lower than its weight in the comparison environment (Placer, J. L., 2015a). This can be interpreted as follows:

- If the coefficient approaches zero, the sector's productivity competitiveness is higher, and
- If it approaches one, the sector's competitiveness is lower.

### Revealed Comparative Advantage Index

According to Vollrath (1991), the Revealed Comparative Advantage (RCA) Index reflects the relative share of a good  $i$  in the trade of a country  $j$  compared to the

share of that same good in global trade (w). It can be calculated using the following formula:

$$IVCR_i^j = VCE_i^j - VCI_i^j$$

Where *VCE* represents the revealed comparative advantage of exports, and *VCI* represents the revealed comparative advantage of imports. They are calculated as follows:

$$VCE_i^j = \ln \left[ \left( \frac{X_i^j}{X_n^j} \right) / \left( \frac{X_i^w}{X_n^w} \right) \right]$$

where:  $X_i^j$  = Exports of product *i* in country *j*;  $X_n^j$  = Total exports less those of product *i* in country *j*;  $X_i^w$  = Exports of product *i* in the world;  $X_n^w$  = Total exports less those of product *i* in the world.

$$VCI_i^k = \ln \left[ \left( \frac{M_i^j}{M_n^j} \right) / \left( \frac{M_i^w}{M_n^w} \right) \right]$$

$M_i^j$  = Value of imports of product *i* in country *j*;  $M_n^j$  = Total value of imports less those of product *i* in country *j*;  $M_i^w$  = Value of imports of product *i* in the world;  $M_n^w$  = Total value of imports less those of product *i* in the world.

The index can take on positive or negative values. A negative index indicates a trade deficit, while a positive index reflects a surplus and expresses a comparative advantage or disadvantage in trade. In other words, a Revealed Comparative Advantage (RCA) index greater than zero indicates the presence of a competitive sector with potential, whereas a negative index suggests a net importing sector lacking competitiveness in the global market.

## RESULTS AND DISCUSSION

According to FAOSTAT, in 2021 the leading blueberry-producing countries were the United States, followed by Peru, Canada, Chile, and Mexico in fifth place. The top blueberry-importing countries in 2021 were the United States which, despite being one of the largest producers, does not meet its domestic demand followed by the Netherlands, Canada, Germany, and the United Kingdom (Trade Map, 2023). The Tariff Information System Online (SIAVI) reports that the primary importer of Mexican blueberries is the United States, which acquired approximately 96% of the total exported volume. The remaining exports were distributed across 31 markets, including Japan, Canada, Hong Kong, Kuwait, the United Arab Emirates, and others (SIAVI, 2023). Mexico has experienced continuous growth in both planted and harvested blueberry area. In 2021, 5,832.66 hectares were harvested, yielding over

66,400 tons of blueberries the highest productivity recorded, with an average yield of 11.4 tons per hectare (SIAP, 2023). Globally, this agricultural activity has gained economic, political, and social relevance and continues to grow and develop (Rebollar, 2013). Since 1996, the United States has been one of the largest global consumers and producers. Due to its proximity and high demand, Mexico has increased its production (Pérez, 2018).

Nationally, the states of Michoacán, Jalisco, and Baja California are the most specialized in blueberry production. In addition to having favorable soil and climate conditions, they also benefit from advanced technology and a skilled labor force for both production and commercialization (SADER, 2018).

### Location quotient

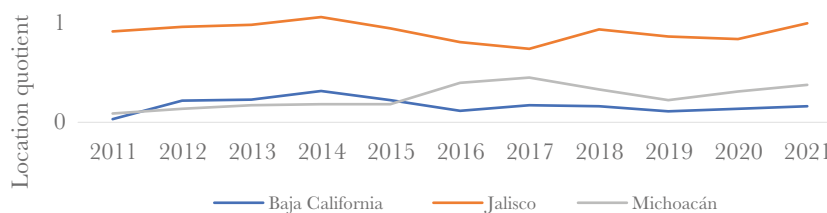
The location quotient allows us to observe and analyze the level of specialization in the three main blueberry-producing states: Jalisco, Michoacán, and Baja California. The calculation of this quotient shows that the higher the concentration of production in a state relative to national production, the greater the degree of specialization. Jalisco demonstrates a high level of specialization in blueberry production, supported by a government initiative coordinated by the Secretariat of Rural Development called the “Berry Agribusiness Development Program in the State of Jalisco” (Government of Jalisco, 2010). This program provided registered producers with blueberry plants to maximize economic returns, along with other measures to boost productivity (Revilla *et al.*, 2023). Baja California reached its highest location quotient in 2014, while Michoacán peaked in 2017 (see Figure 1).

### Lafay International Specialization Indicator

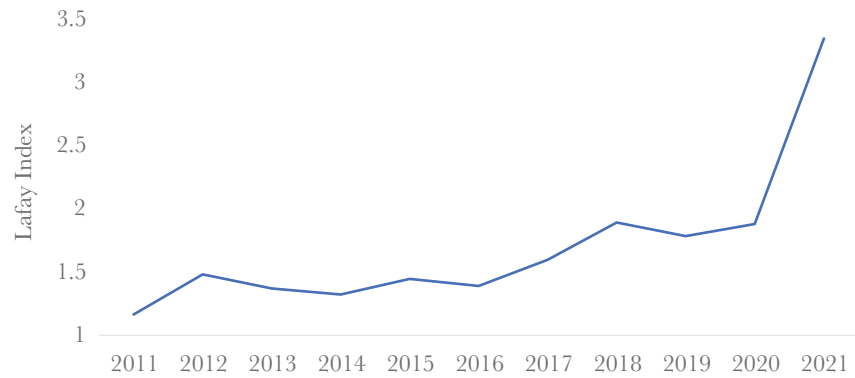
This indicator reveals the degree of a country’s specialization in terms of comparative advantage (Figure 2). It was determined that Mexico is a natural exporter of blueberries, as indicated by a value greater than one, driven by high yields in recent years. This is largely the result of increased planted area and production, particularly since 2017.

### Relative Trade Balance

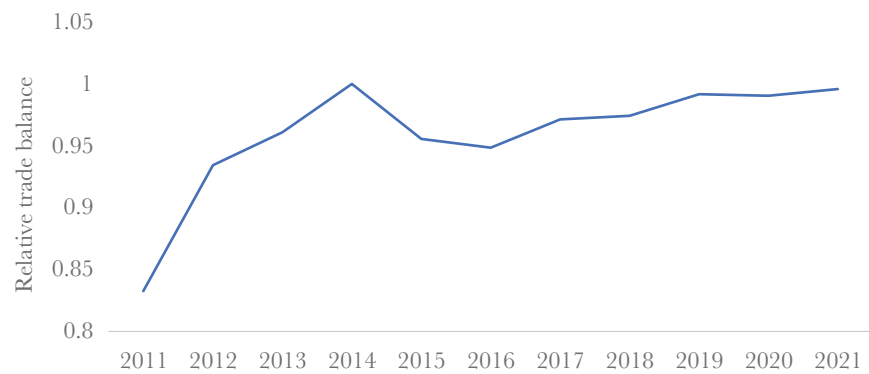
The indicator shows values close to 1 throughout the series, indicating that Mexico did not import or purchase a significant quantity of blueberries from abroad. This confirms that there is no commercial dependency on blueberries in Mexico (see Figure 3).



**Figure 1.** Blueberry Location Quotient by State (2011-2021). Source: Prepared with data from the latest SIACOM update, 2023.



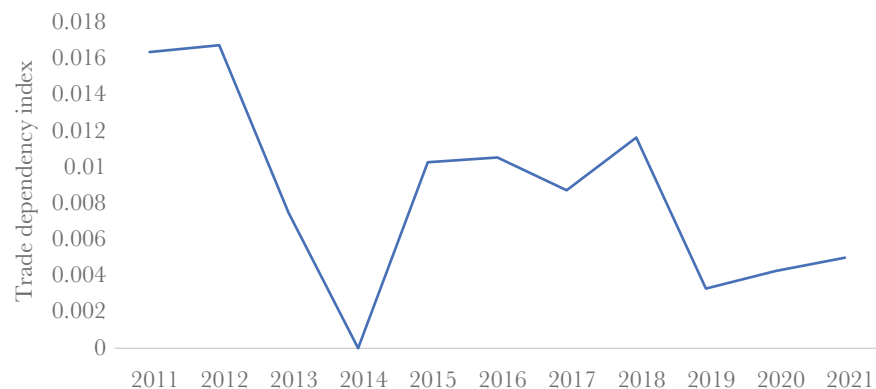
**Figure 2.** Blueberry specialization indicator (2011-2021). Source: Prepared with data from SIAP and SIAVI, 2023.



**Figure 3.** Relative Trade Balance of Blueberries (2011-2021). Source: Prepared with data from SIAVI, 2023.

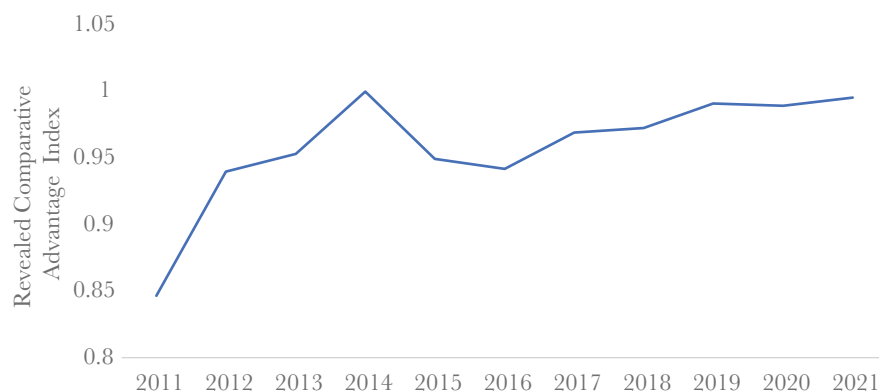
### Commercial Dependency Index

Overall, Mexico’s commercial dependency index for blueberries shows positive results, indicating that the Mexican market is not dependent on the international blueberry market. As shown in Figure 4, the index peaked between 2015 and 2018, meaning that imports exceeded exports during that period. It can be inferred that blueberry competitiveness has increased in recent years.



**Figure 4.** Commercial Dependency Index of Blueberries (2011-2021). Source: Prepared with data from SIAVI and SIAP, 2023.

The Revealed Comparative Advantage (RCA) of Mexican blueberries in the global market has shown positive trends, as illustrated in Figure 5. A positive index indicates a trade surplus and reflects a comparative advantage in trade. An RCA greater than zero demonstrates that the global market presents a favorable sector with potential for blueberry commercialization.



**Figure 5.** Revealed Comparative Advantage Index of Blueberries (2011-2021). Source: Prepared with data from SIAVI and TRADE MAP, 2023.

## CONCLUSIONS

The primary international market for blueberry commercialization is the United States, due to its geographic proximity and the free trade agreement. Nevertheless, Mexico must continue seeking ways to diversify its markets to avoid relying on a single destination. The Mexican blueberry market does not show signs of commercial dependency; as domestic production satisfies internal demand. Competitiveness indices confirm that Mexican blueberries are a strategic export product.

## REFERENCES

- Boisier, S. (1980). *Técnicas de Análisis Regional Con Información Limitada*. ILPES.
- Bustillo, A. (2018). El cultivo del arándano (*Vaccinium corymbosum*) y su proyección en Colombia.
- Durán, J. E., & Alvarez, M. (2018). Indicadores de comercio exterior y política comercial: mediciones de posición y dinamismo comercial. Comisión Económica para América Latina y el Caribe (CEPAL).
- FAOSTAT. (2023). Producción 2021.
- Gobierno de Jalisco. (2010, February 4). "Reglas De Operación Para La Tercera Etapa Del Programa De Desarrollo De La Agroindustria De Berries En El Estado De Jalisco." El Estado de Jalisco, Periódico Oficial.
- Gómez Gómez, A. A., Gómez García, C. A., & Luquez Gaitan, C. E. (2023). Competitividad de la producción de jitomate en el estado de Oaxaca, región Valles Centrales. *Revista De Geografía Agrícola*, (70), 13-29. <https://doi.org/10.5154/r.rga.2023.70.01>
- González, A., & Gloria, C. (2017). Variedades De Arándanos. In *Manual de manejo agronómico del arándano* (pp. 11-19). INDAP. <https://biblioteca.inia.cl/bitstream/handle/20.500.14001/6673/Capitulo%201.pdf?sequence=6&isAllowed=y>
- Nazif Astorga, Ivan. (1977). *Indicadores de Comercio Exterior*. Pérez C., O. (2018). Análisis de la cadena productiva del arándano en México y Chile. PORTES, *Revista Mexicana de Estudios Sobre La Cuenca Del Pacífico*. <https://cdn.blueberriesconsulting.com/2018/09/1546-6002-1-PB.pdf>.
- Placer, J. L. (2015a). Configuración Actual Del Comercio Exterior En La Provincia De León/ Current Foreign Trade Framework In The Province Of León. *Pecunia*, 20, 1-141.

- Placer, J. L. (2015b). Metodológico Índices De Concentración.
- Revilla-Chaviano, A., Soca-Cabrera, J. R., Chaviano-Rodríguez, N. R., & Luquez Gaitan, C.E. (2023). Analysis of tobacco productivity in Mexico between 1980 and 2020 through the KLEMS methodology. *Agro Productividad*. <https://doi.org/10.32854/agrop.v16i2.2386>
- Quiñones, M., Miguel, M., & Aleixandre, A. (2012). Los polifenoles, compuestos de origen natural con efectos saludables sobre el sistema cardiovascular. *Nutr Hosp*, 27(1), 76-89. <https://doi.org/10.3305/nh.2012.27.1.5418>
- Ramírez-Padrón, L. C. 1, Caamal-Cauich, I. 1\*, Pat-Fernández, V. G. 1, & Martínez-Luis, D. 2. (2016). Índices de competitividad de la fresa (*Fragaria vesca* L.) de México en el mercado mundial. *Agroproductividad*. México.
- Rebollar, A. (2013). Berries, situación y perspectiva. Primer foro de berries en Colima.
- SADER. (2018, August 25). Cultivo del arándano en México, reto superado. Gobierno de México. <https://www.gob.mx/agricultura/articulos/cultivo-del-arandano-en-mexico-reto-superado>
- SAGARPA. (2017). Planeación Agrícola Nacional. Frutas del bosque, arándano, frambuesa y zarzamora mexicanas. [https://www.gob.mx/cms/uploads/attachment/file/257076/Potencial-Frutas\\_del\\_Bosque.pdf](https://www.gob.mx/cms/uploads/attachment/file/257076/Potencial-Frutas_del_Bosque.pdf)
- SIAP. (2022). Panorama Agroalimentario 2022. <https://drive.google.com/file/d/1jVWS4EFKK7HGwQOBpGeljUyaDT8X8Iyz/view>
- SIAVI. (2023). Exportaciones e importaciones de México. <http://www.economia-snci.gob.mx>
- SNICE. (2023). LIGIE Versión unificada. [www.snice.gob.mx](http://www.snice.gob.mx)
- Trade Map. (2023). Datos de importación y exportación. <https://www.trademap.org>
- Undurraga, P., & Vargas, S. (2013). Manual de arándano.
- Vollrath, T. L. (1991). A theoretical evaluation of alternative trade intensity measures of revealed comparative advantage.





# Agroecological systems promoted by the Vicente Guerrero Group (GVG): Key factors for their permanence

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## ABSTRACT

**Objective:** To determine the factors that ensure the permanence of agroecological activities and/or systems promoted among three family groups affiliated with the Vicente Guerrero Group (GVG).

**Design/methodology/approach:** The research employed a mixed-methods approach, integrating qualitative techniques such as participant observation, interviews, and workshops with quantitative methods through a structured questionnaire. The survey was administered to 34 families from three different groups.

**Results:** Key factors identified for the continuity of agroecological systems included regular field visits, the presence of a motivated local representative, the establishment of a demonstrative model plot, ongoing training, and the feasibility and adaptability of introduced innovations. To maintain their agroecological orientation, families implemented eight core practices: soil and water conservation, input reduction, polyculture systems, agroecological pest and disease management, efficient input use, crop rotation, field redesign, and on-site input production. Families expressed a strong interest in ongoing training related to agroecological innovations.

**Limitations on study/implications:** The analysis focused solely on three of the 18 family groups connected to the GVG across Tlaxcala and Puebla, which may limit the generalizability of the findings.

**Findings/conclusions:** The sustained success of agroecological initiatives requires dedicated efforts across all actors within the agroecosystem. The long-term adoption of promoted practices and systems hinges on shared commitments between the supporting organization (GVG) and the participating family groups.

**Keywords:** agroecological profiles, agroecological transition, agroecological practices.

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## INTRODUCTION

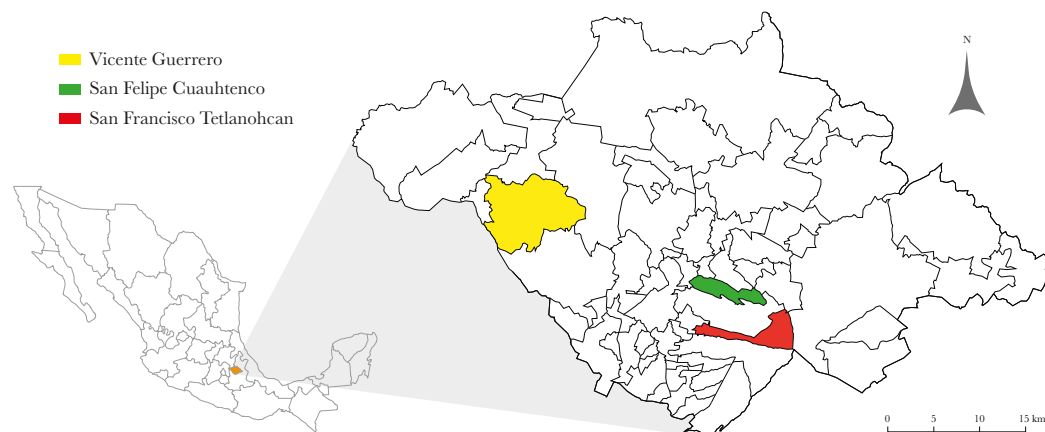
Current challenges facing global agri-food systems, along with prevailing trends in land, water, and biodiversity use, call for the implementation of new food production models that promote food security while preserving natural resources (Sarand n, 2020; Spiegel *et al.*, 2021). These models also aim to contribute to the paradigm of food sovereignty. Agroecological systems are rooted in co-participatory processes that recognize ecological dynamics, peasant knowledge, collective labor, disciplinary insights, and practical applications (Wezel *et al.*, 2009; Sarand n, 2020). Within this framework, farmers are co-promoters of the shift toward agroecological techniques (Osorio, 2015), a process further strengthened by social movements and other actors contributing to agroecological transitions. The Vicente Guerrero Group (GVG) has been a national and international benchmark for over four decades, advancing participatory agroecological strategies for the use and conservation of common goods, fostering connections between producers and consumers, and promoting local self-determination and productive self-sufficiency (Roncancio, 2017). GVG acknowledges that agroecological transitions

require social integration and creativity. Thus, it promotes the development of skills and capacities through facilitators or community promoters, referred to by Baquero (2013) as “outstanding community agents”. These individuals serve as essential catalysts for social dynamism and are vital to agroecological transitions (Guzmán *et al.*, 2016; Méndez *et al.*, 2016). This study seeks to identify the key factors that ensure the continuity of agroecological activities and systems promoted among three family groups affiliated with the GVG. It also aims to identify and analyze specific practices in order to evaluate their operational significance and reinforce the territorial scaling of agroecology.

## MATERIALS AND METHODS

The research was conducted in three localities in the state of Tlaxcala: Vicente Guerrero, in the municipality of Españita ( $19^{\circ} 25' 41''$  N and  $98^{\circ} 02' 23''$  W), San Felipe Cuauhtenco in Contla de Juan Cuamatzi ( $19^{\circ} 18' 48''$  N and  $98^{\circ} 07' 19''$  W), and San Francisco Tetlanohcan, in the municipality of the same name ( $19^{\circ} 15' 36''$  N and  $98^{\circ} 09' 50''$  W) (Figure 1).

The study employed a mixed-methods approach, integrating both qualitative and quantitative methods. Qualitative tools included four participatory workshops, observation, at least five group meetings, attendance at three fairs (Vicente Guerrero, Cuauhtenco, and Ixtenco), several field visits, and a structured interview with each leader of the GVG. The quantitative aspect involved the application of a questionnaire to 34 families from the three studied groups: 5 from San Francisco Tetlanohcan, 12 from San Felipe Cuauhtenco, and 17 from Vicente Guerrero, who have received support for 2, 10, and 40 years, respectively. The questionnaire covered five areas: 1. Socioeconomic characteristics, 2. Agroecological transition, 3. Practices and motivations supporting the permanence of existing systems, 4. Monitoring and training needs. Both qualitative and quantitative data were analyzed, recorded, and graphed using Microsoft Word and Excel, as well as JASP (version 0.18.1.0, 2023). The results are presented in bar and radar charts.



**Figure 1.** Geographic location of the localities, State of Tlaxcala.

## RESULTS AND DISCUSSION

### Methods for monitoring GVG families

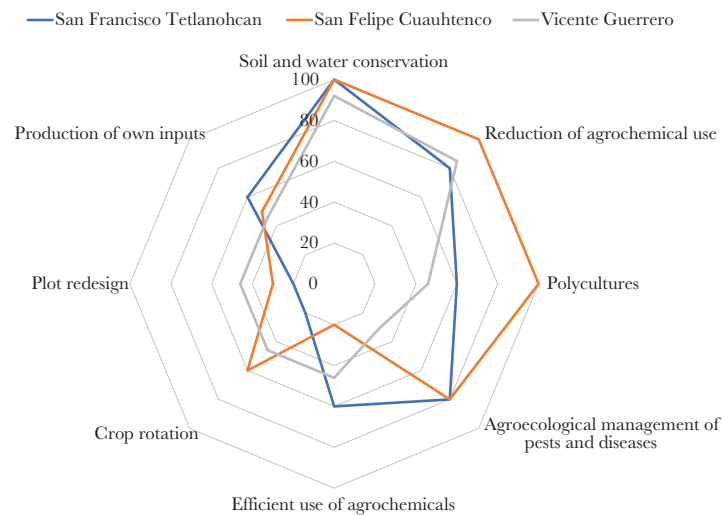
The agroecological transitions promoted by the Vicente Guerrero Group (GVG) are rooted in local needs, identified through participatory methods that not only address current realities but also shape the strategies for follow-up. These efforts aim to build collective self-determination through a peasantry in agroecological transition (Morejón, 2023). The implementation and continuity of agroecological activities in communities take various forms, with participatory strategies such as exchanges, workshops, diagnostics, and field visits emerging as the most effective. These approaches, also emphasized by Merçon (2015), prioritize the most pressing local issues, fostering broader influence within other families in the territory. However, challenges such as the use of unfamiliar or poorly adapted species, and varying levels of commitment and interest, can hinder or even interrupt the continuity of these practices.

The GVG has developed follow-up strategies aimed at ensuring the permanence of each promoted agroecological activity, practice, or system. This includes encouraging ongoing participation of local leaders who act as liaisons between the community and the organization. These processes foster knowledge exchange and skill development among farming families, empowering them to serve as ambassadors of agroecological practices. Together with the GVG, they work to build local self-management and establish synergies between communities and institutions that share this vision (Roncancio, 2017; Zebadúa *et al.*, 2024). Notably, 83% of the families reported receiving some form of support such as training, inputs, employment, income, or invitations to events an average of 15 times per year, which reinforces their agroecological engagement.

For over four decades, the GVG has been recognized as a national and international reference in agroecological promotion, the result of ongoing efforts by the organization, its partners, and member families who bear testimony to their strong socio-environmental commitment. The GVG stands as a beacon of the agroecological movement, championing traditional agricultural systems such as the milpa, local seed varieties, and agroecological innovations across Mexico and Latin America (Zebadúa *et al.*, 2024).

Eight commonly adopted practices were identified as key strategies for maintaining agroecological profiles (Figure 2). Soil and water conservation, reduced use of agrochemicals, and agroecological pest and disease management were highlighted by families as essential to sustaining these systems. These practices form part of broader campesino strategies aimed at addressing the socio-environmental problems generated by conventional agricultural models (Sánchez, 2014; Sarmiento *et al.*, 2017; Zebadúa *et al.*, 2024).

Families particularly emphasize the role of agroecological practices in the recovery and/or preservation of their natural resources. Española, one of the partner communities, is recognized as a pioneer in adapting rainwater harvesting techniques, diversification, and the production of *Tlaxcashi* and other organic inputs findings aligned with those of Hernández (2015). This community exemplifies how local adaptation of agroecological innovations, rooted in campesino experiences, integrates agriculture as a central element of communal life, providing not only food but also delivering vital agro-ecosystem services. Spatial-temporal diversification thus emerges as a local strategy for maintaining



**Figure 2.** Basic practices to maintain agroecological profiles.

agroecological profiles both locally and territorially (Sarandón, 2020), prioritizing the healthiest production methods possible. Across the three communities, families consistently acknowledge the significance of cultivating polycultures practices typically implemented incrementally or at small scales. Polyculture is regarded as essential for preserving and conserving local agrobiodiversity. Mixing different crops contributes to agroecosystem sustainability, fertility, and resilience (Hernández, 2015). In Tetlanohcan (40%), Cuauhtenco (70%), and Vicente Guerrero (54%), polycultures are deemed indispensable as they serve as key sources of nutrition for the family diet and promote the use and conservation of native seeds a practice strongly supported by the GVG through initiatives such as community seed funds and local fairs (Medina, 2016; Sarmiento *et al.*, 2017).

In Tetlanohcan and Cuauhtenco, several families (40%) consider knowledge-sharing dialogues as essential tools for acquiring skills in preparing soil amendments and managing crops, pests, and diseases. Thirty-two of the thirty-four surveyed families expressed their interest in gaining these skills through GVG exchange activities, while eighteen believed this knowledge could be acquired through peer-to-peer training visits. The GVG implements the *Campeño a Campeño* (CaC) methodology, recognized as one of the most effective strategies for disseminating, adopting, and adapting agroecological innovations among farmers. The approach is based on three core components: exchanges, visits, and experimentation, all tailored to the diverse learning styles of participating families. The majority of families (85%) reported that their primary learning occurred through hands-on experimentation testing, observing, and evaluating new techniques directly in their plots (Tuchin, 2023). Visual assessment is the dominant form of evaluation in these processes. Meanwhile, for 32% of families, the most meaningful learning occurred through exchanges that shared real-life experiences within similar contexts. Another 41% highlighted exchange visits as highly effective learning opportunities traditional methods for transmitting knowledge among campesinos. (Ocampo-Álvarez, 2016; Tuchin, 2023).

### **Monitoring and continuity process between GVG and linked families**

The Vicente Guerrero Group (GVG) implements a range of follow-up strategies to support activities promoted among partner families. Over the past three years, the majority of families (71%) have received some form of training through workshops, talks, or courses. A smaller percentage (9%) reported having been invited throughout the year to participate in fairs held in other communities or in cultural events such as “Maize Day” and “Native Seeds Day.” These initiatives serve to strengthen both the communal work and the communication among partner communities.

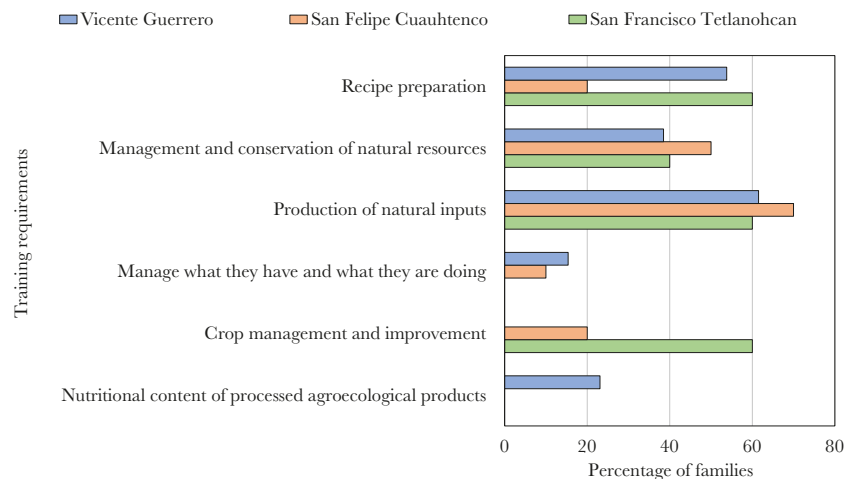
The perceived benefits of implemented practices significantly influence families’ decisions to remain involved with the GVG. Approximately 65% indicated their willingness to continue their engagement through training or participation in various projects, while 18% expressed interest in maintaining involvement through exchange visits. The continued use of agroecological practices is largely an individual decision 97% reported this as a personal choice which highlights the need for strong intrinsic motivations to undertake agroecological transitions (Guzmán *et al.*, 2016; Spiegel *et al.*, 2021).

A noteworthy finding is that most of the surveyed families (88%) expressed a strong will to keep implementing agroecological practices, as they are convinced of the advantages of producing food through such methods. About 82% noted that their involvement was based on deliberate decision-making, while 79% attributed it to the pursuit of common well-being. Overall, families believe that adopting agroecology allows them to reduce harm to others something that can occur when conventional or even certified organic producers use external inputs for crops that are often excluded from their own household diets. Interestingly, 18% of the participants viewed agroecological methods as an integral part of their lives, interpreting them as a local or campesino way of life. This aligns with what Ortega-Espès (2018) refers to as a foundational principle of peasant-environment harmony.

The implementation of agroecological strategies is based primarily on the voluntary choices of families, shaped by their specific needs. As these practices are adopted, new needs emerge, necessitating additional management strategies. Figure 3 presents the training needs identified by the surveyed families, reflecting their interests, length of engagement with the GVG, availability of resources, and evolving priorities.

Topics such as recipe development (food, cosmetics and/or medicines), resource management and conservation, and production of inputs are common needs in all three cases.

It is worth noting that in communities such as Vicente Guerrero and Acxotla del Monte, among others, the Vicente Guerrero Group (GVG) actively fosters the dialogue of knowledge among local groups striving to enhance, empower, and give visibility to peasant women. These initiatives include the preservation of traditional dishes, medicinal formulas, and cosmetic practices. As part of this effort, the “Mujeres de Vicente Guerrero” group GVG partners meet weekly to transform backyard-grown aromatic herbs into various products such as cosmetics (soaps), medicinal remedies (syrups, tinctures), and other items showcased during exchange events. These women play a pivotal role in community transition processes under various identities: as producers, vendors, chefs, backyard caretakers,



**Figure 3.** Training needs of families in the three groups.

artisans, preservers, and seed donors. Their contributions underscore the significance of gendered agroecological innovation. The conservation and sustainable management of local resources remains a key concern for families. The longstanding presence of the GVG, coupled with an inherited awareness among rural families of the importance of preserving natural resources, are foundational reasons why a large portion of families expressed strong interest in participating in training sessions aimed at maintaining agroecological practices. Driven by the need to reduce reliance on external inputs, the GVG has promoted the reuse of organic waste to develop natural inputs for pest, disease, and crop nutrition management (Ávila, 2019). These strategies are not only fundamental to agroecological transition processes (Guzmán *et al.*, 2016) but also essential to the organization's original efforts to increase plot productivity (Sánchez, 2014). In Vicente Guerrero, there is also growing interest in analyzing the nutritional content of locally processed products to inform consumers of their quality and health benefits. Lastly, the families involved in the study acknowledged several achievements and contributions of the GVG, including: a) the production of bio-inputs (60%), b) soil and water conservation efforts (82%), and c) ecotechnologies (71%) such as ferro-cement tanks for rainwater harvesting, fuel-efficient stoves (lorena), vermicomposting systems, seed preservation structures (cuescomates), and simple micro-tunnels for vegetable production. These techniques and structures are now visibly integrated into the agroecosystems of Tlaxcalan communities. Moreover, 33% of families expressed a sense of representation through the native seed protection and rescue law, an important recognition also highlighted by Baquero (2013). The GVG's more than four decades of agroecological history exemplify a model worthy of replication, recognition, preservation, and enhancement as part of broader territorial agroecological transitions.

## CONCLUSIONS

The GVG's promotion of agroecological transitions through collective strategies fosters the adoption and adaptation of innovations tailored to local needs. The continuity of implemented agroecological practices hinges on ongoing communication via field

visits, community interest, and the feasibility and adaptability of each transferred technique. Therefore, the strategy of continuous training and knowledge exchange equips families with tools, skills, and insights essential for the effective management of their agroecosystems.

## REFERENCES

- Ávila, C. J. F. (2019). Construyendo alternativas socio-técnicas en la producción de maíz desde lo local en tres organizaciones en los estados de Puebla y Tlaxcala [Tesis]. Universidad Autónoma Metropolitana.
- Baquero, S. L. (2013). Soberanía Alimentaria, Semillas y Resistencia a la Dominación de Corporaciones Transnacionales (Grupo Vicente Guerrero, Tlaxcala). [Tesis]. Universidad Autónoma Chapingo.
- Guzmán, G. I., López García, D., Román, L., & Alonso, A. (2016). Participatory Action Research for an Agroecological Transition in Spain. In *Agroecology: A Transdisciplinary, Participatory and Action-oriented Approach* (pp. 140-160). CRC Press.
- Hernández, M. E. R. (2015). Una propuesta de política pública agrícola para la población rural del centro de México: la agroecología como modelo de la agricultura de autoconsumo [Tesis, Instituto Tecnológico y de Estudios Superiores de Monterrey.]. <https://gvgtlaxcala.org/tesis/>
- Medina, D. M. L. (2016). La defensa del maíz nativo en Tlaxcala, 2006-2012: en Proceso Social y Político [El Colegio de Tlaxcala]. <https://gvgtlaxcala.org/tesis/>
- Méndez, E., Bacon, C. M., Cohen, R., Gliessman, S. R., & Gutiérrez-Navarro, A. (2016). Agroecology: A transdisciplinary, participatory and action-oriented approach. *Interdisciplina*, 6(14), 243-251. <https://doi.org/10.22201/ceiich.24485705e.2018.14>
- Merçon, J. (2015). Educación campesina y soberanía alimentaria: Enseñanzas del Grupo Vicente Guerrero de Tlaxcala (pp. 107-115). Universidad Veracruzana.
- Morejón, S. E. (2023). Logros y desafíos de la estrategia de acompañamiento técnico en el cultivo cacao, Tabasco (A. Bartra Vergés, L. Paz paredes, R. Cobo González, E. Pérez Suárez, M. G. Hernández García, S. Medellín Urquiaga, & H. García Crespo, Eds.; 1era ed., pp. 113-117). Libros de campo.
- Ocampo-Álvarez, D. (2016). Metodología de campesino a campesino actividades y herramientas ante el cambio climático. <https://www.ipscuba.net/media/2021/08/Metodologia-de-campesino-a-campesino.pdf>
- Ortega-Espès, D. (2018). Agroecología: innovaciones para sistemas agrícolas y alimentarios sustentables. [www.foei.org/es](http://www.foei.org/es)
- Osorio, A.A. (2015). Metodología para la Evaluación de Sustentabilidad a partir de Indicadores Locales para la Planificación y Monitoreo de Programas Agroecológicos, MESILPA (Á. Acevedo-Osorio & A. Angarita-Leiton, Eds.; Primera Ed.). Corporación Universitaria Minuto de Dios. <https://doi.org/10.13140/RG.2.1.3524.0166>
- Roncancio Rodríguez, A. C. (2017). Proyecto de Desarrollo Rural Integral Vicente Guerrero: experiencias e incidencia para una vida sustentable, Tlaxcala. In P. Sánchez-Morales & O. Romero-Arenas (Eds.), *El Sistema Milpa y la producción de maíz en la agricultura campesina e indígena de Tlaxcala* (<https://www.researchgate.net/publication/331585397>)
- Sánchez, M. P. (2014). El cambio Climático y la agricultura campesina e indígena sostenible en el centro y sur de México: Experiencia de seis organizaciones indígenas y campesinas. (M. C. Oviedo & L. Pliego, Eds.; 1era ed.). PIDAASSA.
- Sarandón, S.J. (2020). Biodiversidad, agroecología y agricultura sustentable (J.-S. Santiago & María Margarita Bonicatto, Eds.; 1a ed.). Universidad Nacional de la Plata. <https://www.agroecologia.net/wp-content/uploads/2020/12/biodiversidad-agroecologia-santiago-sarandon.pdf>
- Sarmiento, S. A., Sánchez, M. P., & Hernández, O. P. (2017). Las ferias del maíz y otras semillas nativas como estrategias campesinas e indígenas de resistencia y conservación para la soberanía alimentaria en Tlaxcala y México. In P. Sánchez Morales & O. Romero Arenas (Eds.), *El Sistema Milpa y la producción de maíz en la agricultura campesina e indígena de Tlaxcala* (1era ed., pp. 169–191). Universidad Autónoma de Puebla. <https://gvgtlaxcala.org/libros/>
- Spiegel, H., Miloczki, J., Freyer, B., Surböck, A., Friedel, J. K., Kaul, H.-P., Wagentristl, H., Schaumberger, A., Mayer, R., Bohner, A., Gaube, V., & Sandén, T. (2021). Monitoring agroecological transformation processes induced by climate and agricultural innovations over time and space. In *Copernicus GmbH* (pp. 1-2). <https://doi.org/10.5194/egusphere-egu21-12627>
- Tuchin, F. (2023, March 20). Las claves de la agroecología que hay que copiar de América Latina. *Revista Haz*, 1-9. <https://hazrevista.org/rsc/2023/03/claves-agroecologia-copiar-america-latina/>

- Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., & David, C. (2009). Agroecology as a science, a movement and a practice. A review. *Agronomy for Sustainable Development*, 29(4), 503-515. <https://doi.org/10.1051/agro/2009004>
- Zebadúa, A.J., Hernández, G. M. G., & Taddei, A. J. C. (2024). *Somos granos de maíz: una propuesta de Ley general para la transición agroecológica en México* (1era ed.). Centro de Investigación y Capacitación Rural A.C.



# Development of xylophagous fungi native to Veracruz in sugarcane (*Saccharum* spp.) distillery vinasses on inert materials of zeolite and agricultural lime

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## ABSTRACT

**Objective:** To establish the development conditions of white-rot fungi with the use of vinasse as substrate and zeolite and commercial agricultural lime as support.

**Design/methodology/approach:** Pure vinasse from a sugarcane distillery was used as the main nutrient on a support of vinnase-zeolite and vinasse-lime in 1:1 proportion. The variable of study was the daily radial growth (mm-day<sup>-1</sup>) of each of the four isolates on vinasse-inert culture medium. The experimental unit was glass Petri dishes of 90 × 15 mm by triplicate. A Mann-Whitney U test was conducted (using R Studio).

**Results:** Four fungal isolates (G = *Ganoderma* sp. K., P = *Pleurotus* sp. B., Py = *Pycnoporus* sp. K., and Tr = *Trametes* sp. C.) were cultured on zeolite-vinasse and agricultural lime-vinasse and their daily radial growth was recorded. Two fungal isolates were able to develop tissue covering the Petri dish in 9 days. Zeolite-vinasse was the best treatment, showing a median of 2.1 mm-day<sup>-1</sup> on isolate G and 1.6 mm-day<sup>-1</sup> on isolate P with significant differences (p < 0.05).

**Limitations on study/implications:** All the white-rot fungi strains test were cultured at 28 °C and minimal development conditions with the use of a byproduct of the sugarcane industry and the use of non-conventional inerts.

**Findings/conclusions:** The development of mycelium by the isolated fungi G and P on a substrate with zeolite-vinasse recorded the highest growth compared to the agricultural lime.

**Keywords:** Zeolite, agricultural lime, vinasse, white-rot-fungi.

## INTRODUCTION

Sugarcane (*Saccharum* spp.) is one of the crops that generates an important agroindustrial activity in Mexico. It is grown in 15 states with a surface of 800 thousand hectares, operated



by 49 sugar mills (SADER, 2021). Within this agroindustry, the production of sugarcane ethanol is considered a solid industry (López-Ortega *et al.*, 2021). Vinasse is a black liquid of unpleasant odor generated as a final byproduct of the distillation process of sugarcane juice to obtain ethanol. This vinasse contains a high content of organic matter that could trigger a negative environmental impact if it is not treated adequately (Montiel-Rosales *et al.*, 2022). It is estimated that for every liter of ethanol produced, 10 to 15 L of vinasse is obtained (Cortes-Rodríguez *et al.*, 2018). The excessive incorporation of vinasses into soils modifies the pH and conductivity and can cause toxicity where it is dumped (Nakashima and de Oliveira Junior, 2020). Among the conventional treatments to treat contaminant effluents of agroindustrial activities, anaerobic degradation can be achieved through activated muds, rotative biological contactors, shallow ponds, or percolating filters. However, the processes can be inhibited with the presence of phenol compounds, salt and sulfur ions (Carpanez *et al.*, 2022; Fernandes *et al.*, 2020). Among the treatments of vinasses, the use of fungal biodegradation is considered an alternative potential. Xylophagous fungi called white-rot fungi have demonstrated the ability to degrade different synthetic and natural contaminants, through their lignocellulosic enzymes (Grelska and Noszczyńska, 2020; Sağlam *et al.*, 2018). These enzymes are not specific, although they allow the degradation of recalcitrant compounds (Del Gobbo *et al.*, 2022). There are precedents in the bioremediation of sugarcane vinasses performed in a fixed-bed bioreactor with *Pleurotus ostreatus* (FUNGICOL S.A.S) for the removal of substances that cause coloring in the vinasse, decoloring 83% after 36 days (Tapie *et al.*, 2016). “Airlift” bioreactors with concentric tube have also been evaluated, managing to discolor the vinasse between 58 and 78% using a strain of *Pleurotus sajor-caju* CCB020 (Aragão *et al.*, 2020). Other species such as *Trametes* sp. T3 showed 75% of discoloring when it is immobilized on polyurethane, and a production of laccase enzymes of  $112 \text{ U L}^{-1}$  after 21 days (Ahmed *et al.*, 2022). Usually, all these practices are conducted in liquid media on bioreactors. Among the techniques used in the removal of contaminants from effluents, the use of zeolites has been helpful in the treatment of residual water, mainly because of their crystalline structure, capable of storing water within its pores that can be liberated through heat (de Magalhães *et al.*, 2022). As materials for remediation, they are more efficient in the removal of heavy metals in residual waters than in the soil (Otunola and Ololade, 2020). Given the accomplishments developed, the following research had the single objective of establishing the conditions of development on zeolite and commercial agricultural lime as inert bases for the development of biomass from local isolates of xylophagous fungi using vinasse as the main substrate.

## MATERIALS AND METHODS

The experiment was carried out in the facilities of the Applied Microbial Biotechnology laboratory of Colegio de Postgraduados, Campus Córdoba (N 18° 51' 22" W; 96° 51' 34"), in the municipality of Amatlán de los Reyes, Veracruz.

### Samples of fungi collected

Fructiferous bodies of white-rot fungi were collected from trees fallen in the experimental fields of Colegio de Postgraduados, Campus Córdoba, located on N

18° 51' 22.967" W; 96° 51' 36.434". The collection was conducted according to the methodology by Guzmán (1990).

### Procurement of vinasse

The vinasse was obtained from a storage tank in Alcoholera de Zapopan S.A. de C.V., Atoyac, Veracruz. The vinasse sample was taken directly from the storage tanks. After a few hours of the bioethanol production process, 20 L were collected. The vinasse was transported to the laboratory and stored in a cold room at 4 °C until its use (Del Gobbo *et al.*, 2022). The nutritional composition of vinasse was shared by the technical staff, and it is presented in the following Table 1.

### Procurement of inerts

The zeolite used in this study was acquired from the company Grupo COYPUS SA. De C.V. Based on an X-ray study and EDS chemical analysis, it was found that zeolite is constituted by 10% Clinoptilolite and 90% Heulandite (Not published). Commercial lime from Agrical Grupo Calidra S.A de C.V. was used, whose constitution is CaCO<sub>3</sub>, 90-98.5% and SiO<sub>2</sub>, 0.1-2%.

### Isolation and conservation of white-rot fungi

The sporocarps of xylophagous fungi collected were washed three times with purified water, the soil was removed with sterile gauze, submerged in ethanol at 70% and the excess water was eliminated on previously sterilized filter paper. Then, with the use of

**Table 1.** Nutritional and physicochemical composition of the sugarcane juice vinasse.

| Test         | Result | Contribution kg/L                     |
|--------------|--------|---------------------------------------|
| N %          | 0.07   | 0.71                                  |
| P %          | 0.013  | 0.31 (P <sub>2</sub> O <sub>5</sub> ) |
| K %          | 0.223  | 2.73 (K <sub>2</sub> O)               |
| S %          | 0.057  | 0.58                                  |
| Mg %         | 0.028  | 0.29                                  |
| Ca %         | 0.033  | 0.34                                  |
| Na ppm       | < 250  | < 250                                 |
| Al ppm       | < 50   | < 0.05                                |
| Mn ppm       | 19.2   | 0.019                                 |
| Cu ppm       | < 2.5  | < 0.003                               |
| Zn ppm       | < 12.5 | < 0.013                               |
| B ppm        | < 25   | < 0.025                               |
| Moisture %   | 97.7   | -                                     |
| Dry matter % | 2.3    | -                                     |
| pH           | 3.71   | -                                     |
| CE mmhos/cm  | 8.81   | -                                     |

Laboratories A-L de México, S.A. de C.V. A&L Laboratories, INC.

the blade of a #11 Braun<sup>®</sup> scalpel, the fungus pileus was dissected and a fragment of the tissue from the inside was taken. The tissue dissected was placed on potato dextrose agar (PDA) BD Bioxon<sup>®</sup> (39 g/L<sup>-1</sup>). They were incubated at 28 °C in a Binder<sup>®</sup> incubator for 10 days (Liu *et al.*, 2016). After 10 days of growth in PDA, the fungi mycelium was dissected from the Petri dish, preserving the fungi tissue inside cryovials with distilled water and others with glycerol at 6% under refrigeration at 4 °C (Abatenh, 2018; Linde *et al.*, 2018). Then, it was resown in PDA medium to maintain fresh cultures for the experiments.

### Experimental design

Two treatments were evaluated: 1) Mixture of 20 ml raw vinasse with 20 grams of zeolite, and 2) 20 ml vinasse with 20 g of agricultural lime. Each treatment was mixed homogeneously and placed in crystal Petri dishes of 90×15 mm and sterilized for 15 min at 15 Lb pressure.

Four isolates from the fungi collected after 10 days cultured on PDA were used. From the fungus mycelium, 1 cm<sup>2</sup> was taken from each of the isolates and placed in the middle of the crystal Petri dishes with the mixture of vinasse-zeolite and vinasse-agricultural lime. The Petri dishes with each treatment were sealed with 45 mm plastic film. Triplicates of each isolate were made.

### Radial growth

The radial growth of mycelium on the treatments of raw vinasse mixture on vinasse-zeolite and vinasse-agricultural lime was recorded, where the methodology of radius of the colony was used (Bilay *et al.*, 2000; Zubyk and Klechak, 2023). The growth speed ( $V_c$ ) was estimated through the equation:

$$V_c = \frac{R_i - R_f}{\Delta t}$$

Where:  $R_i$  is the initial radius of the colony in mm and  $R_f$  is the final radius of the colony in mm and  $\Delta t$  is the linear duration in days. The experiment ended when the mycelium colonized the limits of the Petri dish.

### Statistical analysis

The response variable was the radius of the colony. The data distribution was verified and subjected to a Mann-Whitney-U non-parametric analysis, to compare differences in the radial growth on the vinasse-zeolite and vinasse-agricultural lime mixture ( $p < 0.05$ ) according to McKnight and Najab, (2010). Statistical analyses were performed with the Rstudio software (R core team, 2022). The experimental unit was a Petri dish with treatments of 1) vinasse-zeolite and 2) vinasse-agricultural lime, and 3 repetitions of each of the treatments from each isolate were carried out.

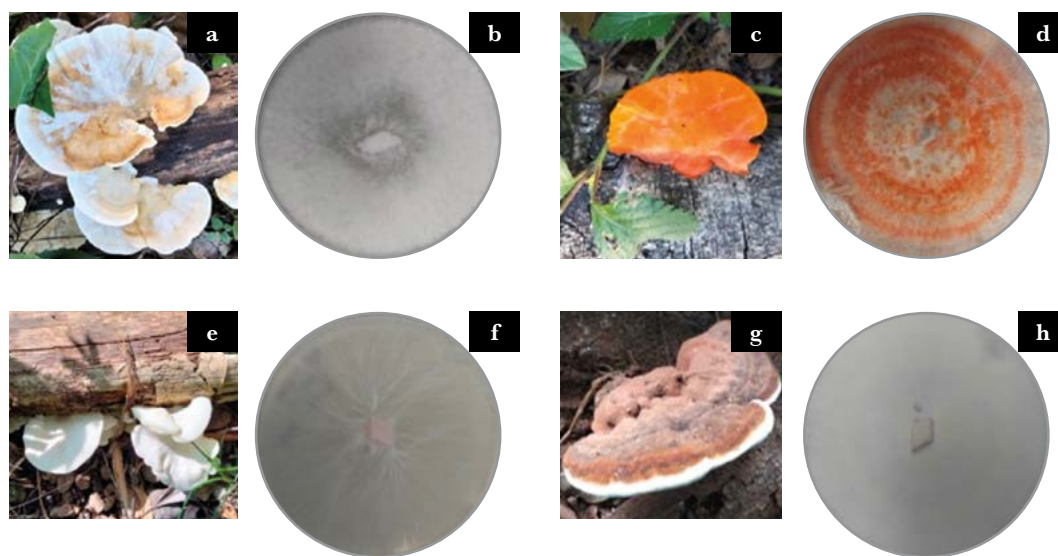
## RESULTS AND DISCUSSION

From the wood rot, 4 fungi were obtained. The determination of mycelium was made following the macroscopic traits (Guzmán, 1990; Stalpers, 1978; Bettucci *et al.*, 1971). Each isolate received a code (Figure 1).

Two isolates showed mycelial development on zeolite and agricultural lime. In both isolates, growth was observed on the treatments. The isolates codified as G and P began to develop on day 4 and 5; and until day 8 and 9, they covered the Petri dish, respectively. The Mann-Whitney-U analysis on the treatments of the isolate G on vinasse-zeolite and vinasse-agricultural lime showed that the radial growth in vinasse-zeolite (median=2.1 mm, Interquartile Range=1.2, 3.5 mm) differed significantly ( $p<0.05$ ) from the growth on vinasse-agricultural lime (median=1 mm, Interquartile Range=0.4, 1.9 mm). Meanwhile, the isolate P on vinasse-zeolite (median=1.6, Interquartile Range 1.1, 3.2 mm) differed significantly ( $p<0.05$ ) from vinasse-agricultural lime (median=0.7 mm, Interquartile Range=0.3,1.8).

During the growth of isolates on the vinasse-zeolite and vinasse-agricultural lime treatments, the mycelium showed different morphology; the isolate G on vinasse-zeolite, vinasse-agricultural lime presented vegetative mycelium, while the isolate P had aerial growth reaching the superior margins of the Petri dish on both treatments (Figure 2).

Because of the microporous structure of zeolite, it allows the transference of matter between the intracrystalline space and the medium surrounding it, in addition to its composition in  $AlO_4$  which confers negative charges that can be neutralized by compensation cations (de Magalhães *et al.*, 2022; De Smedt *et al.*, 2015). These characteristics provide important properties in the capacity for adsorption and ionic exchange for the possible use of zeolite as support for immobilization (Borges-Rodríguez *et al.*, 2012). Meanwhile,

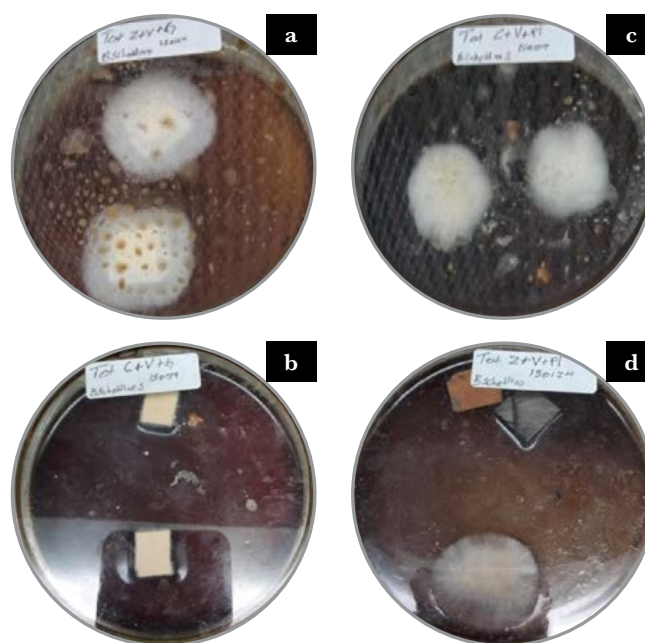


**Figure 1.** White-rot fungi in situ and on PDA after 10 days: a) *Trametes* sp. C (T), b) *Trametes* sp. C (T) on PDA, c) *Pycnoporus sanguineus* aff. K. (Py), d) *Pycnoporus sanguineus* aff. K (Py) on PDA, e) *Pleurotus djamor* aff. B, (P), d) *Pleurotus djamor* aff. B (P) on PDA, g) *Ganoderma* sp. K. (G), h) *Ganoderma* sp. K on PDA.

**Table 2.** Mycelial development of white-rot fungi on vinasse-zeolite and vinasse-agricultural lime. The mean of the radial growth ( $\text{mm}\cdot\text{day}^{-1}$ ) is presented, and the standard deviation, difference between medians of zeolite and agricultural lime ( $\text{mm}\cdot\text{day}^{-1}$ ), respectively.

| Isolate code | Vinasse-Zeolite ( $\text{mm}\cdot\text{day}^{-1}$ ) $\pm$ Standard deviation | Vinasse-Agricultural lime ( $\text{mm}\cdot\text{day}^{-1}$ ) $\pm$ Standard deviation | Median ( $\text{mm}\cdot\text{day}^{-1}$ ) |
|--------------|--|--|--|
| G            | $2.27 \pm 1.44$  | $1.24 \pm 1.14$  | 2.1 vs. 1.0*                               |
| P            | $1.97 \pm 1.27$  | $1.04 \pm 1.01$  | 1.6 vs. 0.7*                               |

\*=Significant difference ( $p < 0.05$ ).



**Figure 2.** Demonstrative assay of mycelium growth on treatments at day 7, where: a) Isolate G with vinasse-zeolite, b) Isolate G with vinasse-agricultural lime, c) Isolate P with vinasse-agricultural lime, and d) Isolate P with vinasse-zeolite.

the capacity for biodegradation of xylophagous fungi is linked to the enzymatic oxidative capacity of oxidases, peroxidases, oxidoreductases, especially laccases, which facilitate the degradation of complex contaminant structures to intermediate metabolites that are easier to degrade (Vaksmas *et al.*, 2023).

## CONCLUSIONS

The fastest growth on the treatments of vinasse-zeolite and vinasse-agricultural lime was obtained on vinasse-zeolite. Therefore, it is possible to use vinasse as a source of substrate to obtain fungal biomass of xylophagous fungi on inert materials such as zeolite and agricultural lime as support. It is the first study where an inert of mineral origin like zeolite is used, agricultural lime as support, and vinasse as substrate for the development of xylophagous or white-rot fungi. The colonization on treatments was achieved in 8 and 9 days. The development of the fungi allowed metabolizing the vinasse that served as

substrate on the support of zeolite and agricultural lime. This study allows the bases to understand with future vision the level of traces retained in zeolite and agricultural lime, so that vinasses have a lower environmental impact when they are dumped in agricultural fields or runoffs that can affect living organisms in bodies of water.

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## REFERENCES

- Abatenh, E. (2018). Mushroom Preservation Protocol. *Open Access Journal of Microbiology & Biotechnology*, 3(1). <https://doi.org/10.23880/OAJMB-16000127>
- Ahmed, P. M., Nieto-Peñalver, C. G., de Figueroa, L. I. C., & Pajot, H. F. (2022). Vinasse odyssey: sugarcane vinasse remediation and laccase production by *Trametes* sp. immobilized in polyurethane foam. *Biodegradation*, 33(4), 333-348. <https://doi.org/10.1007/S10532-022-09985-Y/TABLES/4>
- Aragão, M. S., Menezes, D. B., Ramos, L. C., Oliveira, H. S., Bharagava, R. N., Romanholo Ferreira, L. F., Teixeira, J. A., Ruzene, D. S., & Silva, D. P. (2020). Mycoremediation of vinasse by surface response methodology and preliminary studies in air-lift bioreactors. *Chemosphere*, 244, 125432. <https://doi.org/10.1016/J.CHEMOSPHERE.2019.125432>
- Bettucci, L., Guerrero, Rosa. T., Ferreira, V., & Szpiniak, B. (1971). Hongos estudio xilofagos. *Boletín, Art.* 118.
- Bilay, V., Solomko, E. F., & Buchalo, A. S. (2000). Growth of edible and medicinal mushrooms on commercial agar media. Science and cultivation of edible fungi Proceedings of the 15th International Congress on the Science and Cultivation of Edible Fungi, 779-782. <https://eurekamag.com/research/003/460/003460068.php>
- Borges-Rodríguez, C., Juan-Rodríguez, S., & Nelis, A. (2012). Evaluación de la zeolita como soporte para la formulación del biofertilizante Azospirillum. 46(2), 12-18. <http://www.redalyc.org/articulo.oa?id=223124990002>
- Carpanez, T. G., Moreira, V. R., Assis, I. R., & Amaral, M. C. S. (2022). Sugarcane vinasse as organo-mineral fertilizers feedstock: Opportunities and environmental risks. *Science of the Total Environment*, 832. <https://doi.org/10.1016/J.SCITOTENV.2022.154998>
- Cortes-Rodríguez, E. F., Fukushima, N. A., Palacios-Bereche, R., Ensinas, A. V., & Nebra, S. A. (2018). Vinasse concentration and juice evaporation system integrated to the conventional ethanol production process from sugarcane – Heat integration and impacts in cogeneration system. *Renewable Energy*, 115, 474-488. <https://doi.org/10.1016/J.RENENE.2017.08.036>
- de Magalhães, L. F., da Silva, G. R., & Peres, A. E. C. (2022). Zeolite Application in Wastewater Treatment. *Adsorption Science & Technology*, 2022. <https://doi.org/10.1155/2022/4544104>
- De Smedt, C., Someus, E., & Spanoghe, P. (2015). Potential and actual uses of zeolites in crop protection. *Pest management science*, 71(10), 1355-1367. <https://doi.org/10.1002/PS.3999>
- Del Gobbo, L. M., Rulli, M. M., Villegas, L. B., & Colin, V. L. (2022). Bioremediation of Sugarcane Vinasse by Fungi-Based Biological Methods (pp. 161-171). Humana, New York, NY. [https://doi.org/10.1007/978-1-0716-2006-9\\_13](https://doi.org/10.1007/978-1-0716-2006-9_13)
- Fernandes, J. M. C., Sousa, R. M. O. F., Fraga, I., Sampaio, A., Amaral, C., Bezerra, R. M. F., & Dias, A. A. (2020). Fungal biodegradation and multi-level toxicity assessment of vinasse from distillation of winemaking by-products. *Chemosphere*, 238, 124572. <https://doi.org/10.1016/J.CHEMOSPHERE.2019.124572>
- Grelska, A., & Noszczyńska, M. (2020). White rot fungi can be a promising tool for removal of bisphenol A, bisphenol S, and nonylphenol from wastewater. *Environmental Science and Pollution Research International*, 27(32), 39958. <https://doi.org/10.1007/S11356-020-10382-2>
- Guzmán, G. (1990). Identificación de los hongos, comestibles venenosos alucinantes y destructores de la madera: Vol. V (Quinta Reimpresión). Editorial Limusa, S.A. de C.V.
- Linde, G. A., Luciani, A., Lopes, A. D., Valle, J. S. do, & Colauto, N. B. (2018). Long-term cryopreservation of basidiomycetes. *Brazilian Journal of Microbiology*, 49(2), 220-231. <https://doi.org/10.1016/J.BJM.2017.08.004>

- Liu, S. R., Zhang, W. R., Chen, A. P., & Kuang, Y. B. (2016). Investigating the Effect of Tissue Size on Mycelial Growth of Seven Mushroom Species by Using a Novel Device for Precise Tissue Isolation. *Indian Journal of Microbiology*, 56(4), 516. <https://doi.org/10.1007/S12088-016-0615-3>
- López-Ortega, M. G., Guadalajara, Y., Junqueira, T. L., Sampaio, I. L. M., Bonomi, A., & Sánchez, A. (2021). Sustainability analysis of bioethanol production in Mexico by a retrofitted sugarcane industry based on the Brazilian expertise. *Energy*, 232, 121056. <https://doi.org/10.1016/j.energy.2021.121056>
- McKnight, P. E., & Najab, J. (2010). Mann-Whitney U Test. The Corsini Encyclopedia of Psychology, 1–1. <https://doi.org/10.1002/9780470479216.CORPSY0524>
- Montiel-Rosales, A., Montalvo-Romero, N., García-Santamaría, L. E., Sandoval-Herazo, L. C., Bautista-Santos, H., & Fernández-Lambert, G. (2022). Post-Industrial Use of Sugarcane Ethanol Vinasse: A Systematic Review. *Sustainability*, 14(18), 11635. <https://doi.org/10.3390/su141811635>
- Nakashima, R. N., & de Oliveira Junior, S. (2020). Comparative exergy assessment of vinasse disposal alternatives: Concentration, anaerobic digestion and fertirrigation. *Renewable Energy*, 147, 1969-1978. <https://doi.org/10.1016/j.renene.2019.09.124>
- Otunola, B. O., & Ololade, O. O. (2020). A review on the application of clay minerals as heavy metal adsorbents for remediation purposes. *Environmental Technology & Innovation*, 18, 100692. <https://doi.org/10.1016/j.eti.2020.100692>
- SADER. (2021). Caña de azúcar un cultivo de importancia para México. <https://www.gob.mx/agricultura/articulos/cana-de-azucar-un-cultivo-de-importancia-para-mexico?idiom=es>
- Saglam, N., Yesilada, O., Saglam, S., Apohan, E., Sam, M., Ilk, S., Emul, E., & Gurel, E. (2018). Bioremediation Applications with Fungi (pp. 1-37). [https://doi.org/10.1007/978-3-319-77386-5\\_1](https://doi.org/10.1007/978-3-319-77386-5_1)
- Stalpers, J. A. (1978). Identification of wood-inhabiting Aphylophorales in pure culture. Centraalbureau voor Schimmelcultures.
- Tapie, W. A., Prato-García, D., & Sanchez Guerrero, H. (2016). Biodegradación de vinazas de caña de azúcar mediante el hongo de pudrición blanca *Pleurotus ostreatus* en un reactor de lecho empacado. *Tropical and Subtropical Agroecosystems*, 19(2), 145-150. <https://doi.org/10.56369/tsaes.2191>
- Vaksmas, A., Guerrero-Cruz, S., Ghosh, P., Zeghal, E., Hernando-Morales, V., & Niemann, H. (2023). Role of fungi in bioremediation of emerging pollutants. *Frontiers in Marine Science*, 10, 235. <https://doi.org/10.3389/FMARS.2023.1070905/BIBTEX>
- Zubyk, P. R., & Klechak, I. R. (2023). Cultural and Morphological Features of *Trametes versicolor* (Polyporaceae) Growth on Wood Hydrolyzes Containing Media. *Innovative Biosystems and Bioengineering*, 7(1), 24-33. <https://doi.org/10.20535/IBB.2023.7.1.274343>

# *In Situ* degradability of *Guazuma ulmifolia* Lam. fruits used in targeted nutrition for pelibuey sheep

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## ABSTRACT

**Objective:** To determine the chemical composition and in situ degradability of *Guazuma ulmifolia* Lam. fruits and assess whether targeted nutrition (TN) with 300 g of fruit meal for seven days before the withdrawal of a progestogen influences reproductive variables in Pelibuey ewes.

**Design/Methodology/Approach:** A proximal chemical analysis and in situ degradability assessment of dry matter and protein from *G. ulmifolia* fruits were conducted using two Rambouillet rams fitted with rumen cannulas at different incubation times (0, 6, 12, 24, 48, and 72 h). To evaluate the effect of TN on reproduction, 71 Pelibuey ewes were assigned to one of two treatments: CIDR (n=36) or CIDR+TN (300 g of *G. ulmifolia* fruit meal) for seven days (n=35). On day 9, CIDRs were removed, and TN was discontinued.

**Results:** Estrus synchronization response was similar (p>0.05) between treatments. However, ewes supplemented with *G. ulmifolia* fruits exhibited a shorter time to estrus onset (28.68±1.15 h). Fertility rates were comparable between treatments (p>0.05), while fecundity was higher in the CIDR+TN group.

**Study Limitations/Implications:** The use of *G. ulmifolia* fruits as a dietary supplement promotes their conservation and integration into agroforestry and silvopastoral systems in tropical regions.

**Findings/Conclusions:** TN with 300 g of *G. ulmifolia* fruit meal for seven days before progestogen withdrawal reduced the time to estrus onset and increased fecundity in Pelibuey ewes.

**Keywords:** Local resources, Estrus synchronization, Prolificacy, Food supplement.

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## INTRODUCTION

The productive efficiency of sheep production systems depends, among other factors, on reproductive efficiency. However, this is influenced by the lambing interval and the number of offspring per birth (Martínez-González *et al.*, 2017). One strategy to enhance productivity and profitability in these production units is to improve flock reproductive capacity, thereby increasing the number of lambings per ewe per year and reducing production costs (Hinojosa-Benavides *et al.*, 2019). Among the reproductive



management strategies that enhance ewe performance, the use of biotechnologies such as estrus synchronization stands out. This technique involves the application of effective and easily implementable pharmacological methods to manipulate reproductive physiology, improving both productivity and economic efficiency in sheep production systems (Lozano-González *et al.*, 2012). Nutrition is the key determinant of economic efficiency in livestock production units. Consequently, there is constant pressure to minimize both the quantity and duration of supplementation periods to optimize the cost-benefit ratio of this practice (Baldi *et al.*, 2008). Supplementing with energy- and protein-rich concentrates during specific periods and in appropriate amounts—an approach known as “Targeted Nutrition” (TN)—can enhance reproductive efficiency in females (Martin & Reza, 2016). The fruits and foliage of tropical trees and shrubs (Piñeiro-Vázquez *et al.*, 2013) can serve as valuable feed sources, improving livestock productivity by increasing dietary protein levels (Ku-Vera *et al.*, 2014). Some of these plants contain secondary compounds capable of modifying nutrient degradation rates and transit through the gastrointestinal tract (Getachew *et al.*, 2000; Pirela *et al.*, 2010). The guácimo tree (*Guazuma ulmifolia* Lam.), belonging to the Sterculiaceae family, is widely distributed in the tropical regions of Mexico and adapts well to various soil and climatic conditions (Manríquez-Mendoza *et al.*, 2011). From a producer’s perspective, it represents an alternative forage resource that mitigates seasonal feed shortages for livestock during drought periods (Villa-Herrera *et al.*, 2009). The fruits of *G. ulmifolia* contain up to 13.6% crude protein, 56.0% neutral detergent fiber, 41% acid detergent fiber, 1.5% ether extract, and 49.5% *in vitro* dry matter digestibility (Cervantes-Marín *et al.*, 2015; Hernández-Hernández *et al.*, 2017). Their chemical-nutritional composition makes them a viable supplement to meet the dietary requirements of small ruminants. Based on this, the aim of the present study was to determine the chemical composition and *in situ* degradability of dry matter and crude protein in *G. ulmifolia* fruits. Additionally, the study aimed to evaluate whether TN with 300 g of mature *G. ulmifolia* fruit meal for seven days prior to progestogen withdrawal influences estrus synchronization, prolificacy, and fecundity in Pelibuey ewes.

## MATERIALS AND METHODS

### Study site

The study was conducted from June to December 2015 at the commercial production unit “La Gloria,” located in the community of Tequexquináhuac, Texcoco municipality, State of Mexico (98° 82’ W, 19° 47’ N, 2,480 m.a.s.l.). The climate is classified as temperate sub-humid, with an average annual temperature of 15.9 °C and an average annual precipitation of 686 mm (INEGI, 2023).

### Fruit collection and processing

Mature *G. ulmifolia* fruits were manually collected during the fruiting season (February–March) when they turned dark brown and naturally detached from the tree. Collection took place in pastures within the community of Angostillo, Paso de Ovejas municipality, Veracruz, Mexico (96° 54’ 19” W, 19° 21’ 80” N, 260 m.a.s.l.). After collection, the fruits were sun-dried for approximately two days, then ground using a hammer mill equipped

with a 1/8-inch sieve. The processed fruit meal was stored in sealed containers to prevent moisture absorption. A subsample was further ground using a Thomas Wiley<sup>®</sup> Model 4 mill with a 1.0 mm retention sieve for chemical composition analysis and ruminal incubation to determine in situ degradability.

### **Chemical composition**

Proximal chemical analysis of the ground fruits was performed following the methods of the Association of Official Analytical Chemists (2016). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined using the ANKOM filter bag technique. All analyses were conducted at the Animal Nutrition Laboratory of the Colegio de Postgraduados, Montecillo Campus.

### **In situ ruminal degradability of dry matter and protein**

To estimate the in situ degradability of dry matter and protein, two adult Rambouillet rams ( $65.06 \pm 1.75$  kg body weight) fitted with permanent rumen cannulas (50 mm diameter) were used. The animals were housed in individual cages and fed 2.0 kg DM animal<sup>-1</sup> day<sup>-1</sup> of a total mixed ration consisting of 30% commercial concentrate (Borrega Plus; Alimentos Unión Tepexpan<sup>®</sup>) and 70% oat hay. The degradability of *G. ulmifolia* fruits was assessed over two 72-hour experimental periods, following a 7-day adaptation period designed to stabilize rumen conditions. During adaptation, rams were supplemented with 300 g animal<sup>-1</sup> day<sup>-1</sup> of *G. ulmifolia* fruit meal.

For ruminal incubation, 5×5.5 cm multilayer polyester filter bags (F57 bags, Ankom Technology Corp., Macedon, NY) were used. Each bag was filled with 0.5 g of fruit sample (dry basis) and placed inside a mesh tied to a 70 cm nylon cord with a metal weight to ensure immersion in the ventral sac of the rumen. The bags were incubated at 0, 6, 12, 24, 48, and 72 hours (n=4 bags per incubation time) in reverse order, ensuring all were retrieved simultaneously. After removal, the bags were washed under low-pressure running water until clear, then dried in a forced-air oven at 65 °C for 24 hours and weighed.

To calculate in situ crude protein degradability, dry matter content (AOAC method 954.01) and crude protein (AOAC method 925.09) were analyzed in the ruminal incubation residues (AOAC, 2016). Dry matter loss was estimated as the weight difference of the sample before and after ruminal incubation, following the methodology of Ørskov & McDonald (1979).

The degradation kinetics were modeled using the equation:

$$D = a + b * (1 - e^{-c*t})$$

Where: *a*=soluble fraction of the substrate; *b*=insoluble but potentially degradable fraction and *c*=degradation rate of the potentially degradable fraction; *t*=incubation time.

### **Reproductive performance**

A total of 71 adult Pelibuey ewes ( $3.4 \pm 0.2$  years old,  $47.2 \pm 4.2$  kg BW) were selected. All ewes were fed 2.0 kg ewe<sup>-1</sup> day<sup>-1</sup> of the same total mixed ration used during the

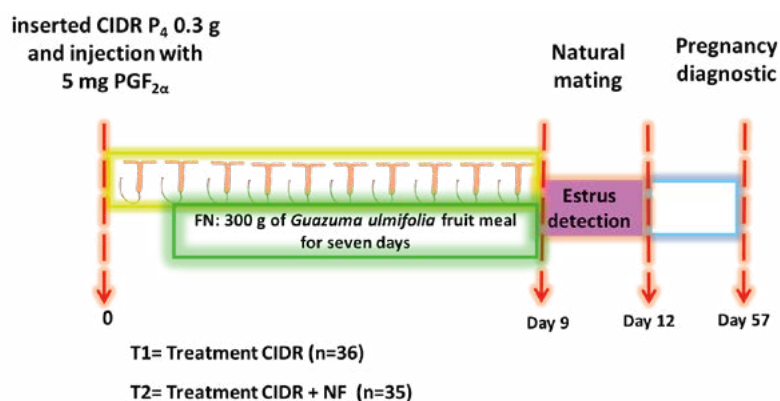
adaptation period (70% oat hay, 30% commercial concentrate), which contained 12.4% CP, 42% ADF, 50% NDF, 2.0% EE, and 9% ash. Seven days before the synchronization protocol, all ewes underwent sanitary management, which included deworming (Closantil oral 5%<sup>®</sup>, Laboratorios CHINOIN) and selenium supplementation combined with vitamin E (MUSE<sup>®</sup>, Intervet Schering-Plough Animal Health), following the recommended dosage for each product.

### Treatments and estrus synchronization protocols

All ewes underwent an estrus synchronization protocol (Figure 1). Each ewe received an intramuscular injection of 1.0 mL prostaglandin  $F_{2\alpha}$  (5 mg dinoprost, Lutalyse<sup>®</sup>, Zoetis) at the time of insertion of a CIDR intravaginal device impregnated with 0.3 g progesterone (CIDR P4), which remained in place for nine days. Seven days before CIDR removal, ewes were randomly assigned to one of two treatments: CIDR (n=36); CIDR+Targeted Nutrition (n=35) (300 g of *G. ulmifolia* fruit meal per day for seven days before CIDR removal). Supplemented ewes received 300 g/day of a wet-based mixture containing ground *G. ulmifolia* fruits, processed to a particle size of 1-4 mm.

### Evaluated variables

Estrus response: number of ewes in estrus relative to the total number of ewes per treatment; time to estrus onset: time elapsed from progesterone removal until the first signs of estrus; fertility rate: number of pregnant ewes relative to the total number of inseminated ewes; prolificacy: number of lambs born per ewe that gave birth; fecundity: number of lambs born per ewe exposed in each treatment. Estrus detection began four hours after CIDR removal and was subsequently monitored every four hours using a teaser ram fitted with an apron; ewes displaying external estrus signs were separated from the group for natural mating, with a second service 12 hours after the first. Fertility was determined 45 days post-insemination via abdominal ultrasound (Contec CMS600P2VET); ewes were classified as pregnant (positive) or non-pregnant (negative) based on the presence or absence of well-defined fetal structures; prolificacy and fecundity were recorded at lambing by counting the number of lambs born per ewe.



**Figure 1.** Estrus synchronization protocol implemented in Pelibuey ewes treated with progesterogens (CIDR) and Targeted Nutrition with *Guazuma ulmifolia* fruits.

### Statistical analysis

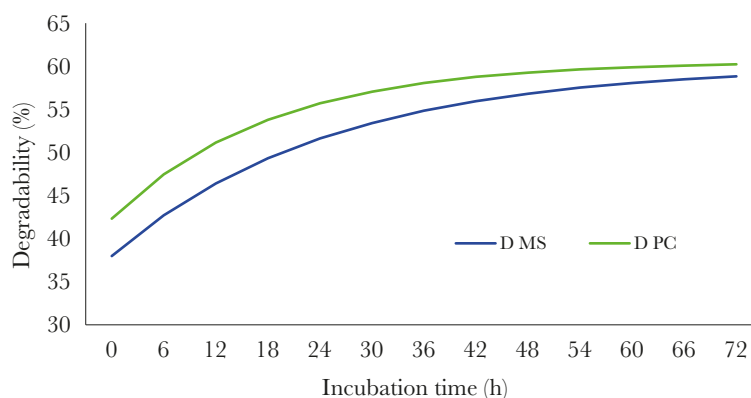
Estrus response and fertility variables were analyzed using a logistic regression model with the Logistic procedure in SAS; time to estrus onset, prolificacy, and fecundity were analyzed using the Log-Rank survival curve method with the Life Test procedure; mean comparisons were performed using the Bonferroni method (SAS, 2011).

## RESULTS AND DISCUSSION

The fruits used for supplementation contained 5.7% moisture, 12.6% crude protein, 1.6% ether extract, 7.1% ash, 47.9% neutral detergent fiber, and 38.8% acid detergent fiber. *In situ* dry matter digestibility (Figure 2) was 58.8%; the degradation parameters were  $a=37.98$ ,  $b=22.09$ ,  $c=0.04$ , resulting in an effective degradation of 59.93% with a passage rate of 0.02%.

*In situ* crude protein digestibility was 60.2%, with degradation parameters  $a=42.32$ ,  $b=18.26$ ,  $c=0.05$ , leading to an effective degradation of 59.9% and a passage rate of 0.02%.

The chemical composition of *G. ulmifolia* fruits falls within the ranges reported by other authors (Cervantes-Marín *et al.*, 2015; Hernández-Hernández *et al.*, 2017) and is considered sufficient to meet the maintenance nutritional requirements of sheep (NRC, 2007). A high proportion of the fruit undergoes ruminal degradation, as *in situ* dry matter degradability reached 58.8%, differing from the 40% previously reported by Román *et al.* (2008) and Gómez-Gurrola *et al.* (2014). The high *in situ* crude protein degradability observed in this fruit may be attributed to its nutritional composition, secondary compounds, and low neutral and acid detergent fiber content, which influence the digestive dynamics of certain feed fractions, as reported in other ruminant studies (Getachew *et al.*, 2000; Piñeiro-Vázquez *et al.*, 2013). No significant difference ( $p>0.05$ ) was observed in estrus response between treatments, as both groups had the same number of ewes in estrus (Table 1), with values similar to those reported by Ake-López *et al.* (2014) and Sosa *et al.* (2014). The estrus synchronization response exceeding 97% confirms the effectiveness of the progestogen-based hormonal treatments used to synchronize estrus in small ruminants. The mechanism of this hormonal method is based on prolonging the luteal phase of the estrous cycle, which inhibits gonadotropin activity. Upon progestogen withdrawal, progesterone action



**Figure 2.** *In situ* ruminal degradation of dry matter (D MS) and crude protein (D PC) from *Guazuma ulmifolia* fruit meal, using the model  $D = a + b * (1 - e^{-c*t})$ .

ceases, leading to gonadotropin release and estrus onset in most ewes within a short period (Córdova-Izquierdo *et al.*, 2019).

However, ewes that received fruit supplementation exhibited estrus sooner after progestogen withdrawal (Table 1) compared to the CIDR group. The time to estrus onset observed in this study was shorter than the values reported by Fraire *et al.* (2013) and Sosa *et al.* (2014) in CIDR-treated ewes.

The reduced time to estrus onset in the CIDR+TN group is likely due to the nutrient intake, as follicular populations in small ruminants are highly sensitive to the availability of energy and protein, which can enhance folliculogenesis through nutrition (Martin *et al.*, 2004). Protein- and energy-rich supplementation increases plasma concentrations of metabolic signals that influence folliculogenesis (Viñoles *et al.*, 2009), ultimately affecting circulating estradiol levels, leading to a shorter time to estrus onset (Scaramuzzi *et al.*, 1999; Martin *et al.*, 2004; Ake-López *et al.*, 2014). The fertility rates obtained in this study (Table 2) were similar between treatments ( $p > 0.05$ ), with acceptable values exceeding 80%. Fertility is influenced by the number of services and body condition at mating (Salomon & Maxwell, 2000; Viñoles *et al.*, 2009). In this study, each ewe received two services, one at estrus detection and a second 12 hours later. Body condition may have also contributed to the high fertility rates, as the ewes' initial body condition scores (BCS) ranged from 3.00 to 3.75 (on a 1-5 scale; Russel *et al.*, 1969), which is considered moderate to high and had a positive effect on pregnancy rates, measured as fertility.

Targeted nutrition with *G. ulmifolia* fruits did not affect prolificacy ( $p > 0.05$ ) in this study; ewes gave birth to 1.44 to 1.66 lambs, values similar to those reported by Fraire *et al.* (2013) in ewes synchronized with progestogens alone and supplemented during the synchronization period. Fecundity (Table 2) differed between treatments ( $p < 0.05$ ) and was higher in ewes receiving targeted nutrition. This index depends on fertility and prolificacy, as well as factors influencing these parameters, including ovulation rate, number of fertilized ova, and embryo survival. These, in turn, are affected by genetic factors (*e.g.*, breed and individual variation) and environmental factors (*e.g.*,

**Table 1.** Reproductive variables of Pelibuey ewes synchronized with progestogens (CIDR) and Targeted Nutrition (TN) for 7 days with 300 g of *Guazuma ulmifolia* fruit meal.

| Treatment | n  | Sheep in estrus | %       | Onset of estrus (h) |
|-----------|----|-----------------|---------|---------------------|
| CIDR      | 36 | 35              | 97.22 a | 32.82±1.71 a        |
| CIDR+FN   | 35 | 35              | 100 a   | 28.68±1.15 b        |

a, b Values with different literals in the same column are statistically different ( $p < 0.05$ ).

**Table 2.** Fertility, prolificacy, and fecundity of Pelibuey ewes synchronized with progestogens (CIDR) and Targeted Nutrition (TN) for 7 days with 300 g of *Guazuma ulmifolia* fruit meal.

| Treatment | n  | Fertility |         | Prolificacy | Fertility   |
|-----------|----|-----------|---------|-------------|-------------|
|           |    | n         | (%)     |             |             |
| CIDR      | 36 | 29        | 80.55 a | 1.44±0.09 a | 1.20±0.12 b |
| CIDR+FN   | 35 | 33        | 94.28 a | 1.66±0.11 a | 1.57±0.12 a |

a, b Values with different literals in the same column are statistically different ( $p < 0.05$ ).

nutritional status before and after mating, and the use of hormonal treatments) (Rojas & Rodríguez, 1995; Rubianes & Ungerfeld, 2002). The higher fecundity observed in the CIDR+TN group with *G. ulmifolia* fruit supplementation is likely related to the higher fertility rate in this group and the effect of targeted nutrition, which stimulates follicular development, increases the number of preovulatory follicles, and ultimately enhances the number of follicles reaching ovulation (Pérez-Hernández *et al.*, 2009). These factors contribute to an increased ovulation rate, directly impacting fecundity (Ratray *et al.*, 1981).

## CONCLUSIONS

The chemical composition and degradability of *G. ulmifolia* fruits are suitable for their use in targeted nutrition for ewes. The consumption of 300 g of these fruits for seven days before progestogen withdrawal reduces the time to estrus onset and increases the fecundity of Pelibuey ewes. Therefore, this resource has potential for inclusion in targeted feeding programs to enhance the reproductive performance of Pelibuey ewes.

## REFERENCES

- Aké-López, J.R., Centurión-Castro, F.G., Magaña-Monforte, J.G., & Aké-Villanueva, J.R. (2014). Efecto del progestágeno y la dosis de gonadotropina coriónica equina en la sincronización del estro y tasa de gestación en ovejas Pelibuey inseminada por laparoscopia. *Ecosist Recur Agropec* 1(3): 261-268.
- AOAC Official Methods of Analysis. Assoc. Off. Agric. Chem. Washington, D.C. 20 th. 2016
- Baldi, F., Banchero, G., Mieres, J., La Manna, A., Fernández, E., Formoso, D., & Montossi, F. (2008). Suplementación en Invernada Intensiva: Hasta donde hemos llegado? *Revista INIA Uruguay* 1: 2-7.
- Cervantes-Marín, A., López-Ortiz, S., Martínez-Dávila, J.P., Gallardo-López, F., Guerrero-Rodríguez, J.D., & Pérez-Hernández, P. (2015). Preferencia de ovinos y bovinos por frutos de seis especies arbóreas. *Agroproductividad* 8: 10-15.
- Córdova-Izquierdo, A., Iglesias-Reyes, A., Guerra-Liera, E., Villa-Mancera, A., Huerta-Crispín, R., & Sánchez-Sánchez, R. (2019). Uso de esponjas intravaginales comerciales *vs* caseras, para la sincronización de estros de ovejas anéstricas. *Abanico Agroforestal* 1: 1-10.
- Fraire, C. S., Pró, M. A., Ramírez, V. G., Sánchez, C., & Gallegos-Sánchez, J. (2013). Selenio y vitamina E en la fertilidad de ovejas Pelibuey sincronizadas con progesterona. *Univ Cienc* 29(1): 33-44.
- Getachew, G., Makkar, H., & Becker, K. (2000). Effect of polyethylene glycol on *in vitro* degradability of nitrogen and microbial protein synthesis from tannin-rich browse and herbaceous legumes. *Br J Nutr* 84: 73-83.
- Goering, H.K., & Van Soest, P.J. (1970). Forage fiber analysis. *Agricultural Handbook*, p 1-19.
- Gómez-Gurrola, A., Partida-Hernández, M., Ramírez-Duran, R., Ramírez-Ramírez, J., Gómez-Gurrola, J.A., González-Mormita, M., & Sanginés-García, L. (2014). Efecto de la inclusión del fruto de *Guazuma ulmifolia* como sustituto de maíz en la dieta sobre el comportamiento productivo y rendimiento en canal de ovinos Pelibuey. *Trop Subtrop Agroecosystems* 17(2): 215-222.
- Hernández-Hernández, E., López-Ortiz, S., Villarruel-Fuentes, M., Pérez-Hernández, P., Velasco-Velasco, J., & Salinas-Ruíz, J. (2017). Feeding rabbits (*Oryctolagus cuniculus*) with tree fruits from tropical deciduous forest. *World Rabbit Sci* 25: 135-145. <https://doi.org/10.4995/wrs.2017.3838>
- Hinojosa-Benavides, R.A., Andía-Salinas, C.T., Lunazco-Gamboa, R., Núñez-Quispe, K., Ruíz-Vilca, W.M., Farfán-Mauri, R., & Vitor-Valladolid, J. (2019). Mirada retrospectiva a la inseminación artificial en ovinos. *PURIQ* 7(01): 99-108. <https://doi.org/10.37073/puriq.1.01.14>
- INEGI. (2023). Instituto Nacional de Estadística y Geografía. <https://www.inegi.org.mx/temas/climatologia/>
- Ku-Vera, J.C., Briceño, E.G., Ruiz, A., Mayo, R., Ayala, A.J., & Aguilar, C. F., *et al.* (2014). Manipulación del metabolismo energético de los rumiantes en los trópicos: opciones para mejorar la producción y la calidad de la carne y leche. *Rev Cuba Cienc Agric* 48(1): 43-53.
- Lozano-González, J.F., Uribe-Velásquez, L.F., & Osorio, J.H. (2012). Control hormonal de la reproducción en hembras ovinas (Ovisaries).” *Veterinaria y Zootecnia* 6(2): 134-147. <https://revistasojs.ucaldas.edu.co/index.php/vetzootec/article/view/4413>

- Martin, G.B., Milton J.T., Davidson, R.H., Banchemo-Hunzicker, G.E., Lindsay, D.R., & Blache, D. (2004). Natural methods for increasing reproductive efficiency in small ruminants. *Anim Reprod Sci* 82-83: 231-245.
- Martin, G.B., & Reza, T. (2016). Clean, Green, Ethical (CGE) Management: What Research Do We Really Need?. *Int J Trop Vet Biomed Res* 1: 1-9.
- Martínez-González JC, Castillo-Rodríguez SP, Villalobos-Cortés A, Hernández-Meléndez J. (2017). Sistemas de producción con rumiantes en México. *Ciencia Agropecuaria*. 26(1):132-152.
- Manríquez-Mendoza, L.Y., López-Ortiz, S., Pérez-Hernández, P., Ortega- Jiménez, E., López-Tecpoyotl, Z.G. & Villarruel-Fuentes, M. (2011). Agronomic and forage characteristics of *Guazuma ulmifolia* Lam. *Trop Subtrop Agroecosystems* 14(2): 453-463.
- NRC. (2007). Nutrient Requirements of Small Ruminants: Sheep, Goats, Cervids, and New World Camelids. The National Academies Press, Washington, DC. <https://doi.org/10.17226/11654>
- Orskov, E.R., & McDonald, I. (1979). The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *J Agric Sci* 92: 499-503.
- Pérez-Hernández, P., García-Winder, M., & Gallegos-Sánchez, J. (2002). Postpartum anoestrus is reduced by increasing the within-day milking to suckling interval in dual purpose cows. *Anim Reprod Sci* 73: 159-168.
- Piñero-Vázquez, A.T., Ayala-Burgos, A.J., Chay-Canul, A.J., & Ku-Vera, J.C. (2013). Dry matter intake and digestibility of rations replacing concentrates with graded levels of *Enterolobium cyclocarpum* in Pelibuey lambs. *Trop Anim Health Prod* 45: 577-583.
- Pírela, M., Perozo, A., Montero, M., Contreras, G., Valbuena, E., & Zambrano, S. (2010). Producción y calidad de la leche de vacas criollo limonero suplementadas con harina de frutos de samán (*Pithecellobium saman*). *Rev Fac Agron LUZ* 27: 607-625.
- Rattray, P.V., Jagusch, K.T., Smith, J.F., Winn, G.W., & MacLean, K.S. (1981). Effects of genotype, liveweight, pasture type and feeding level on ovulation responses in ewes. *Proceedings of the Australian Society of Animal Production* 41: 174-182.
- Rojas, R.O., & Rodríguez, R.O. (1995). Factores que modifican la prolificidad en ovejas Blackbelly en clima tropical. *Tec Pecu Mex* 33(3): 159-167.
- Román, M.M.L., Palma, J.M., Zorrilla, J., Mora, A., & Gallegos, A. (2008). Degradabilidad in situ de la materia seca de la harina del fruto de guácima (*Guazuma ulmifolia*), con dietas de frutos de especies arbóreas. *Zootecnia Trop* 26: 227-230.
- Rubianes, E., & Ungerfeld, R. (2002). Perspectivas de la investigación sobre reproducción ovina en América Latina en el marco de las actuales tendencias productivas. *Arch Latinoam Prod Anim* 10(2): 117-125.
- Russel, A., Doney, J.M. & Gunn R.J. (1969). Subjective assessment of body fat in live sheep. *J Agr Sci* 72: 451-454
- Salamon, S., & Maxwell, M. (2000). Storage of ram semen. *Review Anim Reprod Sci* 62: 77-111.
- SAS. (2011). JMP. Statistic visual. Version 9.2 institute inc. campus Drive. Cary. NC 27517.
- Scaramuzzi, R.J., Murray, J.F., Downing, J.A., & Campbell, B.K. (1999). The effects of exogenous growth hormone on follicular steroid secretion and ovulation rate in sheep. *Domest Anim Endocrinol* 17(2-3): 269-277.
- Sosa-Pérez, G., Pérez-Hernández, P., Vaquera-Huerta, H., Salazar-Ortiz, J., Sánchez del Real, C., Cadena-Villegas, S., & Gallegos-Sánchez, J. (2014). Somatotropina bovina recombinante en sincronización de estros y prolificidad de ovejas Pelibuey. *Arch Zootec* 63(241): 219-222.
- Villa-Herrera, A., Nava-Tablada, M., López-Ortiz, S., Vargas-López, S., Ortega-Jimenez, E., & Gallardo-López, F. (2009). Utilización del guácimo (*Guazuma ulmifolia* Lam.) como fuente de forraje en la ganadería bovina extensiva del trópico mexicano. *Trop Subtrop Agroecosystems* 10(2): 253 -261.
- Viñoles, C., Banchemo, G., Quintans, G., Pérez, C.R., Soca, P., & Ungerfeld, R., et al. (2009). Estado actual de la investigación vinculada a la Producción Animal Limpia, Verde y Ética en Uruguay. *Agrociencia* 13(3): 59-79.

# Prevalence of *Cryptosporidium* spp. in lactating calves from cattle ranches in the temperate zone of Central Veracruz, Mexico

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## ABSTRACT

**Objective:** to determine the prevalence of *Cryptosporidium* spp. in a population of lactating calves from one to 60 days of age.

**Design/Methodology/Approach:** this was an under convenience cross-sectional epidemiological study in cattle ranches located in five municipalities in the temperate zone of Veracruz, Mexico. The complete sample size was 500 animals (Win Episcopo<sup>®</sup> 2.0), 100 per municipality. A feces sample was taken directly from the rectum with a latex glove and transported in refrigeration (4 °C) to the laboratory for analysis. The samples were analyzed using modified the Faust centrifugation method, and the Ziehl-Neelsen technique. Statistical analyses were performed in STATA<sup>®</sup> 14.0. at a 95% confidence interval.

**Results:** all municipalities presented *Cryptosporidium* spp. An overall prevalence of 62.6% was found, within a range of 49% to 83% according to the municipality. In regard to sex, a prevalence of 78.4% (95%CI 69.9-85.0) of *Cryptosporidium* spp. was found in males. Regarding age, the highest prevalence of *Cryptosporidium* spp. 75.6% in living tissue was found in calves one to 15 days old (95%CI 69.8-80.7). The highest prevalence 78.7% was found in liquid feces (95%CI 71.6-84.6), which proves that diarrhea sometimes fetid, is the main sign of *Cryptosporidium* spp. presence in lactating calves.

**Limitations/ Implications of the study:** the study did not consider other pathogens that also can cause diarrhea in lactating calves.

**Findings/Conclusions:** *Cryptosporidium* spp. is present in lactating cattle in the temperate zone of central Veracruz, Mexico. The highest prevalence was found in lactating calves one to 15 days old, in males, and in those with liquid stools.

**Keywords:** bovine, diarrhea, protozoan, Ziehl-Neelsen.



## INTRODUCTION

*Cryptosporidium* spp. is a single-celled protozoan that inhabits the intestinal villi of calves, lambs and other animal species including humans. Transmission is fecal-oral by ingestion of sporulated oocysts (Yang *et al.*, 2021). Also, indirectly by water and food contaminated with fecal material, by contact with contaminated environmental surfaces, or person-to-person contact (Pezzani, 2023). The life cycle of this protozoan begins with the ingestion and decystation of oocysts that involves asexual and sexual phases, and ends with the infective phase of the parasite, which is eliminated in large quantities in the feces (Gunasekera *et al.*, 2020). Oocysts are environmentally resistant, and remain viable for a long time (Olson *et al.*, 2004).

There are 29 mammalian species of *Cryptosporidium* (Ryan *et al.*, 2021), of which six have been found infecting cattle, the most common being *Cryptosporidium parvum*, widely distributed in intensively produced dairy cattle (Thomson *et al.*, 2017) and has been identified as one of the primary etiological agents of neonatal diarrhea (Wells and Thomson 2014; Santin, 2020). Clinical cryptosporidiosis is characterized by profuse watery diarrhea, loss of weight yield, and death (Thompson *et al.*, 2016). In calves (less than six weeks of age) it reduces daily weight gain. Young calves can shed a large quantity ( $3.89 \times 10^{10}$ ) of oocysts in six to 12 days (Shaw *et al.*, 2020). Older calves ( $\geq 6$  months) and adult cattle may be naturally infected with *C. parvum* and excrete oocysts, while remaining subclinical or asymptomatic (Shaw *et al.*, 2021).

Cryptosporidiosis is recognized as endemic in cattle worldwide and is one of the leading causes of neonatal enteritis in calves around the world. In various studies implemented in Europe, North America and Egypt, it has been reported that in calves from meat production systems the prevalence is lower than in dairy calves; with prevalence values 6-78% of *Cryptosporidium parvum* in calves from dairy herds (Garro *et al.*, 2016 Brainard *et al.*, 2020; Weldemariam *et al.*, 2024). This behavior has also been reported in meta-analyses of *Cryptosporidium* spp. in ungulates (Hatam-Nahavandi *et al.*, 2019). In South America, prevalence values from 7.3% in Colombia (Bulla-Castañeda *et al.*, 2024) to 51.75% in Brazil (Candeias *et al.*, 2022) are reported. Various risk factors have been identified, such as contact with other species (goats and sheep), use of a semi-intensive breeding system, absence of hygienic conditions —fecal contamination of food and water (Conceição *et al.*, 2021) and high animal density in hot and humid climate (Brainard *et al.*, 2020; Bulla-Castañeda *et al.*, 2024).

In Mexico, in the states of Coahuila and Durango, prevalence values 56.41% and 87.17% of *Cryptosporidium* spp. have been reported in adult animals and calves. This suggests that the parasite is endemic and represents a risk to the dairy industry; in addition to risks to public health if manure is applied as fertilizer in agricultural lands (López *et al.*, 2020). In the northern region of the state of Veracruz, a prevalence 78% was reported in calves from one-day old to six months of age in a beef cattle production system (Aguilar *et al.*, 2007). Similarly, another study in dual-purpose production systems found an overall prevalence 73.6% of *Cryptosporidium* spp. in calves from three to 12 months of age from three ecological regions of central Veracruz (Castelán-Hernández *et al.*, 2011).

In Mexico there is a wide variety of calf breeding systems in the different dairy regions of the country. In specialized livestock management in the state of Veracruz there are no reports of *Cryptosporidium* spp. in calves. Therefore, it is important to know the situation of livestock farming and thus be able to establish appropriate control strategies for the disease caused by this parasite. The objective of this research was to determine the prevalence of *Cryptosporidium* spp. in calves  $\leq 60$  days of age in cattle ranches; under the hypothesis that a prevalence higher than 50% can be found in calves from 1 to 60 days of age, in the temperate zone of Veracruz, México.

## **MATERIALS AND METHODS**

### **Study site**

The study was implemented across the municipalities Acatlan (19° 4' N; 96° 50' W), Landero y Coss (19° 44' N; 96° 51' W), Miahuatlan (19° 43' N; 96° 53' W), Xico (19° 25' N; 97° 00' W), and Naolinco (19° 39' N; 96° 51' W), in the temperate zone of central Veracruz.

### **Experimental design and protocols**

The collection of samples was based on an under convenience cross-sectional epidemiological study with lactating calves from one to 60 days of age, regardless of sex, presence or absence of diarrhea, in cattle ranches located in the five municipalities above mentioned. The number of calves included in the study was estimated with the statistical software Win Episcopo<sup>®</sup> 2.0 (Thrusfield *et al.*, 2001), considering a 50% prevalence, a 5% margin of error, and a confidence level at 95%, the animal sampling size was set in  $N \leq 500$  animals. The study protocol was approved by the Bioethics and Animal Welfare Commission of the Faculty of Veterinary Medicine and Zootechnics under Universidad Veracruzana, in compliance with the Mexican Standard (NOM-062-ZOO-1999).

### **Collecting and transporting of samples**

From each one of the municipalities, 100 animals were selected in order to obtain samples from 500 lactating calves. Samples were collected from February to July 2023, in the ranches where producers agreed to participate. A feces sample was taken directly from the rectum of each calf, using a latex glove and deposited in a bag. Individual samples were identified with the ID-number of the animal, date of birth, and the number or name of the mother. The fecal samples were kept refrigerated (4 °C) and transported to the Parasitology Laboratory of the Diagnostic Unit Ranch "Torreón del Molino" of the Faculty of Veterinary Medicine and Zootechnics, under Universidad Veracruzana.

### **Diagnose laboratory techniques**

The samples were analyzed using the modified Faust centrifugation method and the modified Ziehl-Neelsen technique (Figuroa-Castillo *et al.*, 2015), in order to detect the presence of *Cryptosporidium* spp.

### Statistical analysis

Data was stored in a Microsoft Excel<sup>®</sup> database. Overall and specific prevalence by age was calculated according to age class (1 to 15 days, 16 to 39 days, and 40 to 60 days); also by sex, municipality and the structural consistency of the feces (normal, pasty, semi-liquid, or liquid). For the data analysis, the statistical software STATA<sup>®</sup> 14.0 was used. A Chi-Square test ( $\chi^2$ ) with a 95% confidence interval was performed to determine the relationship between the presence of *Cryptosporidium* spp., and the sex, age, or consistency of the feces.

### RESULTS AND DISCUSSION

Table 1 shows the prevalence of *Cryptosporidium* spp. per municipality. Positive samples were obtained in the five municipalities, with an overall 62.6% prevalence within a range 49% to 83% ( $\chi^2=27.08$  y  $p<0.001$ ) depending on the municipality (Table 1). In addition, the actual 64.08% prevalence was obtained by means of the formula developed by Ameni *et al.* (2008) for the Zielh-Neelssen test.

These results coincide with other studies, such as those in the state of Veracruz and other Mexican southern states, and the Lagunera Region of Mexico. In Veracruz, 12-20% prevalence values have been reported per municipality (Aguilar *et al.*, 2007); also an overall prevalence up to 73.6% (Castelán-Hernández *et al.*, 2011). Whereas in the Lagunera Region, a 71.79% prevalence of *Cryptosporidium* spp. is reported in cattle (López *et al.*, 2020). Variation in prevalence may be due to possible differences in facilities, management, or diet in each study. Likewise, it has been described that environmental factors such as temperature and humidity influence the survival and transmission of *Cryptosporidium* spp. oocysts, the hot climate with a high humidity content favor the persistence and propagation of this parasite. In addition, *Cryptosporidium* oocysts are extremely resistant to the action of commonly used chemical control agents. Oocysts can survive in ambient conditions, maintaining their infective capacity in the environment for prolonged periods about three months or more (Ikiroma and Pollock, 2021; Weldemariam *et al.*, 2024).

In this study, according to the sex of the evaluated animals, a 78.4% prevalence was observed in males, higher than 66.1% found in females, statistically significant ( $\chi^2=4.58$ ;  $p=0.032$ ). In regard to the age of the animals, significant differences were found among

**Table 1.** Prevalence of *Cryptosporidium* spp. found with the Zielh-Neelssen technique in lactating calves per municipality sampled in Veracruz, Mexico.

| Municipality   | Lactating calves | Positive(+) Lactating calves | Prevalence (%) | * <sub>95%</sub> CI |
|----------------|------------------|------------------------------|----------------|---------------------|
| Acatlan        | 100              | 57                           | 57.0           | 46.7-66.7           |
| Landero y Coss | 100              | 49                           | 49.0           | 38.9-59.1           |
| Miahuatlan     | 100              | 83                           | 83.0           | 73.8-89.5           |
| Xico           | 100              | 59                           | 59.0           | 48.7-68.6           |
| Naolinco       | 100              | 65                           | 65.0           | 54.7-74.0           |
| Total          | 500              | 313                          | 62.6           | 58.1-66.8           |

\*Confidence Interval at 95%.

the age classes ( $\chi^2=41.5$ ;  $p<0.001$ ). The highest prevalence 75.6% of *Cryptosporidium* spp. was found in calves of 1-15 days of age. However, animals aged 16-39 days and those aged 40-60 days also had a moderate prevalence of 53.1% and 41.1%, respectively (Table 2).

Some studies have indicated that there may be differences in the prevalence and severity of infections between male and female calves. In a previous study in Veracruz, the prevalence was 78.7% for females and 45.5% for males; Although the prevalence was considerably higher in female calves, it was suggested that could be due to female sampled population, which was larger than that of males (Castelán-Hernández *et al.*, 2011). In our study, despite we got a larger population of females than males, the trend was opposite, we found a higher prevalence of *Cryptosporidium* spp. in males than in females (78.4% *vs.* 66.1%, respectively). Some studies mention that there is no relationship between a greater or a lesser presence of *Cryptosporidium* spp. when comparing females and males (Bulla-Castañeda *et al.*, 2024). However, the variability in the results in different studies related to the sex of calves focuses more on the management given to them on farms (Silverlås *et al.*, 2009).

Regarding age, López *et al.* (2020) observed a higher prevalence in weaned calves 87.17% than in adult cattle 56.41%. However, in studies on calves, other authors indicate that higher prevalence values and higher odds ratios (OR) are found in animals <20 days of age (Thomson *et al.*, 2019; de Alba *et al.*, 2023). This high prevalence in calves under three weeks-old is because they are more susceptible to *Cryptosporidium* infection due to their immature immune systems. Also, because there is a higher probability of exposure to contaminated environments (Bilata and Shimelis, 2023). In another study, Zeleke *et al.* (2017) mentioned that the prevalence of *Cryptosporidium* infection decreases as the age of the animal increases, which is consistent with what was found in this study, because calves aged 1-15 days had a 75.6% prevalence, whereas in those aged 40-60 days, prevalence was reduced to 41.1% (Table 2).

Regarding the consistency of the feces and prevalence of *Cryptosporidium* spp., we found that there were significant differences ( $\chi^2=77.8$ ;  $p<0.001$ ). Table 3 shows that the highest prevalence was in the consistency of semi-liquid stool 70.7%, and liquid stool 78.7%; This proves that the main sign of *Cryptosporidium* spp. in lactating calves is the

**Table 2.** Prevalence of *Cryptosporidium* spp. by the Ziehl-Neelssen technique in lactating cattle according to sex and age classes (1-15, 16-39, and 40-60 days) in Veracruz, Mexico.

| Sex        | Lactating calves | Positive(+) Lactating calves | Prevalence (%) | *95% CI   |
|------------|------------------|------------------------------|----------------|-----------|
| Female     | 325              | 215                          | 66.1           | 60.6–71.2 |
| Male       | 175              | 98                           | 78.4           | 69.9–85.0 |
| Age (days) |                  |                              |                |           |
| 1-15       | 255              | 193                          | 75.6           | 69.8–80.7 |
| 16-39      | 160              | 85                           | 53.1           | 45.1–61.0 |
| 40-60      | 85               | 35                           | 41.1           | 30.7–52.3 |
| Total      | 500              | 313                          | 62.6           | 58.1–66.8 |

\*Confidence Interval at 95%.

**Table 3.** Prevalence of *Cryptosporidium* spp. by the Ziehl-Neelsen technique in lactating calves related to the consistency of the feces.

| Consistency of the feces | Lactating calves | Positive(+) Lactating calves | Prevalence (%) | * <sub>95%</sub> CI |
|--------------------------|------------------|------------------------------|----------------|---------------------|
| Normal                   | 58               | 15                           | 25.8           | 15.6-39.2           |
| Pasty                    | 89               | 35                           | 39.3           | 29.3-50.2           |
| Semi-liquid              | 188              | 133                          | 70.7           | 63.6-77.0           |
| Liquid                   | 165              | 130                          | 78.7           | 71.6-84.6           |
| Total                    | 500              | 313                          | 62.6           | 58.1-66.8           |

\*Confidence Interval at 95%.

presence of diarrhea, which sometimes, can be fetid. That is why an empirical diagnosis of cryptosporidiosis could be done by observing the consistency of the feces, since the presence of this protozoan could be suspected through the appearance of the stools.

The high prevalence of *Cryptosporidium* spp. reported in this study could indicate that feces of liquid consistency are unequivocal sign related to the distinct presence of this parasite. In Italy, Diaz *et al.* (2018) associated the presence of liquid feces with *Cryptosporidium*. However, it is possible that the consistency of the feces is caused by other pathogens that weaken the immune system of calves, making them more susceptible to *Cryptosporidium* infection (Conceição *et al.*, 2021). Diarrhea caused by this parasite is associated with the excretion of a large number of oocysts, but it is not evident that such an excretion always occurs at the same time of diarrhea (Castro *et al.*, 2002).

Nonetheless, the relative risk between the presence of *Cryptosporidium* spp. oocysts and the occurrence of diarrhea is significant in calves. It is demonstrated there is a relationship between them (Aguirre *et al.*, 2013), since those animals that had feces of liquid consistency had a higher prevalence (78.7%). This also coincides with Hernández-Valdés (2018) who reported the highest prevalence 75.5% in the semi-liquid feces of dual-purpose cattle in the central region of the state of Veracruz. Both examples are similar to our findings in this study.

In order to reduce the presence of *Cryptosporidium* in calves, better sanitary practices should be implemented; some of which are that calves got adequately access to colostrum; to separate calves apart from adult animals; to isolate those animals that excrete diarrhea; as well as an efficient cleaning when new animals are brought into management areas. Better management practices are relevant because *Cryptosporidium* presence in lactating calves has a negative impact on growth. In addition, because that is a parasite highly resistant to environmental conditions, it can contaminate water, feed and feed management; thus affecting other animal species, even people.

## CONCLUSIONS

The infection caused by *Cryptosporidium* spp. infection was confirmed in lactating calves in cattle ranches of five municipalities located in the temperate zone of central Veracruz, Mexico. The highest prevalence of *Cryptosporidium* spp. occurred in newborn calves from one to 15 days of age, particularly in males, and in those that excreted liquid feces.

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## REFERENCES

- Aguilar, B. G., Romero, S. D., & Martínez, H. D. I. (2007). Prevalencia de *Cryptosporidium* spp., en sistemas ganaderos de carne en el centro de Veracruz, México. XX Reunión Científica-Tecnológica Forestal y Agropecuaria Veracruz, IX Simposio Internacional y IV Congreso Nacional de Agricultura Sostenible. pp. 1-7.
- Aguirre, F. L., Bagattín, M. F. Ruiz, M. Allasia, & J. L. Otero. (2013). Presencia de *Cryptosporidium* spp. en terneros de crianza artificial. XIV Jornadas de Divulgación Técnico-Científicas 2013. Jornada Latinoamericana.
- Ameni G, Hewinson G, Aseffa A, Young D, Vordermeier M. (2008) Appraisal of interpretation criteria for the comparative intradermal tuberculin test for diagnosis of tuberculosis in cattle in central Ethiopia. *Clin Vaccine Immunol.* 15(8):1272-6. doi: 10.1128/CVI.00114-08
- Bilata, T & Shimelis E. (2023) Isolation of common calves diarrhea-causing bacterial and protozoal enteropathogen and associated risk factors from the dairy farms in and around Assela town Arsi zone, Oromia Regional state of Ethiopia. *South Asian Res J Agri Fish.*; 5: 68-80.
- Brainard, J., Hooper, L., McFarlane, S., Hammer, C.C., Hunter, P.R., & Tyler, K. (2020) Systematic review of modifiable risk factors shows little evidential support for most current practices in *Cryptosporidium* management in bovine calves. *Parasitology Research*, 119, 3571-3584. <https://doi.org/10.1007/s00436-020-06890-2>
- Bulla-Castañeda, D. M., Lancheros Buitrago, D. J., Castañeda Sedano, L. B., Higuera Piedrahita, R. I., & Pulido-Medellin, M. O. (2024). Prevalence and risk factors associated with *Cryptosporidium* spp. in dairy cattle in Chiquinquirá (Colombia). *Revista Mexicana de Ciencias Pecuarias*, 15(2).
- Candeias, A. P. M., Huff, G. M., Rosado, A. F., Beninca, A. L. V., Souza, L. Z., Osaki, S. C., & Fernandes, N. L. M. (2022). Evaluation of fecal smear methods for research on *Cryptosporidium* spp. oocysts in the feces of dairy calves. *Semina: Ciências Agrárias*, 43(2), 585-598.
- Castelán-Hernández, O. O., Romero-Salas, D., García-Vázquez, Z., Cruz-Vázquez, C., Aguilar-Domínguez, M., del Jesús Ibarra-Priego, N., & Muñoz-Melgarejo, S. (2011). Prevalencia de criptosporidiosis bovina en tres regiones ecológicas de la zona centro de Veracruz, México. *Tropical and Subtropical Agroecosystems*, 13(3), 261-267.
- Castro, H. J., L. Y. González, M. M. Mezo, & M. E. Ares. (2002). A study of cryptosporidiosis in a cohort of neonatal calves. *Vet. Parasitol.* 106: 11-17.
- Conceição, A. I., Almeida, L. P. S., Macedo, L. O., Mendonça, C. L., Alves, L. C., Ramos, R. A. N., & Carvalho, G. A. (2021). Prevalence of infection by *Cryptosporidium* spp. in calves and associated risk factors in Northeastern Brazil. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, 73, 34-40.
- de Alba, P., Garro, C., Florin-Christensen, & M., Schnittger, L. (2023). Prevalence, risk factors and molecular epidemiology of neonatal cryptosporidiosis in calves: The Argentine perspective. *Current Research in Parasitology & Vector-Borne Diseases* 4: 100147
- Díaz, P., Varcasia, A., Pipia, A.P., Tamponi C., Sanna, G., Prieto, A., Ruiu, A., Spissu, P., Díez-Baños, P., Morrondo, P & Scala A. (2018). Molecular characterisation and risk factor analysis of *Cryptosporidium* spp. in calves from Italy. *Parasitol Res* 117, 3081-3090 <https://doi.org/10.1007/s00436-018-6000-x>
- Figuroa-Castillo, J.A., Jasso-Villazul, C., Liéban-Hernández, E., Martínez-Labat, P., Rodríguez-Vivas, R.I. & Zárate-Ramos, J.J. (2015). Capítulo 3: Examen coproparasitoscópico. En: Técnicas para el diagnóstico de parásitos con importancia en salud pública y veterinaria. Rodríguez-Vivas R.I. Editor. AMPAVE-CONASA. México, D.F. pp. 78-128.
- Garro, C.J., Morici, G.E., Utgés, M.E., Tomazic, M.L. & Schnittger, L. (2016). Prevalence and risk factors for shedding of *Cryptosporidium* spp. oocysts in dairy calves of Buenos Aires Province, Argentina. *Parasite Epidemiology and Control*, 1: 36-41.
- Gunasekera, S., Zahedi, A., O’Dea, M., Rey, B., Monis, P., Thierry, B., Carr, J.M., & Ryan, U. (2020). Organoides y modelos intestinales de bioingeniería: posibles soluciones al dilema del cultivo de *Cryptosporidium*. *Microorganismos* 8, 715.

- Hatam-Nahavandi K., Ahmadvpour E., & Carmena D. (2019). Cryptosporidium infections in terrestrial ungulates with focus on livestock: a systematic review and meta-analysis. *Parasit Vectors*, 12:453.
- Hernández-Valdés S. C. (2018). Prevalencia de *Cryptosporidium* spp. en becerros de doble propósito en municipios de la zona central del estado de Veracruz, México. Tesis de Licenciatura en Medicina Veterinaria y Zootecnia. Facultad de Medicina Veterinaria y Zootecnia, Universidad Veracruzana, Veracruz, México. 45p.
- Ikiroma IA., Pollock KG. (2021). Influence of weather and climate on cryptosporidiosis-A review. *Zoonoses Public Health*. 68(4):285-298. doi: 10.1111/zph.12785
- López Torres, L. L., López Cuevas, O., Vázquez Vázquez, C., Alvarado Gómez, O. G., Vázquez Alvarado, R. E., Rodríguez Fuentes, H., Chaidez Quiroz, C., & Vidales Contreras, J. A. (2020). Prevalence of *Cryptosporidium* spp. in dairy livestock from the Laguna region, Mexico. *Revista Bio ciencias*, 7, e881. <https://doi.org/10.15741/revbio.07.e881>
- Olson, M.E., O'Handleyz R.M., Ralston, B.J., McAllister, T.A. & Thompson R.C. (2004). Update on Cryptosporidium and Giardia infections in cattle. *Trends Parasitol. Apr.* 20(4):185-91. doi: 10.1016/j.pt.2004.01.015
- Pezzani, B.C. (2023). Parasitología comparada. Modelos parasitarios. Parte I. Protozoos. Capítulo 6 *Cryptosporidium* spp. Criptosporidiosis. Editorial de la Universidad Nacional de La Plata (EDULP). 69-77 pp. ISBN: 978-950-34-2205-2
- Ryan, U.M., Feng, Y., Fayer, R., Xiao, L. (2021). Taxonomy and molecular epidemiology of Cryptosporidium and Giardia –a 50-year perspective (1971-2021), *International J Parasitol*, 51(13-14), 1099-1119. <https://doi.org/10.1016/j.ijpara.2021.08.007>
- Santin, M. (2020). Cryptosporidium and Giardia in Ruminants. *Vet. Clin. N. Am. Food Anim. Pract.* 36, 223-238.
- Shaw, H. J., Innes, E. A., Morrison, L. J., Katzer, F., & Wells, B. (2020). Long-term production effects of clinical cryptosporidiosis in neonatal calves. *International journal for parasitology*, 50(5), 371-376. <https://doi.org/10.1016/j.ijpara.2020.03.002>
- Shaw, H.J., Armstrong, C., Uttley, K., Morrison, L.J., Innes, E.A., & Katzer, F. (2021). Genetic diversity and shedding profiles for *Cryptosporidium parvum* in adult cattle and their calves *Curr. Res. Parasitol. Vector Borne Dis.*, 10.1016/j.crvbd.2021.100027
- Silverlås, Ch, Emanuelson, U, de Verdier, K & Björkman, C. (2009). Prevalence and associated management factors of Cryptosporidium shedding in 50 Swedish dairy herds, *Preventive Veterinary Medicine*, 90(3). 242-253. <https://doi.org/10.1016/j.prevetmed.2009.04.006>
- Thompson, R.C.A., Koh, W.H., & Clode, P.L. (2016). Cryptosporidium - What is it? *Food and Waterborne Parasitology*, 4: 54-61. <https://doi.org/10.1016/j.fawpar.2016.08.004>
- Thomson, S., Hamilton, C. A., Hope, J. C., Katzer, F., Mabbott, N. A., Morrison, L. J., & Innes, E. A. (2017). Bovine cryptosporidiosis: impact, host-parasite interaction and control strategies. *Veterinary research*, 48(1), 42. <https://doi.org/10.1186/s13567-017-0447-0>
- Thomson, S., Innes, E.A., Jonsson, NN., & Katzer, F. (2019). Shedding of Cryptosporidium in calves and dams: evidence of re-infection and shedding of different gp60 subtypes. *Parasitology*. 146(11). 1404-1413. doi: <https://doi.org/10.1017/S0031182019000829>
- Thrusfield, M., Ortega, C., De blas, I., Noordhurzen, J., & Frankena, K. 2001. Win Episcopo 2.0 improved epidemiological software for veterinary medicine. *Vet. Rec.* 148: 567-572.
- Weldemariam, D.T., Awoke, M.G., & Aklilu, M.A. (2024). Review on Bovine Cryptosporidiosis, its Associated Risk Factors and Diagnostics Methods. *M Trop Med J* 6: 8.
- Wells, B., & Thomson, S. (2014) Cryptosporidiosis in cattle. News Sheet. Vol 6, Edinburgh UK, p 12.
- Yang, X.; Guo, Y.; Xiao, L.; Feng, Y. (2021). Molecular epidemiology of human cryptosporidiosis in low- and middle-income countries. *Clin. Microbiol. Rev.* 34.
- Zeleke, M. A., Francesca, S., Gezahegn, M., & Getachew, T. (2017). Cryptosporidium infection in dairy cattle calves and its public health significance in central Ethiopia. *Journal Advanced Vet Res*, 7(2), 59-65. <https://advetresearch.com/index.php/AVR/article/view/12>

# Aquaponics production of white radish microgreens (*Raphanus sativus* var. Daikon) as an option for Tilapia Resource-limited aquaculture farmers

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## ABSTRACT

**Objective:** to evaluate the production of white radish microgreens (*Raphanus sativus* var. Daikon) in on-demand coupled aquaponics systems without climate control.

**Design/Methodology/Approach:** three treatments with three replicates each were established production of white radish microgreens with no substrate. In treatment H, a 50% commercial hydroponic solution was used, in treatment D distilled water was used, and in treatment T we used water derived from the tilapia culture.

**Results:** the production of radish microgreens in semi-open systems without climatic control was similar in the treatments with water derived from tilapia culture and the 50% hydroponic solution.

**Limitations/Implications of the study:** it is necessary to test this type of microgreens culture with a greater number of species and under different conditions, as well as testing restrictions or sanitary remediation. The production obtained presented significant biological contamination issues, so radish microgreens were not suitable for human consumption.

**Findings/Conclusions:** it was possible to use the water from a tilapia farm in aquaponics systems coupled on-demand for the hydroponic production of white radish microgreens. However, there was no difference between aquaponics and the production obtained with hydroponic fertilizers.

**Keywords:** functional-foods production, circular economy, AREL — Resource-limited aquaculture-farmers.

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## INTRODUCTION

Aquaponics is a food production technology, growing interest in recent years. In this technology, aquaculture and hydroponics are symbolically integrated, so fish and plants are grown on shared resources (Tokunaga *et al.*, 2015). In economic terms for some cases of aquaponics production, the plant component is usually responsible for the majority of income (Quagraine *et al.*, 2018). Because in these on-demand coupled systems plant yield is measured by unit (or kg), and it depends on plant density (plants per m<sup>2</sup>), production period (weeks), and unit value (\$, currency), Bailey and Ferrarezi (2017) proposed using “\$ m<sup>-2</sup> per week” as a unit that groups those factors together and provides a common

point for comparison between two very different cultures. This becomes useful because an alternative crop with high economic value and short cultivation time can be a reasonable option for the production of plants in aquaponics systems.

Microgreens are short-cycle vegetables (7 to 21 days) that are harvested without roots when cotyledon leaves are fully developed, still turgid, and the first true leaves are present (Lee *et al.*, 2004; Kyriacou *et al.*, 2016). Due to their phytochemical compound content, these vegetables are considered functional foods (Kyriacou *et al.*, 2019), which are foods and food components that can provide benefits beyond basic nutrition (IFIC, 2011). Therefore, microgreens culture can be a good option for non-commercial and small-scale aquaponics, as it is the case with Resource-limited Aquaculture farmers —AREL.

Because microgreens are plants in their early life stage, their nutrient needs are lower because the seed content is the nutrient needed for that stage. This can be explored in aquaponics systems, as it has been suggested that plants with lower nutritional requirements are better suited for cultivation within them (Kloas *et al.*, 2015; Yep y Zheng, 2019).

According with reported by García-Sifuentes *et al.* (2024), radish production in aquaponics systems is a topic of interest for micro- and small-scale tilapia producers in the states of Guerrero and Oaxaca. The production of radish microgreens in decoupled aquaponics systems that use water from tilapia production systems may represent a first approach to radish production for these producers. In this case, without the need to implement complete coupled aquaponics systems, aiming to produce functional foods with high nutritional and economic values. The objective of the study was to evaluate the aquaponics production of white radish microgreens as a productive alternative.

## MATERIALS AND METHODS

An experiment was established for the aquaponics production of white radish microgreens. Three treatments were established, each one with three replicates. In each treatment the solution for the growth of the microgreens was different. Treatment (D) was distilled water; (H) was a 50% commercial hydroponic solution, and (T) was water derived from a semi-intensive open-air tilapia culture (Table 1).

For treatment T, a share of the aquaculture water (10 L) was taken and after allowing the algae to settle for 48 h in refrigeration, only the supernatant was used without the microalgae sediments. The three solutions remained refrigerated at 4 °C until they were used.

The hydroponics solution was prepared with distilled water as base and a commercial hydroponic fertilizer; with a calibrated composition to obtain 10% N, 8% P, 18% K,

**Table 1.** pH and electrical conductivity values ( $\text{mS cm}^{-2}$ ) in treatments D: distilled water, H: 50% hydroponic solution and T: water from tilapia culture.

| Treatment | pH   | Electrical conductivity ( $\text{mS cm}^{-2}$ ) | N-NO <sub>3</sub> ( $\text{mg L}^{-1}$ ) |
|-----------|------|---|--|
| H         | 6.75 | 0.88  | 75 ( $\text{mg L}^{-1}$ , N)             |
| D         | 8.20 | 0.01  | 0.12                                     |
| T         | 8.43 | 1.15  | 4.34                                     |

$\text{mS cm}^{-2}$ : SI equivalent unit, millisiemens per square centimeter.

**Table 2.** Concentration ( $\text{mg L}^{-1}$ ) of macro- and microelements of the hydroponic solution at 50% concentration, according to the guaranteed composition of the commercial fertilizer.

| Macroelement | Concentration ( $\text{mg L}^{-1}$ ) | Microelement | Concentration ( $\text{mg L}^{-1}$ ) |
|--------------|--------------------------------------|--------------|--------------------------------------|
| N            | 75.00                                | Fe           | 0.75                                 |
| P            | 60.00                                | B            | 0.015                                |
| K            | 135.00                               | Zn           | 0.075                                |
| S            | 18.75                                | Cu           | 0.0015                               |
| Mg           | 13.50                                | Mn           | 0.015                                |
| Ca           | 44.25                                |              |                                      |

2.50% S, 1.80% Mg, 5.90% Ca, 0.10% Fe, 0.002% B, 0.010% Zn, 0.0002% Cu and 0.002% Mn. From this, a dilution to 50% of the concentration indicated for edible vegetables was prepared (Table 2).

### Trial condition

For microgreens culture we used hydroponics trays, (Bisphenol A) BPA-free, with measurements of  $0.33 \times 0.25 \times 0.03$  (length  $\times$  width  $\times$  depth, cm). The trays consist of three parts, the first one (bottom) is used to contain the solution for growth; the second (middle) is a grid on which the seeds are placed to allow the roots to develop towards the lower tray, where the solution for growth is contained.

The third (upper) part is a temporary tray that is placed on the seeds during the first days of growth, in order to generate pressure on them and facilitate the roots to grow into the right direction; otherwise they are not directed towards the lower tray. These trays can be used with or without substrate in the middle part with grid; for this trial, only the grid was used, with no substrate (Figure 1).

Microgreens production was implemented in two stages, both without climatic control, in semi-open systems. During the experimental period, in both stages, the maximum and minimum ambient temperature and humidity were recorded with a thermohygrometer (Thermopro™ TP359S, Canada).



**Figure 1.** Hydroponics trays for microgreens production with no substrate.

The first stage, with a duration of 5 days, corresponds to germination and the blackout (dark phase). This was done in the growth area of fish larvae and fry, which is an open and roofed area. During that stage, temperatures were 25.5 °C average minimum and 34 °C average maximum; while the minimum relative humidity was 47% and the maximum, 93%.

The second stage, which corresponds to the photosynthesis phase, was done in a shade house with anti-aphid mesh walls and monofilament mesh shade roof, for 30% radiation reduction with UV light stabilizer (Textiles Agrícolas, Mexico). During this stage, temperatures were 25.5 °C average minimum and 46.7 °C average maximum. The extremes of relative humidity were 44% minimum and 88% maximum.

### **Seed pretreatment**

Special Daikon (white radish) seeds were acquired for microgreens production (De mi Siembra, Hidalgo, Mexico). For each tray, 15 g of seeds were weighed, which corresponds to a density of 176 g m<sup>-2</sup> as it is recommended by specialized producers (Johnny's Selected Seeds, Maine, USA) of seeds for microgreens. The seeds were hydrated for 6 hours in distilled water and then distributed in each of the growing trays. After their distribution on each tray they were covered with the upper tray and a weight of 3 kg was placed on them to exert pressure on them and force the roots to go to the lower part of the tray.

For 3 days the seeds were sprinkled with distilled water twice a day. On days 4 and 5, the dark phase took place, which is a period in which first sprouts remain without light to force the elongation of the stems. On the fourth day, the weight was removed and after randomly assigning the treatments, 120 mL of solution corresponding to each treatment was added to the lower tray. On day 5, 50 mL of extra solution were added to each of the replicates according to their treatment.

From day-6 to day-9, the microgreens were installed in the shade house and the amount of water added daily was recorded. On ninth day, when the first true leaves began to sprout, the experiment was completed. The microgreens were harvested and for each treatment, fresh weight and average dry weight of microgreens (g), and fresh weight and average dry weight of roots (g) were recorded. The length of 10 microgreens per replicate was randomly measured to obtain the average length per treatment (mm). With the data obtained, the productivity (g m<sup>-2</sup>) of radish microgreens was calculated, also was the seed yield (g g<sup>-1</sup>), microgreens sprouted per seed.

### **Statistical analyses**

A completely randomized experimental design was used. For all variables, after checking the assumptions of normality and homoscedasticity in the results, data were analyzed with analysis of variance and the means contrasted with the Tukey's test ( $p \leq 0.05$ ). STATISTICA<sup>®</sup> 12.0 (StatSoft Inc., 2013) was used for the analyses.

## **RESULTS AND DISCUSSION**

On day six, when the microgreens were installed in the shade house, insect larvae were detected in some of the replicates. The solution was removed from all of them and 120

mL of the solution corresponding to each treatment (distilled water, hydroponic solution at 50% concentration, or water derived from tilapia culture) were added. This process had to be carried out daily, because from day seven onwards insect larvae were present in all the trays and the solutions presented brown color and bad smell. However, we decided to continue with the experiment to record the effects of the treatments, and to test if the presence of larvae would cause the death of the white radish microgreens.

Fresh weight, dry weight, overall productivity of the microgreens, and seed yield of white radish were similar ( $p \leq 0.05$ ) in the H and T treatments and lower in D (Table 3, Figure 2).

The microgreens produced in the treatments with hydroponic solution at 50% concentration, and those in the water derived from the tilapia culture were similar in size and apparent vigor, while in treatment D the production was lower. This is consistent with what was reported by Murphy *et al.* (2010) and Murphy and Pill (2010), who indicated that a higher concentration of nitrates improves shoot yield.

However, even though the concentrations of  $N-NO_3$  were different in the solutions of the H and T treatments, the productive variables evaluated were statistically similar. It has been reported that microgreens production may be higher in aquaponics systems than in

**Table 3.** White radish microgreens produced with treatments, D: distilled water, H: commercial hydroponics solution at 50% concentration, and T: water derived from Tilapia culture.

| Variable   | Treatment                   |                              |                              |
|--|-----------------------------|------------------------------|------------------------------|
|  | D                           | H                            | T                            |
| Microgreens fresh weight (g)                     | 8.77 ± 1.23 <sup>a</sup>    | 44.84 ± 16.81 <sup>b</sup>   | 43.65 ± 11.63 <sup>b</sup>   |
| Discarded fresh weight (g)                       | 83.87 ± 6.92 <sup>a</sup>   | 83.72 ± 15.95 <sup>a</sup>   | 88.57 ± 7.01 <sup>a</sup>    |
| Microgreens dry weight (g)                       | 0.87 ± 0.27 <sup>a</sup>    | 3.94 ± 1.29 <sup>b</sup>     | 4.47 ± 1.39 <sup>b</sup>     |
| Discarded dry weight (g)                         | 10.23 ± 0.34 <sup>a</sup>   | 8.52 ± 1.04 <sup>a</sup>     | 8.85 ± 1.46 <sup>a</sup>     |
| Shoots height (mm)                               | 59.36 ± 6.34 <sup>a</sup>   | 71.66 ± 1.43 <sup>a</sup>    | 71.09 ± 6.37 <sup>a</sup>    |
| Productivity ( $g\ m^{-2}$ )                     | 106.30 ± 14.89 <sup>a</sup> | 543.56 ± 203.72 <sup>b</sup> | 529.09 ± 140.91 <sup>b</sup> |
| Seed yield ( $g\ g^{-1}$ , microgreens per seed) | 0.58 ± 0.08 <sup>a</sup>    | 2.99 ± 1.12 <sup>b</sup>     | 2.91 ± 0.78 <sup>b</sup>     |



**Figure 2.** White radish microgreens produced with H, T and D treatments. In columns (from left to right), H: commercial hydroponics solution at 50% concentration, T: water derived from tilapia farming, and D: distilled water.

traditional systems (Guerreiro *et al.*, 2024), but it was not demonstrated in this study. In addition, insect larvae were present in the three treatments; For this reason, it is considered that the use of any tested solution did not represent a greater risk or an advantage in regard to the proliferation of insect larvae.

For AREL producers interested in reusing water from aquaculture farming, the production of microgreens of different species (in this case radish) in aquaponics systems coupled on-demand may represent a viable option to produce functional foods, either for their own consumption or for sale. However, this type of farming requires cost-efficient investment and know-how, because it uses water from aquaculture farming, of which only replacement water can be used. Moreover, the structure for coupled farming can be built with local materials.

These characteristics make coupled systems be seen as ideal for AREL producers, who generally have limited access to financing, formal education and technical training. It is these producers that a low-cost aquaponics system can benefit (Adeleke *et al.*, 2022; Flores Nava *et al.*, 2013). The sale of microgreens could support food security for AREL tilapia farmers. However, an additional economic benefit would depend on the presence or developing of appropriate markets.

The presence of insect larvae during the production of radish microgreens made it impossible to use them for human consumption. Tests are needed to prevent microgreens contamination. In addition, it is advisable to perform tests with a greater number of plant species, as well as to characterize the quality and safety of those microgreens to be used as food for human consumption.

## CONCLUSIONS

The production of radish microgreens in aquaponics systems coupled on-demand was similar to that obtained with the 50% commercial hydroponic solution, but higher than that obtained with distilled water. A productive alternative cannot be generalized due to the conditions of this test. More research and sanitary control are needed.

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## REFERENCES

- Adeleke, B., Cassim, S., & Taylor, S. (2022). Pathways to low-cost aquaponic systems for sustainable livelihoods and economic development in poor communities: defining critical success factors. *Aquaculture International*, 30(3), 1575-1591. <https://doi.org/10.1007/s10499-022-00865-z>
- Bailey, D. S., & Ferrarezi, R. S. (2017). Valuation of vegetable crops produced in the UVI Commercial Aquaponic System. *Aquaculture Reports*, 7(May), 77-82. <https://doi.org/10.1016/j.aqrep.2017.06.002>
- Flores-Nava, A. (2013). Diagnóstico de la Acuicultura de Recursos Limitados (AREL) y de la Acuicultura de la Micro y Pequeña Empresa (AMYPE) en América Latina. FAO.
- Guerreiro, S. L. M., Cabral Júnior, J. F. G., Eiras, B. J. C. F., Miranda, B. dos S., Lopes, P. C. A., Melo, N. F. A. C. de, Luz, R. K., Sterzelecki, F. C., & Palheta, G. D. A. (2024). Integrating Aquaponics

- with *Macrobrachium amazonicum* (Palaemonidae: Decapoda) Cultivation for the Production of Microgreens: A Sustainable Approach. *AgriEngineering*, 6(3), 2718-2731. <https://doi.org/10.3390/agriengineering6030158>
- IFIC (International Food Information Council). (2011). Functional foods. In: Adequate Food for All: Culture, Science, and Technology of Food in the 21st Century (p. 8). IFIC Foundation. <https://doi.org/10.1201/9781420077544>
- Kloas, W., Groß, R., Baganz, D., Graupner, J., Monsees, H., Schmidt, U., Staaks, G., Suhl, J., Tschirner, M., Wittstock, B., Wuertz, S., Zikova, A., Rennert, B., Baganz, D., Graupner, J., Monsees, H., Schmidt, U., Staaks, G., Suhl, J., ... Rennert, B. (2015). A new concept for aquaponic systems to improve sustainability, increase productivity, and reduce environmental impacts. *Aquaculture Environment Interactions*, 7(2), 179-192. <https://doi.org/10.3354/aei00146>
- Kyriacou, M. C., El-Nakhel, C., Graziani, G., Pannico, A., Soteriou, G. A., Giordano, M., ... & Roupheal, Y. (2019). Functional quality in novel food sources: Genotypic variation in the nutritive and phytochemical composition of thirteen microgreens species. *Food Chemistry*, 277, 107-118. <https://doi.org/10.1016/j.foodchem.2018.10.098>
- Kyriacou, M. C., Roupheal, Y., Di Gioia, F., Kyratzis, A., Serio, F., Renna, M., De Pascale, S., & Santamaria, P. (2016). Micro-scale vegetable production and the rise of microgreens. *Trends in Food Science and Technology*, 57, 103-115. <https://doi.org/10.1016/j.tifs.2016.09.005>
- Lee, J. S., Pill, W. G., Cobb, B. B., & Olszewski, M. (2004). Seed treatments to advance greenhouse establishment of beet and chard microgreens. *Journal of Horticultural Science and Biotechnology*, 79(4), 565-570. <https://doi.org/10.1080/14620316.2004.11511806>
- Murphy, C. J., Llorca, K. F., & Pill, W. G. (2010). Factors affecting the growth of microgreen table beet. *International Journal of Vegetable Science*, 16(3), 253-266. <https://doi.org/10.1080/19315261003648241>
- Murphy, C. J., & Pill, W. G. (2010). Cultural practices to speed the growth of microgreen arugula (*Eruca vesicaria* subsp. *sativa*). *Journal of Horticultural Science and Biotechnology*, 85(3), 171-176. <https://doi.org/10.1080/14620316.2010.11512650>
- Quagraine, K. K., Flores, R. M. V., Kim, H. J., & McClain, V. (2018). Economic analysis of aquaponics and hydroponics production in the U.S. Midwest. *Journal of Applied Aquaculture*, 30(1), 1-14. <https://doi.org/10.1080/10454438.2017.1414009>
- StatSoft Inc. (2013). STATISTICA (Versión 12). StatSoft Incorporated.
- Tokunaga, K., Tamaru C., Ako H., & Leung, P.S. (2015) Economics of Small-scale Commercial Aquaponics in Hawai'i. *Journal of the World Aquaculture Society*, 46(1), 20-32. DOI: 10.1111/jwas.12173
- Yep, B., & Zheng, Y. (2019). Aquaponic trends and challenges A review. *Journal of Cleaner Production*, 228, 1586-1599. <https://doi.org/10.1016/j.jclepro.2019.04.290>



# Social and environmental impacts of pesticide use in mango cultivation

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## ABSTRACT

**Objective:** to identify the social and environmental impacts derived from the inappropriate use and management of pesticides by mango producers in the municipality of San Marcos, Guerrero, Mexico, emphasizing the effects on the health of farmers and environmental contamination.

**Design/Methodology/Approach:** a cross-sectional study was applied to 40 mango producers using a questionnaire. In addition, focus groups were conducted to delve into pesticide management practices and farmer perceptions of risks. Data were analyzed through descriptive statistics with the GraphPad Prism 7 software.

**Results:** farmers interviewed (100%) use pesticides, although only 40% identified to what pests those are used. The most commonly used agrochemicals belong to the organophosphate and pyrethroid chemical groups. Ninety-one percent of farmers do mix two or more pesticides without using personal protective equipment; 50% have presented some symptoms of poisoning. Empty containers are left in the orchards and the remains are dumped directly into the soil, contaminating groundwater aquifers.

**Limitations/Implications of the study:** the design of appropriate pesticide management programs is needed; also the promotion of sustainable agriculture practices in the region.

**Findings/Conclusions:** almost all the producers (91%) use pesticides improperly, half of them have experienced some chemical intoxication. This study highlights the importance of developing awareness strategies that include training programs based on scientific evidence, in order to teach the proper handling of agrochemicals, with a focus on the prevention for human health and environmental risks.

**Keywords:** agrochemicals, agricultural practices, environmental contamination.

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## INTRODUCTION

Mango, usually considered the top of tropical fruits, is grown in different regions of the world. Mango fruit (Anacardiaceae) is native to India, and is known for more than 4000 years. It is grown in tropical and subtropical climate areas with 24 to 27 °C optimal temperatures for development. Mango prefers soils with 5.5 to 7.5 pH, at altitudes between 600 and 1200 m (Lebaka *et al.*, 2021). In 2019, mango production was 51 million tons

(Megagrams, Mg) in 85 countries around the world. India was the main producer and exporter with approximately 22 million Mg per year (Sial *et al.*, 2015). Different varieties of mango are grown in the world, the most common are Alfonso in India, Carabao in the Philippines, Ataulfo and Manila in Mexico and Tommy Atkins and Keitt in Florida.

In Mexico, the variety with the largest cultivation area is Ataulfo, whose production occurs in April and May, and it is marketed nationally for fresh or industrial use. Due to its low firmness and short shelf life, it is exported in small volumes. In Guerrero, the Costa Chica region stands out for a high production of this fruit. An estimation of approximately 7117.8 hectares are planted for a harvest around 103 055 Mg. Mango varieties highlighted in terms of production are Ataulfo, Manila, Tommy Atkins and Haden. However, producers face heavy economic losses because they do not have the necessary infrastructure for the post-harvest stage. Particularly, absence of packing facilities and necessary conditions for storage, phytosanitary problems, low prices and the absence of marketing channels (Luna-Esquivel *et al.*, 2006).

Indiscriminate use of pesticides is considered another major problem. Mainly because it is used intensively despite the restrictions. Previous studies have shown that exposure to these chemical compounds is associated not only with environmental pollution, but with effects on human health (Lyll *et al.*, 2017). It is considered that pesticides enter the human body by dermal, respiratory or oral route (Daley *et al.*, 2014). Prolonged exposure over the years increases risks to human health with several effects, such as renal, hepatic, or endocrine damage, among others (Peres *et al.*, 2006; Sagiv *et al.*, 2008; Mnif *et al.*, 2011). Therefore, it is necessary to implement studies to acknowledge the social and environmental problems derived from the use of pesticides; as well as to develop strategies to address them adequately.

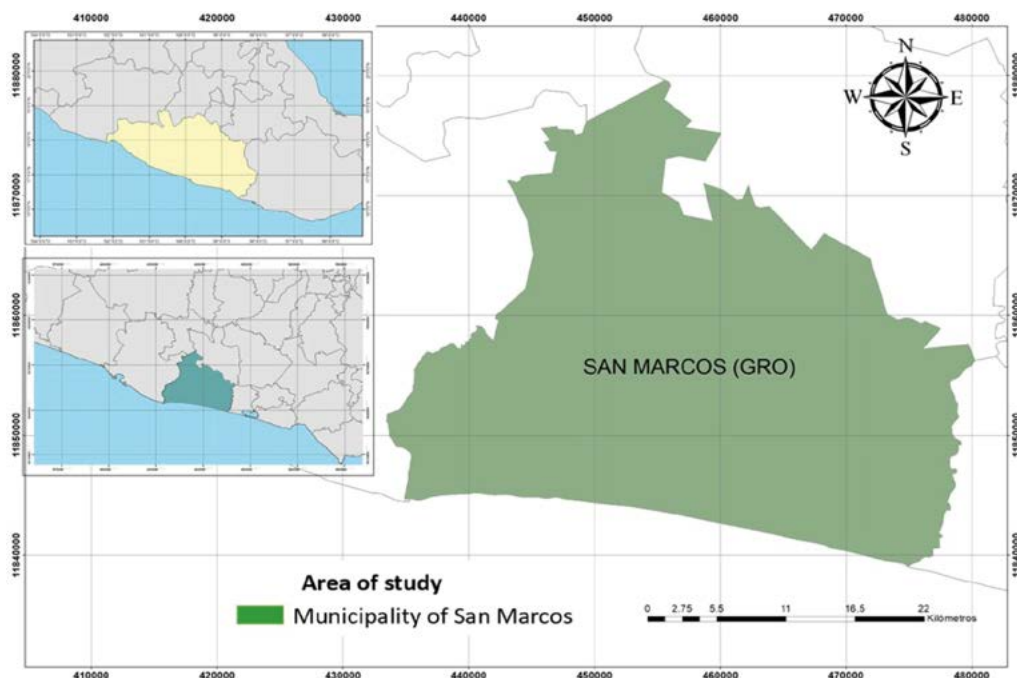
In this context, this research aimed to answer What are the social and environmental impacts derived from the inappropriate use of pesticides in mango harvest operation in the Costa Chica region, Guerrero, Mexico? The objective was to assess the social and environmental impacts of the indiscriminate use and management of pesticides by mango producers in the municipality of San Marcos (Guerrero) Mexico.

## **MATERIALS AND METHODS**

### **Characteristics of the study area**

The study was carried out in the municipality of San Marcos, Guerrero, in the geographical coordinates (DD) 16.794444 N and -99.391111 W, at an average 50 m altitude (Figure 1). This municipality is characterized by the high production of mango of different varieties, the most outstanding are Ataulfo and Manila. The study area was tracked along several routes visiting the mango orchards, accompanied by local farmers. Fruitful dialogues were established with them, with the research project as framework. Meetings with the local producers were attended by the major (president of the municipality) of San Marcos, the president of the National Committee of the Mango Product-System A.C. and other leaders in the region.

In a meeting with the producers, the research team presented the problems related to mango cultivation in the region, derived from a documentary analysis. An extended



**Figure 1.** Location of the study area. Municipality of San Marcos (Guerrero) Mexico. ISystem/Datum: WGS 1984; Projection: UTM, zone 14N.

research proposal was also presented, which obtained a positive unanimous response. In addition, an exploratory talk was held that allowed to know the producers' ideas, opinions and expectations about the activities to be implemented.

### Research techniques and procedure

We used a mixed methodology with a participative exploratory approach. A flexible, iterative design was used to collect data from a variety of sources, through interviews and focus groups. Producers from six localities in the municipality of San Marcos (Guerrero), Mexico participated in this research; San Marcos, Estero Verde, Alto de Ventura, Las Vigas, Nuevo Tecumulapa and El Palomar.

In the first discussion meeting, producers were asked to identify the main pests that affect their mango orchards. As well as the pesticides that farmers regularly use to combat pests and in what concentrations they use pesticides. In both activities, discussion groups were formed and bond paper was provided, allowing producers to respond to the questions: What are the main pests that affect mango cultivation? What pesticides do you use to combat pests? What concentrations of pesticide do you use to fumigate?

At the end, each team presented results and conclusions. The next activity consisted of conducting visits to the mango orchards, to verify the physical condition of the trees and to record whether an inappropriate disposal of empty pesticide containers existed. Also, if given the case, to verify the presence of agrochemical residues in the soil after fumigation. Data obtained were systematized and analyzed using the GraphPad Prism 7 statistical software to calculate averages and to generate graphic analyses. All the information was

collected after informed and voluntary consultation to participate in the research. Also, all procedures were approved by the Bioethics Committee of the Research Directorate of the Autonomous University of Guerrero (Fol. Num. CB-004/23).

To learn about the use and management of pesticides, symptoms of poisoning, social and environmental impacts generated by the use of pesticides, a semi-structured interview was applied. The interviews were conducted at the facilities of the City Council of San Marcos, Guerrero, where a total of 40 mango producers from the six localities attended. They were questioned about the preparation of agrochemicals, personal protection equipment or measures they use; also, about the existence of symptoms of poisoning, and their awareness of the social and environmental problems caused by an inadequate disposal of chemical remains of pesticides and containers (either empty or burned).

## RESULTS AND DISCUSSION

### Identification of pests and diseases in mango plantations

Information collected from interviewees showed that mango producers usually use agrochemicals to control pests and diseases, trying to avoid losses in mango production. However, even with this use farmers report average losses of 30%, and in some cases 50%. The toxic potential of those products, which allows to control diseases and destroy pests, also makes them potentially harmful to human health and the environment (Plenge-Tellechea *et al.*, 2007).

During the identification of pests that affect mango production, farmers informed problems in leaves, vegetative shoots, flowering and fruits. The most common pests include fungi of the genera *Colletotrichum*, *Fusarium*, *Oidium*, *Capnodium*, and *Erysiphe*. Other important pests are the fruit fly (*Anastrepha*) which damages the mesocarp; bacteria of the genus *Xanthomonas* which causes the black spot; and the snow mealybug, which feeds on the sap and causes a plant general weakening (Figura 2).

Over time, farmers have observed various pests in their orchards; they highlight the importance of identifying these pests correctly and in time to proceed with treatment and elimination.



**Figure 2.** Mango producers during identification of main pests that affect mango production.

### Pesticide use and management

Once the producers identified the mango pests, our interest moved towards the knowledge of the process they implement to mitigate or eradicate the damage. To do this, six focus groups were organized, then we provided them a set of images of commercial pesticides, and we asked them to select which ones they used regularly. Then, producers explained what type of pests they fought and in what concentrations pesticides are used. A similar study implemented in a banana area in Colombia highlighted the importance of identifying the pesticides that producers use. Their purpose was to develop a Hazardous Waste Management Plan, and to ensure their proper management (Camargo *et al.*, 2021).

The conclusions of the focus groups revealed the lack of a standard measure and procedure for the preparation of pesticides. Some producers have 16-liter pumps, while others use 25-liters pumps. For liquid pesticides, they use the measuring cup included in the package. However, for powdered pesticides they use a soup spoon, which causes variability in the measurement. Some producers add two soup spoons for each 25-liter pump, while others add four to five spoons (Figure 3). Despite the differences in concentrations, producers know the group of pests to be controlled by each pesticide; whether it is an insecticide, fungicide, bactericide or herbicide. The latter are commonly known as “ultimate killers”. Producers are also aware that beneficial pollinating insects die along with pests.

The presence of pests and diseases in orchards is one of the main phytosanitary problems. For this reason, the use of agrochemicals is an integral part of the production system, with the aim of improving crop yields. However, it is important to recognize the adverse impacts that agrochemicals have on the environment (Mena-Espino y Couoh-Uicab, 2015).

### Evaluation of producer exposure to pesticides

The average age of the producers interviewed was 52 years old; 53% of them have used pesticides for more than ten years, while 46% have applied chemicals for less than ten years. Mango producers learned how to prepare pesticides on the recommendation of neighbors or acquaintances who are dedicated to the same type of crop; with the exception



**Figure 3.** Mango producers during identification of pesticides used for pest control in their orchards.

of four producers who follow the indications of the labels on the packaging. A factor to consider about the levels of exposure to chemicals is the low level of education of the producers. Because this could be associated with the lack of reading comprehension of the instructions for use of each product. In addition to the very small letters on the containers, which include complex mathematical formulas and a technical language that is difficult to understand.

This exponentially increases the risk of poisoning due to improper handling of active substances. In the study by López-Dávila *et al.* (2019), the degree of training of farmers in the use of pesticides was low; only 28.3% had received specialized courses for that use. On the other hand, similar data were reported in the state of Durango, where only 40% of producers had received training on the appropriate use and management of pesticides (Esquivel-Valenzuela *et al.*, 2019). To achieve effective pest control, 92% of producers mix two or more pesticides. Common combinations include Foley<sup>®</sup> Rey/Manzate Mancozeb<sup>®</sup>, Foley<sup>®</sup> Rey/Captan<sup>®</sup>, Foley<sup>®</sup> Rey/Benomyl<sup>®</sup>, Velcron<sup>®</sup>/Manzate Mancozeb<sup>®</sup> and Malathion<sup>®</sup>/Amistar<sup>®</sup>. The goal of mixing these active compounds from pesticides is the allegedly faster control of fungi and insects.

Sometimes, at the end of the fumigation days, the remains of pesticide are poured directly onto the ground at the edges of the orchards. Whereas empty containers are thrown away or burned; since there is no Agency or public policy that regulates this action, farmers have normalized this situation, without paying attention to the social and environmental consequences that this entails. Yáñez and Camarena (2019) also reported in Sinaloa, that 61% of farmers leave containers in the field or burn them after use. Interviews recorded that 40% of producers wear masks, boots and sometimes, gloves. However, the protection is not complete, so there is a direct exposure to agrochemicals during the handling and application process. The lack of protection during pesticide application is also a common practice in the state of Coahuila, where it was reported that 75% of producers lack personal protective equipment; while in the state of Chihuahua that percentage is 73% (Esquivel-Valenzuela *et al.*, 2019; Ordoñez-Beltrán *et al.*, 2019).

According to Khan *et al.* (2015), in the process of preparing the solution or in the application by spraying, producers are exposed to pesticides spillage and contact, because they use defective sprayers. Adverse weather conditions or inadequate preventive measures are other factors to consider (Tsimbiri *et al.*, 2015). Pesticides can remain in the environment for much longer than intended, because of some specific characteristics that include toxicity, persistence, and organic effects. For this reason, people who work in agricultural fields are exposed to these risks, without awareness (Bejarano, 2017).

During the preparation and application of agrochemicals, it is essential to wear personal protective equipment, as this protects from possible adverse consequences (Houbraken *et al.*, 2016). Jiménez-Quintero *et al.* (2016) mentioned that despite producers know the importance of protective equipment, they do not use it during the labor. According to Negatu *et al.* (2016), pictograms on pesticide labels help to inform about risks to human health and advise the use of personal protective equipment. In contrast, the interviewed producers stated that labels are not understandable, because their size is too small. Of producers, 30% are unaware of the long-term health effects of pesticide

exposure; whereas 50% stated that they had experienced some symptoms of poisoning at least once; such as, blurred vision, vomiting, headache or dizziness (Figure 3).

A study conducted in Tanzania showed that 93% of farmers have suffered poisoning from pesticide exposure, mainly from organophosphate pesticides (Lekei *et al.*, 2014). According to Eskenazi *et al.* (2007) these symptoms can be avoided when farmers wear full personal protective equipment (coveralls, masks, gloves and boots) and they have water available for hand washing. In agreement, farmers in Cuba and India expressed that the instructions for use and safety procedures on labels are difficult to understand. Mainly because most of labels, in addition to appear in small print, use technical vocabulary in a foreign language (Kumari and Reddy, 2013). Producers also believe that a lack of knowledge can lead to situations such as an incorrect election of products, inappropriate dosage, and misuse of pesticides, which jointly lead to a failed pest control.

The pesticides most commonly used by producers are fungicides and insecticides of the chemical group of organophosphates, carbamates and pyrethroids. The most commonly used pesticides belong to grade II toxicity, which according to the World Health Organization corresponds to moderately toxic (Table 1).

The interviews conducted with the producers made it visible the social and environmental problems related to the use of pesticides. First of which is the loss of biodiversity, mainly pollinating insects. Also, farmers consider that dumping the remaining pesticide on the orchards and adjacent lands contaminates the subsoil, while burning the empty containers causes air pollution. The inadequate disposal of empty pesticide containers was confirmed, thus the low awareness of farmers about the risk to which they are exposed (Negatu *et al.*, 2016). Because these pesticides are dispersed in the air and become pollutants for biotic systems (animals and plants), and for abiotic systems (soil, air and water). As well as,

**Table 1.** Types of pesticides and frequency of use by mango producers.

| Trade name | Chemical group                 | Active ingredient                 | Product type                 | Toxicity* |
|------------|--------------------------------|-----------------------------------|------------------------------|-----------|
| Foley Rey  | Organophosphate/<br>pyrethroid | Chlorpyrifos ethyl/<br>permethrin | Insecticide                  | II        |
| Malathion  | Organophosphates               | Malathion                         | Insecticide                  | II        |
| Velcron    | Organophosphates               | Monocrotophos                     | Insecticide and<br>acaricide | II        |
| Sultron    |                                | Elemental sulfur                  | Fungicide and<br>acaricide   | II        |
| Benomyl    | Benzimidazoles                 | Benomyl                           | Fungicide                    | II        |
| Captan     | Carboximides                   | Captan                            | Fungicide                    | II        |
| Manzate    | Carbamates                     | Mancozeb                          | Fungicide                    | II        |
| Amistar    | Methoxyacrylates               | Azoxystrobin                      | Fungicide                    | II        |
| Dimethoate | Organophosphate                | Dimethoate                        | Insecticide                  | II        |
| Permethrin | Pyrethroids                    | Permethrin                        | Insecticide and<br>acaricide | II        |
| Pervel     | Pyrethroids                    | Permethrin                        | Insecticide and<br>acaricide | II        |

\*Toxicity classification by the World Health Organization. AI: extremely toxic; BI: highly toxic; II: moderately toxic; III: slightly toxic.

pesticides are a risk to environmental stability, which potentially can lead to a public health problem. Other aspects on which farmers reflected were the frequency with which they present symptoms of poisoning, as well as the harvest of contaminated fruits. Similarly, producers have detected that the early fall of fruits while growing is becoming more and more frequent.

According to Bustamante-Villaruel *et al.* (2014) and López-Dávila *et al.* (2020), the indiscriminate use of pesticides, as well as their application at inappropriate times, becomes a potential hazard to the environment with impacts on soil fertility, beneficial organisms, wildlife, water reservoirs, and even on human health.

This research with mango producers in the Costa Chica region allowed us to learn directly about their agricultural practices and their experience in pesticide management. Moreover, on their perceptions of the damage to pollinators, which are key elements in the production chain of their crops. This study highlighted the importance of developing awareness strategies that include scientific evidence-based training programs. Such programs should teach the correct handling of agrochemicals, with a focus on the prevention of health and environmental risks. It is critical that these programs involve agricultural authorities, public health experts, and local communities.

## CONCLUSIONS

The lack of use of personal protective equipment, the inability to properly interpret product labels, and low risk perception are critical factors that increase pesticide exposure and, therefore, health risks. A 91% of farmers mix two or more pesticides without full knowledge, and 50% have suffered symptoms of poisoning. These findings highlight the urgent need to implement effective interventions.

Mango production generates considerable economic and social benefit for the region; this relevance justifies the proper intervention of Science academy and the Government to work together with the producers. Academy should supply data and experiences that support the development of sustainable agricultural practices; and governmental entities should strengthen regulation and control of pesticide use. While, producers should make efforts towards adopting safer and more sustainable practices.

Future research should focus on measuring the long-term effects of pesticide use on local ecosystems; also, in developing alternative and less toxic methods and technologies for pests control in agriculture production. In addition, there is a need to evaluate the effectiveness of educational interventions in reducing the risk of exposure to pesticides.

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## REFERENCES

- Bejarano, F. (2017). Los plaguicidas altamente peligrosos en México. RAPAM, pp. 421. <https://www.rapam.org/wp-content/uploads/2017/09/Libro-Plaguicidas-Final-14-agst-2017sin-portada.pdf>
- Bustamante-Villaruel, S., Segales-Rojas, D. J., Zurita-Herrera, L., Fernandez-Arancibia, M., Torrico-Condarco, S., & Jarro- Mena, R. (2014). Uso inadecuado de plaguicidas y sus consecuencias en la

- salud de la población La Villa, Punata, Cochabamba, Bolivia, 2013. *Gaceta Médica Boliviana*, 37(1), 11-14. <https://www.gacetamedicaboliviana.com/index.php/gmb/article/view/324>
- Camargo Caicedo Y., Tovar-Bernal F., Álvarez-Pineda E. (2021). Residuos de plaguicidas en cultivos del municipio zona bananera, departamento del Magdalena, Colombia. *Revista Internacional de Contaminación Ambiental*, 37, 53725. <https://doi.org/10.20937/RICA.53725>
- Daley, J.M., Paterson, G., Drouillard, K.G. (2014). Bioamplification as a bioaccumulation mechanism for persistent organic pollutants (POPs) in Wildlife. *Rev. Environ. Contam. Toxicol.* 227, 107-154. doi: 10.1007/978-3-319-01327-5\_4.
- Eskenazi, B., Marks, A. R., Bradman, A., Harley, K., Barr, D. B., Johnson, C., Jewell, N. P. (2007). Organophosphate Pesticide Exposure and Neurodevelopment in Young Mexican-American Children. *Environmental Health Perspectives*, 115(5), 792-798. doi:10.1289/ehp.9828.
- Esquivel-Valenzuela, B., Cueto-Wong, J. A., Valdez-Cepeda, R. D., Pedroza-Sandoval, A., Trejo-Calzada, R., Pérez-Veyna, Ó. (2019). Prácticas de manejo y análisis de riesgo por el uso de plaguicidas en la Comarca lagunera, México. *Revista Internacional de Contaminación Ambiental*, 35(1), 25-33. <https://doi.org/10.20937/RICA.2019.35.01.02>
- Houbraken, M., Bauweraerts, I., Fevery, D., Labeke, M. Van, & Spanoghe, P. (2016). Pesticide Knowledge and Practice among Horticultural Workers in the Lâm Đồng Region, Vietnam: A case study of chrysanthemum and strawberries. *Science of the Total Environment*, 550, 1001-1009. doi: 10.1016/j.scitotenv.2016.01.183.
- Jiménez-Quintero CA, Pantoja-Estrada A, Leonel HF. (2016). Riesgos en la salud de agricultores por uso y manejo de plaguicidas, microcuenca “la pila”. *Rev Univ. Salud.* 18(3): 417-431. DOI: <http://dx.doi.org/10.22267/rus.161803.48>
- Khan M, Mahmood H.Z, Damalas C.A. (2015). Pesticide use and risk perceptions among farmers in the cotton belt of Punjab, Pakistan. *Crop. Prot.* 67, 184-190. <https://doi.org/10.1016/j.cropro.2014.10.013>
- Kumari, P. L., & Reddy, K. G. (2013). Knowledge and Practices of Safety Use of Pesticides among Farm Workers. *Journal of Agriculture and Veterinary Science*, 6(2), 1-8. doi:10. 9790/2380-0620108
- Lebaka, V. R., Wee, Y.-J., Ye, W., Korivi, M. (2021). Nutritional Composition and Bioactive Compounds in Three Different Parts of Mango Fruit. *International Journal of Environmental Research and Public Health*, 18(2), 741. <https://doi.org/10.3390/ijerph18020741>
- Lekei, E. E., Ngowi, A. V, & London, L. (2014). Farmers' knowledge, practices and injuries associated with pesticide exposure in rural farming villages in Tanzania. *BMC Public Health*, 14(389), 1-13. doi:10.1186/1471-2458-14-389
- López-Dávila, E., Ramos Torres, L., Houbraken, M., Du Laing, G., Romero Romero, O., & Spanoghe, P. (2019). Conocimiento y uso práctico de plaguicidas en Cuba. *Ciencia y Tecnología Agropecuaria*, 21 (1),1282. [https://doi.org/10.21930/rcta.vol21\\_num1\\_art:1282](https://doi.org/10.21930/rcta.vol21_num1_art:1282)
- Luna-Esquivel, G., M. Arévalo-Galarza, S. Anaya-Rosales, Á. Villegas-Mon-7 ter, M. Acosta-Ramos, y G. Leyva-Ruelas. (2006). Calidad del mango ataulfo sometido a tratamiento hidrotérmico. *Revista Fitotecnia Mexicana*, 123-128. [https://doi.org/10.35196/rfm.2006.Especial\\_2.123](https://doi.org/10.35196/rfm.2006.Especial_2.123)
- Lyll, K., Croen, L.A., Sjodin, A., Yoshida, C.K., Zerbo, O., Kharrazi, M., Windham, G. (2017). Polychlorinated biphenyl and organochlorine pesticide concentrations in maternal mid-Pregnancy serum samples: Association with autism spectrum in disorder and intellectual disability. *Environ. Health. Perspect.* 125, 474-480. doi: 10.1289/EHP277.
- Mena-Espino X. y Couoh-Uicab Y. (2015). Efectos de los plaguicidas utilizados para el control de la Sigatoka negra en plantaciones bananeras en México, así como su efecto en el ambiente y la salud pública. *Tecnociencia Chihuahua* 9(2), 115-122. <https://doi.org/10.54167/tch.v9i2.594>
- Mnif, W., Hassine, A. I., Bouaziz, A., Bartegi, A., Thomas, O., Roig, B. (2011). Effect of endocrine disruptor pesticides: a review. *International J. Environ. Research Public Health.* 8(6), 2265-303. doi: 10.3390/ijerph8062265
- Negatu, B., Kromhout, H., Mekonnen, Y., & Vermeulen, R. (2016). Use of Chemical Pesticides in Ethiopia: A Cross- Sectional Comparative Study on Knowledge Attitude and Practice of Farmers and Farm Workers in Three Farming Systems. *Annal of Work Exposures and Health*, 60(5), 551- 66. doi:10.1093/annhyg/mew004.
- Ordoñez-Beltrán, V., Frías-Moreno, M., Parra-Acosta, H., Martínez-Tapia, M. (2019). Estudio sobre el uso de plaguicidas y su posible relación con daños a la salud. *Revista de Toxicología*, 36(2), 148-153.
- Peres, F., Moreire, C.J., Rodrigues, M.K., Claudio, L. (2006). Risk perception and communication regarding pesticide use in rural work: a case study in Rio de Janeiro State, Brazil. *Int. J. Occup. Environ. Health* 12(4), 400-7. DOI: 10.1179/oeh.2006.12.4.400
- Plenge-Tellechea, F., Sierra-Fonseca, J. A., & Castillo-Sosa, Y. A. (2007). Riesgos a la salud humana causados por plaguicidas. *Tecnociencia Chihuahua*, 1(3), 4-6. <https://doi.org/10.54167/tecnociencia.v1i3.55>

- Sagiv, S.K., Nugent, J.K., Brazelton, T.B., Choi, A.L., Tolbert, P.E., Altshul, L.M. (2008). Prenatal organochlorine exposure and measures of behavior in infancy using the Neonatal Behavioral Assessment Scale (NBAS). *Environ. Health. Perspect.* 116(5), 666-73. doi: 10.1289/ehp.10553
- Sial M, Saeed Q, Saeed S, Jaleel W, Naqqash MN, Majeed F. (2015). Susceptibility of Mango cultivars against larvae of Mango midge *Procontarinina mangicola* Shi (Cecidomyiidae: Diptera). *Applied Sciences and Business Economics* 2:1-7.
- Tsimbiri, P. F., Moturi, W. N., Sawe, J., Henley, P., & Bend, J. R. (2015). Health Impact of Pesticides on Residents and Horticultural Workers in the Lake Naivasha Region, Kenya. *Occupational Diseases and Environmental Medicine*, 3(2), 24-34. doi:10.4236/odem.2015.32004
- Yáñez Quijada, A. I., Camarena Gómez, B.O. (2019). Salud ambiental en localidades agrícolas expuestas a plaguicidas en Sonora. *Sociedad y Ambiente*, 19, 55-82. <https://doi.org/10.31840/sya.v0i19.1939>



# Hydrogen peroxide in seed germination and initial development of maize seedlings (*Zea mays* L.)

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## ABSTRACT

**Objective:** the objective of this study was to evaluate the effect of hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) on seed germination and initial development of maize seedlings (*Zea mays* L.) based on water stress or irrigation.

**Design/Methodology/Approach:** seeds of seven maize materials were treated with four doses of H<sub>2</sub>O<sub>2</sub> (150, 100, 50 and 0 mM). The elongation of the mesocotyl, coleoptile and other characters of maize seedlings were evaluated. Individual and combined analyzes of variance were performed with SAS<sup>®</sup> v. 9.1 for Windows (SAS<sup>®</sup> Institute, Inc., 2002). A comparison of means was performed with the Tukey test (p≤0.05), as well as principal components analysis (PCA).

**Results:** the effect of H<sub>2</sub>O<sub>2</sub> in the seed of native and hybrid maize showed positive effects for the rate and percentage of emergence, length of mesocotyl and coleoptile and dry matter production in both humidity environments. The analysis of dispersion on principal components allowed us to visualize that the doses of 50 and 100 mM were superior for Xnuc Naal and San Pabléño genotypes, both in irrigation and drought.

**Limitations/Implications of the study:** this study was limited to evaluate seedlings. It is suggested to extend evaluations to the reproductive stage.

**Findings/Conclusions:** doses of H<sub>2</sub>O<sub>2</sub> at 50 and 100 mM showed a positive effect on seed germination and initial development of maize seedlings.

**Keywords:** water stress, ecophysiology, biomass.

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## INTRODUCTION

Hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) has been of interest in agronomic research due to effects on plant growth and development under conditions of water stress (Černý *et al.*, 2018). Plants usually generate reactive oxygen species (ROS), such as H<sub>2</sub>O<sub>2</sub>, which is a highly reactive oxygen molecule that acts as a regulator in plant growth as a response to biotic and abiotic stress (Choudhury *et al.*, 2017). Excessive accumulation of H<sub>2</sub>O<sub>2</sub> can be harmful to plants



by causing oxidative damage, so the importance of managing an adequate dose of  $H_2O_2$  is highlighted (Guo *et al.*, 2023).

Some studies have shown that the use of  $H_2O_2$  as a treatment in seeds could mitigate the adverse effects of water stress by modulating various physiological and biochemical processes (Cetinel *et al.*, 2021). Guo *et al.* (2021) indicated that  $H_2O_2$  improves seedling vigor, so it could be useful as a promoter of germination and emergence of maize seedlings in irrigation or drought. In addition, it has been observed that  $H_2O_2$  can induce antioxidant responses, and regulate the expression of stress-related genes in plants exposed to drought conditions (Khedia *et al.*, 2019). Drought regularly affects the emergence, elongation of mesocotyl and coleoptile of seedlings, and development of adult maize plants (Villalobos *et al.*, 2024).

The mesocotyl is the region that connects the plumule (top of the seedling) to the radicle (at the bottom). Whereas the coleoptile is the protective sheath that surrounds the plumule emerging from the seed during germination (Niu *et al.*, 2020). The study of these structures could have important implications for acclimatization under conditions of water stress and deep seeding of maize seedlings (Zhao *et al.*, 2021; Villalobos *et al.*, 2024). The objective of this study was to evaluate the effect of  $H_2O_2$  on seed germination and initial development of maize seedlings (*Zea mays* L.), with water stress and irrigation as evaluation conditions.

## MATERIALS AND METHODS

### Location of the study and genetic material

The experiment was established in greenhouse conditions at the Chiná Technological Institute located in Chiná, Campeche, Mexico, in the 2024 spring-summer cycle. Seeds of seven maize genotypes were used: one variety (Chichen Itza), five native races (San Pablano, Xnuc Naal, Dzib Bacal, Pix Cristo, Chaac Mejen Naal), and one commercial hybrid (Zarco) as the control.

### Establishing conditions of the experiment

A series of seedbeds were established with soil known in the region as kan-kab or luvisol. Seeds of all genotypes were treated with four concentrations of  $H_2O_2$  150, 100, 50 and 0 mM for a period of eight hours. Subsequently, seeds were sown in the seedbeds at a depth of 15 cm, and they were distributed at a distance of 5 cm between plants and 10 cm between rows. A randomized complete blocks design was used and the experimental unit consisted of 20 seeds with two replicates. The seedbed measurements were 1.5 m × 0.70 m × 0.20 m (length × width × height), after sowing irrigation to saturation was applied for all treatments. For the irrigation treatment, constant watering was implemented in order to keep the substrate moist and for the drought treatment only that irrigation to saturation was applied. The variables were recorded seven days after planting.

### Variables and statistical analysis

The percentage of emergence (PE) was determined by counting the number of seedlings emerged at the end of the trial related to the number of seeds sown per experimental unit. The emergence velocity rate (VE) was calculated by counting the seedlings that emerged

per day in the days following the appearance of the first seedling. The units of measurement were seedlings per day (Maguire, 1962).

$$PE = \left[ \left( \text{Number of seedlings emerged} \right) / 25 \right] \times 100 \quad (1)$$

$$VE = \sum_{i=1}^n \frac{ei}{i} \quad (2)$$

Where,  $X_i$ : number of seedlings emerged on the  $i$ -th day.  $N_i$ : number of days after sowing until the  $i$ -th day.

The following variables were recorded in each seedling, but reported as averages. Mesocotyl length (LOM, cm) was measured from the seed junction to the base of the coleoptile; coleoptile length (LOC, cm) from the base of the coleoptile to its apex, with a ruler. The total dry weight of the biomass (TDW, mg) composed by the dry weights of mesocotyl (DWM, mg), coleoptile (transparent sheath) (DWC, mg) and aerial portion of the plant (developing green leaves) (DWA, mg). All dry weights were obtained by drying those structures in an oven (MEMMERT<sup>®</sup>) at 70 °C for 72 h, then weighed on an analytical scale (METLER<sup>®</sup>).

With the data obtained, individual and combined analyses of variance were performed, as well as the comparison of means with the Tukey test ( $p \leq 0.05$ ) in SAS<sup>®</sup> v. 9.1 for Windows. A principal component analysis (PCA) was performed from the matrix of correlations between the characters, with the SAS<sup>®</sup> princomp procedure. Likewise, a graph of dispersion on principal components, with the first two of them as vectors in each case, was developed to explain the variation due to moisture, genotype, and dose of H<sub>2</sub>O<sub>2</sub>.

## RESULTS AND DISCUSSION

Some interactions such as dose × moisture, dose × genotype, moisture × genotype, and dose × moisture × genotype were significant ( $p \leq 0.05$ ) in specific characteristics shown (Table 1). That is, there was genetic diversity in the variables under study, for genotypes effect in each dose of H<sub>2</sub>O<sub>2</sub>, and based on soil moisture content. The absence of an interaction humidity × genotype in LOM and dry weight of seedling structures implies that, although water stress reduces those in regard to the irrigation condition, the effect was proportional and parallel for all genotypes.

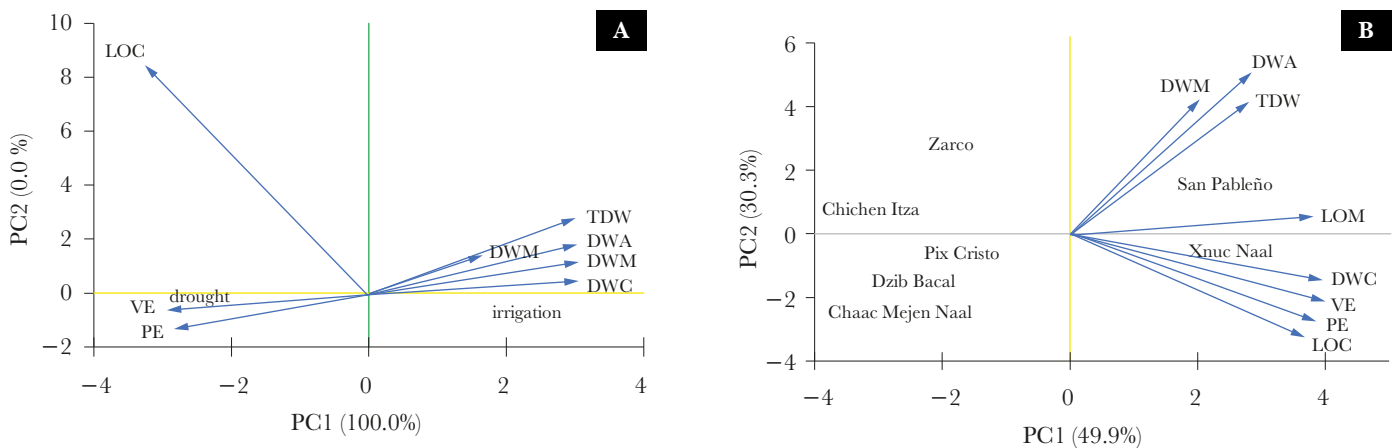
**Soil moisture.** LOM and DWM, DWC, DWA, and TDW were positively associated with the irrigation condition (Figure 1A). Likewise, VE and PE did not present a favorable association under drought conditions; that is, drought reduced both rate and percentage of seed emergence (Figure 1A, quadrant 3). In a similar study, Li *et al.* (2017) associated such differences with water stress, which led to a reduction in water absorption, seed moisture content, seed germination and vigor index, as well as seedling growth and DWA. Zhao *et al.* (2021) indicated that among maize varieties there is a variability in the amount of water required to initiate the germination and emergence processes of seedlings. Length of coleoptile was not associated with any of the other variables studied.

**Table 1.** Results of the analysis of variance of mesocotyl length and other characteristics of maize with different doses of H<sub>2</sub>O<sub>2</sub> under irrigation or drought during the 2024 spring-summer cycle.

| FV     | DF | VE     | EP       | LOM                | LOC               | DWM                | DWC                | DWA                 | TDW                |
|--------|----|--------|----------|--------------------|-------------------|--------------------|--------------------|---------------------|--------------------|
| RE     | 1  | 0.04** | 17.6**   | 0.07 <sup>ns</sup> | 0.2 <sup>ns</sup> | 2.36*              | 0.53 <sup>ns</sup> | 108.9 <sup>ns</sup> | 91.5 <sup>ns</sup> |
| M      | 1  | 1.45** | 5516.0** | 17.4**             | 4.2**             | 4.21**             | 1.80 <sup>ns</sup> | 395.3**             | 541.5**            |
| G      | 6  | 1.10** | 3585.7** | 18.5**             | 11.5**            | 1.83**             | 1.27*              | 196.4**             | 214.3**            |
| D      | 3  | 3.00** | 7849.6** | 10.4**             | 0.7*              | 22.2**             | 6.41**             | 546.5**             | 930.5**            |
| D*M    | 3  | 0.03** | 313.4**  | 1.5**              | 0.6*              | 0.12 <sup>ns</sup> | 0.19 <sup>ns</sup> | 7.1 <sup>ns</sup>   | 8.2 <sup>ns</sup>  |
| D*G    | 18 | 0.28** | 662.9**  | 4.5**              | 2.0**             | 1.16**             | 0.99*              | 58.0*               | 66.1*              |
| M*G    | 6  | 0.08** | 235.9**  | 0.4 <sup>ns</sup>  | 0.7*              | 0.06 <sup>ns</sup> | 0.09 <sup>ns</sup> | 5.2 <sup>ns</sup>   | 6.4 <sup>ns</sup>  |
| D*M*G  | 18 | 0.04** | 91.7**   | 0.5*               | 0.5*              | 0.13 <sup>ns</sup> | 0.10 <sup>ns</sup> | 11.4 <sup>ns</sup>  | 12.3 <sup>ns</sup> |
| Error  |    | 0.01   | 0.69     | 0.31               | 0.22              | 0.69               | 0.50               | 32.3                | 35.23              |
| Total  |    |        |          |                    |                   |                    |                    |                     |                    |
| C.V. % |    | 0.07   | 1.32     | 8.89               | 12.01             | 8.76               | 12.33              | 23.35               | 15.61              |

FV: variation factor; DF: degrees of freedom; RE: replicate; M: moisture; G; genotype; D: dose; CV: coefficient of variation; VE: emergence rate (seedlings per day); EP: emergence percentage (%); LOM: length of mesocotyl, cm; LOC: length of coleoptile, cm; DWM: dry weight of mesocotyl, mg; DWC: dry weight of coleoptile, mg; DWA: dry weight of the aboveground portion, mg; and TDW: total dry weight of seedling, mg. Significant at \*p≤0.05; \*\*p≤0.01; ns: non-significant.

**Genotype.** Maize genotypes Xnuc Naal and San Pabléño were positively associated with LOM, DWM, DWA, and TDW (Figure 1B, second quadrant). Sáenz and Cassab (2021) indicated that some genotypes have developed long mesocotyls that allow plant to emerge at greater depths than others, such as Xnuc Naal and San Pabléño. Likewise, LOC was positively associated with PE, VE and DWC (Figure 1B, third quadrant). The maize variety Chichen Itza and the Zarco (hybrid) showed a lower association in regard to all the characteristics studied compared to the native races.



**Figure 1.** Dispersion of means of A: characteristics and B: genotypes of maize in irrigation and drought based on the first two principal components (2024 spring-summer cycle). VE: emergence rate (seedlings emerged per day); PE: percentage of emergence; LOM: length of mesocotyl, cm; LOC: length of coleoptile, cm; DWM: dry weight of mesocotyl, mg; DWC: dry weight of coleoptile, mg; DWA: dry weight of the aboveground portion, mg; and TDW: total dry weight of seedling, mg.

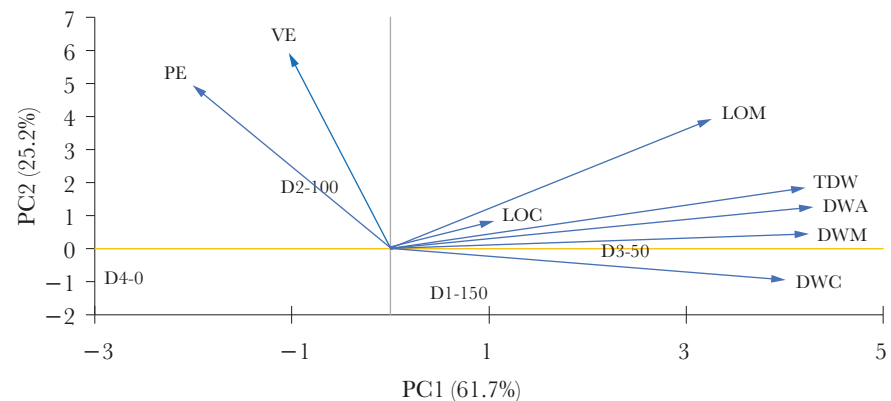
**Hydrogen Peroxide dose.** Based on the projection and angles of the vectors, TDW, DWA, DWM, LOC and LOM were positively associated with the dose 50 mM of  $H_2O_2$  (Figure 2, quadrant 2). Likewise, when the seeds did not contain  $H_2O_2$ , there was no positive association in any characteristic (Figure 2, quadrant 3).

At a high dose (150 mM) of  $H_2O_2$  there was a lower effect on the characteristics of maize seedlings (Figure 3, quadrant 4). Both VE and PE were positively associated with the 100 mM dose of  $H_2O_2$  (Figure 2, quadrant 1); that is,  $H_2O_2$  could be useful as a promoter of seed germination and plant emergence (Guo *et al.*, 2021) of maize seedlings in irrigation or drought.

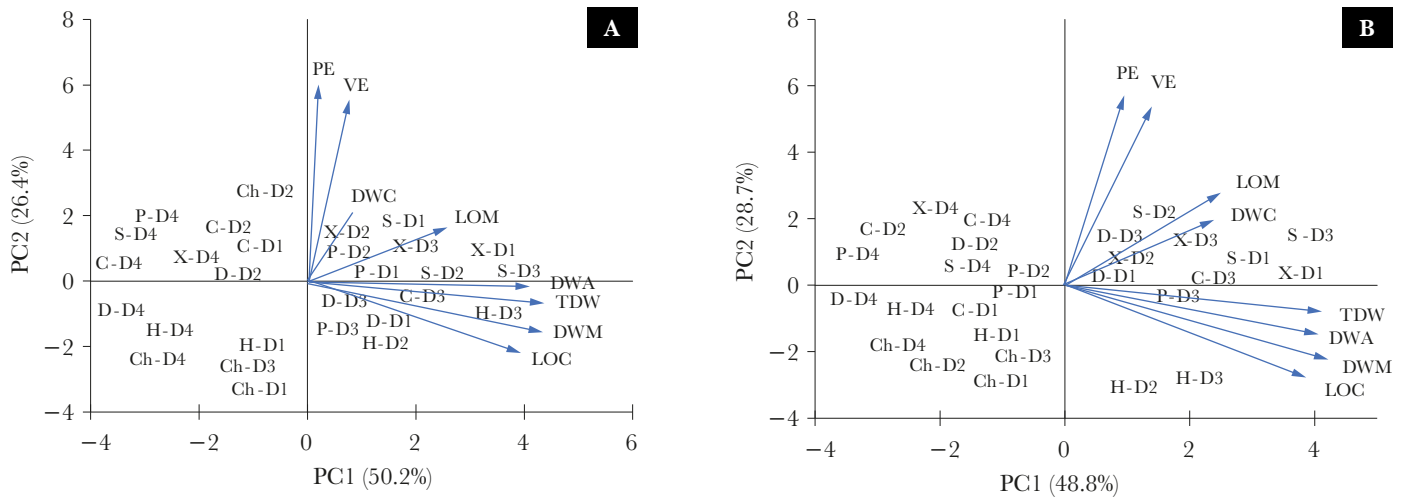
Interaction dose  $\times$  genotype  $\times$  moisture. Principal component analysis (PCA) indicated that the first two components (PC1 and PC2) together accounted for, 76.6% in drought (Figure 3A), and 77.5% in irrigation (Figure 3B), of the total variation observed among  $H_2O_2$  doses, genotype, and moisture. Cargnelutti and Toebe (2021) indicated that at least two main components are sufficient to adequately represent the variation of the evaluated characteristics.

In this study, for the first component (PC1) the most important variables in regard to dose of  $H_2O_2$  were LOC, DWM, TDW and DWA in drought (Figure 3A) and irrigation (Figure 3B). For the second component (PC2), the origin variables with superior weight were PE, VE, LOM and DWC in both moisture conditions (Figure 3A, B). Other studies reported that the mesocotyl-coleoptile elongation contributes to improve crop establishing in maize, which leads to a higher percentage of emergence and population density. In such conditions, re-sowing is not necessary and this impact positively the production costs of maize crop (Reed *et al.*, 2022).

In this context, based on the PCA (PC1 and PC2) shown in Figure 3, it can be observed that the 50 mM dose of  $H_2O_2$  in drought and irrigation was the most determinant at PC1; this is, the characteristic of greater relevance in the explanation of the variation observed. This means that, the lower the concentration of  $H_2O_2$ , the better response was obtained on the characteristics of the maize seedlings (Černý *et al.*, 2018).



**Figure 2.** Dispersion of  $H_2O_2$  doses based on the first two principal components (2024 spring-summer cycle). VE: emergence rate (seedlings emerged per day); PE: percentage of emergence; LOM: length of mesocotyl, cm; LOC: length of coleoptile, cm; DWM: dry weight of mesocotyl, mg; DWC: dry weight of coleoptile, mg; DWA: dry weight of the aboveground portion, mg; and TDW: total dry weight of seedling, mg. D1, D2, D3 and D4: doses 150, 100, 50 and 0 mM of  $H_2O_2$ .



**Figure 3.** Dispersion of genotypes based on the dose of H<sub>2</sub>O<sub>2</sub> in A: drought and B: irrigation, for the first two principal components (2024 spring-summer cycle). VE: emergence rate (seedlings emerged per day); PE: percentage of emergence; LOM: length of mesocotyl, cm; LOC: length of coleoptile, cm; DWM: dry weight of mesocotyl, mg; DWC: dry weight of coleoptile, mg; DWA: dry weight of the aboveground portion, mg; and TDW: total dry weight of seedling, mg. D1, D2, D3 and D4: doses 150, 100, 50 and 0 mM of H<sub>2</sub>O<sub>2</sub>. S: San Pablano; X: Xnuc Naal; D: Dzib Bacal; P: Pix Christ; C: Chaax Mejen Naal; H: Zarco (control).

## CONCLUSIONS

The effect of hydrogen peroxide on native and hybrid maize seeds showed positive effects on rate and percentage of emergence, length of mesocotyl, length of coleoptile and dry matter production in both moisture environments. The dispersion on principal component analysis allowed us to observe that the 50 and 100 mm doses were paramount through the Xnuc Naal and San Pablano genotypes, in irrigation and drought.

## REFERENCES

- Cargnelutti, F. A. and Toebe, M. (2021). Sample size for principal component analysis in corn. *Pesquisa Agropecuária Brasileira*, 56. e02510. <https://doi.org/10.1590/S1678-3921.pab2021.v56.02510>
- Černý, M., Habánová, H., Berka, M., Luklová, M., and Brzobohatý. (2018). Hydrogen Peroxide: Its Role in Plant Biology and Crosstalk with Signalling Networks. *International Journal Molecular Sciences*, 19(9). 2812. <https://doi.org/10.3390/ijms19092812>
- Cetinel, A. H. S., Yalcinkaya, T., Akyol, T. Y., Gokce, A. and Turkan, I. (2021). Pretreatment of seeds with hydrogen peroxide improves deep-sowing tolerance of wheat seedlings. *Plant Physiology and Biochemistry*, 167. 321-336. <https://doi.org/10.1016/j.plaphy.2021.08.016>
- Choudhury, F. K., Rivero, R. M., Blumwald, E. and Mittler, R. (2017). Reactive oxygen species, abiotic stress and stress combination. *The Plant Journal*, 90(5). 856-867. <https://doi.org/10.1111/tpj.13299>
- Guo, W., Xing, Y., Luo, X., Li, F., Ren, M. and Liang, Y. (2023). Reactive Oxygen Species: A Crosslink between Plant and Human Eukaryotic Cell Systems. *International Journal Molecular Sciences*, 24(17). 13052. <https://doi.org/10.3390/ijms241713052>
- Guo, Z., Zhao, J., Wang, M., Song, S., and Xia, Z. (2021). Sulfur dioxide promotes seed germination by modulating reactive oxygen species production in maize. *Plant Science*, 312. 111027. <https://doi.org/10.1016/j.plantsci.2021.111027>
- Kheddia, J., Agarwal, P., Agarwal, P. K. (2019). Deciphering hydrogen peroxide induced signalling towards stress tolerance in plants. *3 Biotech*, 9(11). 395. <https://doi.org/10.1007/s13205-019-1924-0>
- Li, W. U., Zhang, X., Ashraf, U., Mo, Z., Suo, H., and Li, G. (2017). Dynamics of seed germination, seedling growth and physiological responses of sweet corn under peg-induced water stress. *Pakistan Journal of Botany*, 49(2). 639-646.
- Maguire, D. J. (1962). Speed of Germination: Aid in Selection and Evaluation for Seedling Emergence and Vigor. *Crop Science*, 2. 176-177. <https://doi.org/10.2135/cropsci1962.0011183X000200020033x>

- Niu, L., Hao, R., Wu, X., and Wang, W. (2020). Maize mesocotyl: Role in response to stress and deep sowing tolerance. *Plant Breeding*, 139(3). 466-473. <https://doi.org/10.1111/pbr.12804>
- Reed, R. C., Bradford, J.F. and Khanday, I. (2022). Seed germination and vigor: Ensuring crop sustainability in a changing climate. *Heredity*, 128. 450-459. <https://doi.org/10.1038/s41437-022-00497-2>.
- Sáenz, R. M. N. and Cassab, G. I. (2021). Primary Root and Mesocotyl Elongation in Maize Seedlings: Two Organs with Antagonistic Growth below the Soil Surface. *Plants*, 10. 1-20. <https://doi.org/10.3390/plants10071274>
- Villalobos, G. A., Benítez, R. I., Castillo, G. F., Mendoza, C. M. D., and Espinosa, C. A. (2024). Genetic Parameters in Mesocotyl Elongation and Principal Components for Corn in High Valleys, Mexico. *Seeds*, 3(1). 149-168. <https://doi.org/10.3390/seeds3010012>
- Zhao, X., Zhong, Y. and Zhou, W. (2021). Molecular mechanisms of mesocotyl elongation induced by brassinosteroid in maize under deep-seeding stress by RNA-sequencing, microstructure observation, and physiological metabolism. *Genomics*, 113(6). 3565-3581. <https://doi.org/10.1016/j.ygeno.2021.08.020>





# Factors influencing the adoption of modern nitrogen dose reduction technologies: the case of wheat in the Yaqui Valley

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## ABSTRACT

**Objective:** The article examines the factors influencing the adoption of nitrogen dose reduction technologies among wheat farmers in the Yaqui Valley, Mexico.

**Design/methodology/approach:** Through the analysis of a sample of 336 farmers, the study identifies key factors associated with technology adoption, including gender, educational level, farm size, and land tenure. Additionally, factors such as access to technical advice and a positive perception of the technology's adaptability and relevance also play a crucial role. A random utility model was used to determine the probability that a wheat farmer would decide to adopt the described technology.

**Results:** The findings suggest that the male farmers male, higher education levels, technical advice, prior knowledge of the technology, and a positive perception of its adaptability, usefulness, and relevance influence the likelihood of adopting the proposed technology. Additionally, adoption is less likely when production is carried out without the support of technical advisors or when the farmers is not legally constituted as a legal entity.

**Limitations on study/implications:** The research focuses on a specific type of technology and a particular region.

**Findings/conclusions:** The use of new technologies among agricultural farmers is a high-impact tool in public policy aimed at supporting rural areas. Additionally, it is suggested that further actions, such as establishing demonstration plots with the proposed technology and inviting regional associations and farmers, as well as accompanying the technological proposals with certified technical advisors, can lead to a higher adoption rate, offsetting low educational levels and small plot sizes.

**Keywords:** Agriculture 4.0, technology adoption, wheat, logit.

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## INTRODUCTION

The sustainability of wheat production is increasingly challenged by environmental concerns and the need for efficient resource management. Nitrogen, a key nutrient in wheat cultivation, plays a crucial role in yield and quality; however, its excessive and inefficient use leads to economics losses and severe environmental impacts, such as soil degradation water contamination, and greenhouse gas emissions (Matson *et al.*, 1998; Beman *et al.*,

2005). Addressing this problem requires the adoption of modern technologies, known as Industry 4.0 (Schwab, 2017), that optimize fertilizer application and maintain productivity.

This study examines the factors influencing the adoption of nitrogen dose reduction technologies among wheat farmers in the Yaqui Valley during the Fall-Winter 2022/2023 cycle.

The Yaqui Valley, located in northern Mexico, in the states of Sonora and Chihuahua, has historically been a center for agricultural innovation. It was a pivotal region during the Green Revolution, introducing high-yield wheat varieties, mechanization, and expensive fertilizer use (Cerutti, 2019). While these advancements increased productivity, they also contributed to nitrogen overuse, which remains a challenge today. Nitrogen use efficiency in the region is reported to be approximately 31%, highlighting the need for improved management strategies (Millar *et al.*, 2018; CIMMYT, 2021). Modern precision agriculture technologies, such as optical sensors, have been developed to optimize nitrogen application by detecting the crop's specific nutrient needs and adjusting fertilizer doses accordingly (Ortiz *et al.*, 2007; Ruan *et al.*, 2005; Santillano *et al.*, 2013; Crain *et al.*, 2012). Therefore, these technologies can reduce nitrogen application rates while maintaining or even improving wheat yields. Despite their potential benefits, adoption rates among farmers in the Yaqui Valley remain low.

However, it is noteworthy that access to the new technologies has not been widespread, and the conditions for accessing them are unequal (Mehrabi *et al.*, 2021), whether due to indispensable factors for suppliers to expand them, or due to demand factors that limit adoption, such as educational, digital capabilities, or tradition and inertia in production methods (Elizondo *et al.*, 2023).

Lapidus (2017) points to some impediments to its adoption, highlighting the dependence on donor resources to transfer the technology to farmers through advisors. On the other hand, it is common that when it comes to adopting input-saving technologies, incentives tend to interfere between input-supplying companies that provide credit, and farmer organizations. By identifying the economic, technical, and institutional barriers to adoption, this research seeks to provide valuable insights for policymakers, researchers, and stakeholders interested in promoting sustainable nitrogen management practices in wheat production. The hypothesis of the study was that The adoption of nitrogen dose reduction technologies among wheat farmers in the Yaqui Valley is influenced by a combination of economic, technical, and institutional factors. Specifically, it is hypothesized that farmers with greater financial resources, higher levels of technical knowledge, and stronger institutional support are more likely to adopt these technologies. Conversely, traditional farming practices, limited access to credit, and weak extension services act as barriers to adoption.

## **MATERIALS AND METHODS**

The concurrence of high fertilizer prices resulting from the beginning of the Russia-Ukraine war, in the fall-winter (F-W) 2022/2023 cycle, motivated the Fideicomisos Instituidos en Relación con la Agricultura (FIRA) to implement a support scheme to encourage the adoption of efficient fertilization practices. FIRA absorbed 65% of the cost of

the technological proposal corresponding to equipment rental, training and hiring of field advisors, diagnostic, recording in field logs, coordination of the application, supervision and validation of its use.

### **Proposed agricultural technology and practice**

The first element inherent to the technology evaluated in this study was the diagnosis of the need for nitrogen by means of images taken by remote sensors integrated to drones. The images make it possible to estimate the quantity and quality of vegetation by measuring the intensity of radiation in the red and infrared bands of the electromagnetic spectrum emitted by the vegetation. The imaging varies according to the desired resolution. Related to the choice of technology (Späti *et al.*, 2021) have found that drones are more effective for fields with high spatial heterogeneity although not at any cost compared to other available alternatives, such as satellite imagery or handheld devices (*e.g.* green seeker).

The second element consisted of more efficient fertilizer application practices that considered no nitrogen use prior to planting, then an application of a maximum of 100 units of nitrogen, buried and solid, in the first fertilization at the time of planting. Then, prior to the first irrigation, the crop was diagnosed by means of a multispectral image obtained by the drone. Based on the interpretation of the image taken, recommendations were generated for the dose of nitrogen required to cover the needs in the strongest stage of crop development. Finally, in a subset of farmers, a second crop diagnosis using the drone was proposed prior to the second irrigation to determine a possible additional nitrogen requirement in order to ensure the quality of the grain.

### **Target population and study sample**

The population of farmers for whom the Yaqui irrigation district issued permits in the F-W 22/23 cycle corresponds to 138,252 hectares of wheat managed by 11,073 irrigation users. In addition, the local ministry of agriculture (SAGARHPA) identified, in addition to irrigation users, 5,648 farmers who used irrigation permits in the F-W 22/23 cycle. Since the collection of information requires the estimation of various parameters, the most relevant of which is the proportion of farmers adopting the technology, a sample size was used to reach a confidence level of 95% and precision in the estimator of technology adoption of 3% for the population described resulting in sample size of 321 farmers (Cochran, 1977).

### **Technology promotion**

In the first phase, the local association of farmer unions AOASS (Asociación de Organismos de Agricultores del Sur de Sonora) promoted the technological program to the representatives of each of the farmer unions that make up the association and provided institutional support for its subsequent dissemination to the respective farmers. In the second phase, the representatives of each association disseminated the technology and FIRA's institutional support to the farmers of their respective union. Finally, AOASS held a meeting in each of the respective premises to further explain the technology, its benefits, the work plan and the respective cost reduction support.

### Data collection

The data collection process was designed following established methodologies for studying technology adoption in agriculture. To ensure scientific rigor, we incorporated elements from meta-analyses by Mwangi and Kariuki (2015) and Ruzzante *et al.* (2021), which synthesize a wide array of studies on farmer's decisions to adopt new technologies. These studies highlight four key dimensions relevant to adoption processes: i) exposure of the farmer to the technology, ii) economic- productive characteristics of the farmers, iii) institutional support elements for the application of the technology and iv) socioeconomic profile of the farmer's household. Based on these dimensions, a structured survey was developed and validated through expert consultation with agricultural economists and extension specialists. The survey was administered through in-person interviews by trained enumerators at the end of the 2022-2023 fall-winter agricultural cycle. The sample consisted of 336 farmers from the Yaqui Valley who had been exposed to the initial offer of nitrogen reduction technologies. The selection process followed a stratified random sampling approach to ensure representation across different farm sizes, production systems, and access to institutional support.

Data collection adhered to standardized protocols to minimize bias, ensuring that all enumerators received training in survey administration. The data were then digitized and verified for consistency before analysis. This methodological approach ensures that the findings accurately reflect the factors influencing the adoption of nitrogen reduction technologies among wheat farmers in the region.

### Diagnostic method

A random utility model (Ben-Akiva *et al.*, 1985) was used to determine the probability that a wheat farmer would decide to adopt the described technology. The model is defined as:

$$U_{in} = V_{in} + \varepsilon_{in}, \quad i = 1, \dots, I \wedge n = 1, \dots, N \quad (1)$$

Where  $U_{in}$  is the expected utility of alternative  $i$  for farmer  $n$ ,  $V_{in}$  is the deterministic component of the utility and  $\varepsilon_{in}$  is the random component. In the hypothetical case that  $V_{in}$  contains perfect information about the determinants of utility, the farmer would choose the highest alternative. Therefore, the probability that farmer  $n$  chooses alternative  $i$  over alternative  $j$  is:

$$\begin{aligned} P_{in}(i) &= \Pr(U_{in} \geq U_{jn}) \\ &= \Pr(V_{in} + \varepsilon_{in} \geq V_{jn} + \varepsilon_{jn}) \\ &= \Pr(\varepsilon_{jn} - \varepsilon_{in} \leq V_{in} - V_{jn}), \text{ for all } i, j \in C_n \end{aligned} \quad (2)$$

where  $C_n$  is the set of options for farmer  $n$ , which in the present case is considered as  $[C_n = \{i, j\} = \{Adopt, Not\ adopt\}]$ .

Equation (1) assumes that the random errors are independently and identically distributed across the  $I$  alternatives and  $N$  individuals ( $n = 1, \dots, N$ ) and follow an extreme value distribution meaning  $\varepsilon_n = \varepsilon_{jn} - \varepsilon_{in}$  in equation (2) is logistically distributed. The probability of choosing  $i$  is obtained by integrating equation (2) over a continuum of all possible values for  $\varepsilon_n$ . Thus, the probability that farmer  $n$  chooses alternative  $i$  is given by:

$$P_n(i) = \frac{e^{\mu V_{in}}}{\sum_{j \in C_n} e^{\mu V_{jn}}} \quad (3)$$

where  $\mu$  is a positive scale parameter,  $\mu > 0$ . The choice probability model with two probability options ( $i = 1$  y  $j = 0$ ) has a more succinct expression as follows:

$$\begin{aligned} P_n(i=1) &= \frac{e^{\mu V_{in}}}{e^{\mu V_{in}} + e^{\mu V_{jn}}} \\ &= \frac{1}{1 + e^{-\mu(V_{in} - V_{jn})}} \\ &= \frac{1}{1 + e^{\mu \beta' x_{jn}}} \end{aligned} \quad (4)$$

where  $\beta'$  is the vector of parameters to be estimated.

## RESULTS AND DISCUSSION

The results are grouped according to farmer characteristics as follows: i) socioeconomic profile, ii) economic-productive characteristics and iii) knowledge and previous exposure to technology.

### Socioeconomic profile

Adoption rates show significant differences according to gender and schooling level. The odds ratio presented in Table 1 show that gender significantly influences technology adoption, with an OR of 0.057 meaning that male are 94.3% less likely (1-0.057) to adopt technology compared to women, all other variables being constant.

Regarding women's participation, the finding is consistent with some similar studies such as Ndiritu *et al.* (2014) which noted that women farmers in Kenya are less likely to adopt intensified farming practices such as minimum tillage and use of animal fertilizer. However, it should be noted that the present study highlights structural differences in the economic-productive characteristics of men and women, since female have on average smaller landholdings (34 hectares) compared to men (79 hectares), in addition to the fact that land tenure is their own in 28% of cases compared to 50% in the case of men. These facts are interpreted as proxies for other potential explanatory factors in the low adoption rate shown by women.

Thus, farmers with basic and secondary less school likely to adopt technology compared to those with higher education.

According to Ruzzante *et al.* (2021) farmer education is positively correlated with adoption motivation. Similarly, Feder *et al.* (1985) concludes that “the most educated farmers are the first to adopt modern technologies”. On the other hand, Knight *et al.* (2003) find that schooling positively influences the adoption of modern inputs both directly and indirectly, through a reduction in risk aversion. These results reinforce current findings in the context of the Yaqui valley wheat producers.

### Economic-productive characteristics

The size of the plot is one of the variables with the greatest theoretical and practical support with respect to its importance in terms of the decision to adopt new technologies. This hypothesis has been identified by Feder *et al.* (1985) and is generally linked to a proxy role for other potentially determining factors, such as the ability to withstand greater risks, access to essential inputs, information on technologies, access to specialized labor, among others.

Although it is common to elaborate on the “scale neutrality” of technologies, *i.e.* that technologies are of equal benefit to small and large-scale farmers, data from the sample revealed that plot size was critical in explaining adoption in favor of farmers with larger size of land. There also seems to be a trade-off between scale and form of access to land, since farmers that commonly lease land to third parties as a way to increase scale and thus make technology adoption attractive, in this sample, renting land decreases the propensity to adoption. This behavior seems to be associated with the idea that “the returns to investment for the use of these technologies are lower as time horizon of the exploitation of a given area is shortened” (Lachman *et al.*, 2022), due to the high turnover that can occur on rented land. The first studies regarding this association were

**Table 1.** Socioeconomic characteristics associated with technology adoption.

| Independent variable | Category                     | Adopter | Non-adopter | Odds Ratio (OR) | p-value  |
|----------------------|------------------------------|---------|-------------|-----------------|----------|
|                      |                              | (a)     | (b)         | a/b             |          |
|                      |                              | (c)     | (d)         | c/d             |          |
| Gender               | 1: Female                    | 1       | 72          | 0.057           | 0.005*** |
|                      | 0: Men ( <i>ref.</i> )       | 49      | 214         |                 |          |
| Age                  | 1: <30 years ( <i>ref.</i> ) | 3       | 26          |                 |          |
|                      | 2: 30 to 40 years old        | 7       | 31          | 1.957           | 0.364    |
|                      | 3: 40 to 50 years old        | 6       | 44          | 1.182           | 0.824    |
|                      | 4: 50 to 60 years old        | 11      | 60          | 1.589           | 0.504    |
|                      | 5: ≥60                       | 23      | 125         | 1.595           | 0.473    |
| Schooling            | 0: No studies                | 0       | 2           |                 |          |
|                      | 1: Basic                     | 7       | 86          | 0.294           | 0.005*** |
|                      | 2: Secondary                 | 4       | 57          | 0.247           | 0.012**  |
|                      | 3: Higher ( <i>ref.</i> )    | 39      | 141         |                 |          |

\*\*\*p-value<0.01; \*\* p-value<0.05; \*p-value<0.10

**Table 2.** Economic and productive characteristics associated with technology adoption.

| Independent variable           | Category             | Adopter | Non-adopter | Odds Ratio (OR) | p-value  |
|--------------------------------|----------------------|---------|-------------|-----------------|----------|
|                                |                      | (a)     | (b)         | a/b             |          |
|                                |                      | (c)     | (d)         | c/d             |          |
| Land tenure                    | 1: Rented (ref.)     | 33      | 130         | 2.285           | 0.010**  |
|                                | 0: Own               | 17      | 153         |                 |          |
| Production Form                | 1: Individual (ref.) | 25      | 204         | 0.397           | 0.003*** |
|                                | 2: Legal entity      | 25      | 81          |                 |          |
| Plot size (ha)                 | 1: <20 ha (ref.)     | 4       | 114         | 0.131           | 0.000*** |
|                                | 0: ≥20 ha            | 46      | 172         |                 |          |
| Access to credit               | 1: Yes               | 48      | 256         | 2.813           | 0.166    |
|                                | 0: No                | 2       | 30          |                 |          |
| Technical Advisor <sup>2</sup> | 1: Yes (ref.)        | 44      | 204         | 2.948           | 0.017**  |
|                                | 0: No                | 6       | 82          |                 |          |
| Wheat yield                    | (ton/ha)             | 50      | 284         | 1.776           | 0.002*** |
| % of total income from wheat   |                      | 50      | 284         | 1.005           |          |

\*\*\*p-value<0.01; \*\* p-value<0.05; \*p-value<0.10

carried out in the context of the green revolution, for example, Vyas (1975) found that the form of land tenure did not significant influence adoption of technologies and, rather, as these technologies showed their potential, they were gradually adopted by all farmers. However, with the emergence of new and more diverse technologies, the phenomenon was further explored and farmers with owned land were found to more often adopt those technologies with higher costs (*e.g.* stone terraces in Ethiopia; Gebremedhin and Swinton, 2003) or with positive medium and long-term sustainable effects on land (*e.g.* natural resource management technologies, especially prevention of soil erosion; Ruzzante *et al.*, (2021). It is worth mentioning that the technology addressed in the present study has positive effects on cost reduction in the short term and generates medium- and long-term environmental benefits by making less intensive use of nitrogen and mitigate soil erosion.

Adoption is less likely when farmer's production is carried out without the support of technical advisors or when the farmer is not established as a legal entity. These findings suggest the presence of "network effects", where interactions with other actors could be enhancing the adoption of these technologies, which are not necessarily easily assimilated independently and autonomously by farmers. This highlights the crucial role of external information sources and peer influence in the diffusion and adoption process of these and other technologies, as emphasized by Lachman *et al.* (2022).

### Prior knowledge of technology

The farmer's prior knowledge of the technology, as well as the farmer's revealed perceptions regarding its positive adaptability, usefulness, and relevance, make them more likely to adopt it.

**Table 3.** Characteristics of prior knowledge of technology.

| Independent variable | Category     | Adopter | Non-adopter | Odds Ratio (OR) | p-value  |
|----------------------|--------------|---------|-------------|-----------------|----------|
|                      |              | (a)     | (b)         | a/b             |          |
|                      |              | (c)     | (d)         | c/d             |          |
| Complexity           | 1: Yes       | 4       | 40          | 0.535           | 0.254    |
|                      | 0: No        | 46      | 246         |                 |          |
| Useful               | 1: Yes       | 32      | 88          | 4.000           | 0.000*** |
|                      | 0: No        | 18      | 198         |                 |          |
| Relevance            | 1: Yes       | 46      | 233         | 2.616           | 0.077*   |
|                      | 0: No        | 4       | 53          |                 |          |
| Adaptation           | 1: Yes       | 45      | 215         | 2.972           | 0.026**  |
|                      | 0: No        | 5       | 71          |                 |          |
| Pre-application      | 1: Yes       | 15      | 19          | 5.030           | 0.000*** |
|                      | 0: No        | 35      | 223         |                 |          |
| Previous results     | 1: Yes       | 19      | 48          | 3.039           | 0.001*** |
|                      | 0: No        | 31      | 238         |                 |          |
| Test                 | 0: No test   | 20      | 81          | 0.593           | 0.099*   |
|                      | 1: With test | 30      | 205         |                 |          |

\*\*\* p-value < 0.01; \*\* p-value < 0.05; \* p-value < 0.10

### Joint impact assessment

The proportion of farmers that used the nitrogen dose reduction technology in the sample is 14.8%. In order to jointly test the effects that significantly explain this behavior, the various groups of variables were tested simultaneously therefore enhancing their precision and the nature of their statistical significance reducing the possibility of error in the interpretation of individual parameters. The estimates of all parameters revealed an association consistent with the direction suggested by the individual analysis.

The estimates of all parameters used in the model revealed their expected signs (Table 4). They also confirmed statistical significance with respect to their univariate counterparts. In general, farmers' characteristics show, through their respective parameters, a lower impact on the probability of adoption if they are considered jointly. For instance, schooling shows that a greater number of years of education increases the probability of adoption by 1.52% for each additional year of schooling and not by 2.70% as suggested when considered individually. However, of greater relevance is the comparison of marginal effects for impact variables, particularly those that are of a non-idiosyncratic nature. Noteworthy is the fact that having previous exposure to the new technology in a neighboring plot increases the probability of adoption in 14.5% while, for example, a smaller plot size reduces it by only 11.4%. In this way, small farmers previously exposed to the new technology can be compensated for other limiting characteristics and enhanced on their probability of adoption. A similar result is obtained if a technical advisor is present to support the farmer in the normal course of his activities.

**Table 4.** Parameter Estimates and Marginal Effects of the multiple variable Logit Model.

| Independent variables                      | Category          | Estimation (standard error) | Average marginal effects |
|--|-------------------|-----------------------------|--------------------------|
| <b>Socio-economic characteristics</b>      |                   |                             |                          |
| Gender***                                  | Female (ref.)     | -2.740                      | -16.18%                  |
|  | Men               | (1.042)                     |                          |
| Age  |                   | -0.008                      | -0.08%                   |
|  |                   | (0.013)                     |                          |
| Schooling**                                |                   | 0.160                       | 1.52%                    |
|  |                   | (0.070)                     |                          |
| <b>Productive economic characteristics</b> |                   |                             |                          |
| Land Tenure*                               | Own (ref.)        | 0.644                       | 6.12%                    |
|  | Rented            | (0.389)                     |                          |
| Production Form                            | Individual (ref.) | -0.331                      | -3.26%                   |
|  | Legal entity      | (0.383)                     |                          |
| Plot size (ha)**                           | <20ha (ref.)      | -1.399                      | -11.36%                  |
|  | >20ha             | (0.595)                     |                          |
| Access to Credit                           | Yes (ref)         | 1.215                       | 9.24%                    |
|  | No                | (0.860)                     |                          |
| Technical Advisor*                         | Yes (ref)         | 0.954                       | 8.24%                    |
|  | No                | (0.499)                     |                          |
| Wheat yield (ton/ha) **                    |                   | 0.548                       | 5.24%                    |
|  |                   | (0.234)                     |                          |
| % Wheat of total productive plots**        |                   | 0.020                       | 0.19%                    |
|  |                   | (0.009)                     |                          |
| <b>Prior knowledge of the technology</b>   |                   |                             |                          |
| Previous results***                        | No (ref)          | 1.299                       | 14.52%                   |
|  | Yes               | (0.406)                     |                          |
| Const.                                     |                   | -11.092                     |                          |
|  |                   | (2.713)                     |                          |

\*\*\*p-value<0.01; \*\*p-value<0.05; \*p-value<0.10

The reference class for the estimation of the respective parameter is highlighted in parentheses (ref). Number of observations=329. Likelihood ratio test: -100.730. McFaden  $R^2=0.281$ . ROC=0.855.

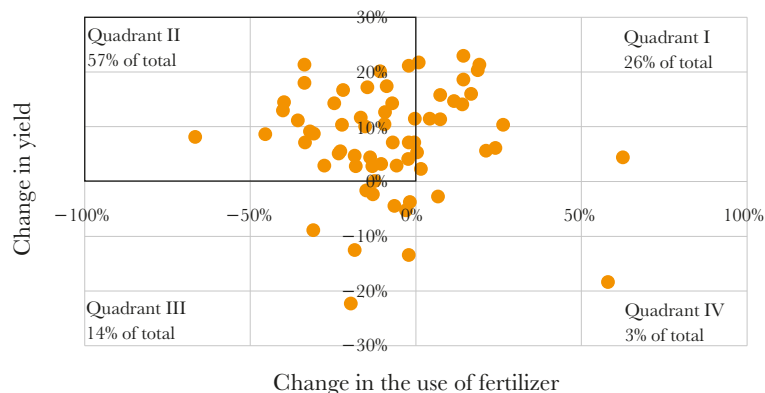
The variables Age and Schooling are treated as discrete numerical variables.

The marginal effect indicates the change in the expected probability of adopting the technology for a unit change in an explanatory variable.

Technical advisor: Farmers with declared availability of technical advisor during previous productive activities.

### Effectiveness of the technology

Figure 1 illustrates the changes with respect to the previous cycle in terms of fertilizer use and in terms of crop production (tons per hectare). As for the fertilizer, various nitrogen molecules were used, such as urea (67%), ammonia (23.3%) and phosphonitrate (2.9%), among others. As can be seen, the majority (57%) of adoptive farmers are in quadrant (II), which simultaneously shows an increase in yield and a decrease in fertilizer use. On



**Figure 1.** Change vs. previous cycle in fertilizer use and yield (tons per hectare).

average, within this quadrant there is a 20% lower use of fertilizer, and a 10% higher yield compared to the previous cycle.

Likewise, the evaluation of field results shows that wheat production is more profitable with the technology tested in this study with respect to the traditional technology. If we consider the Benefit/Cost ratio for the farmer as proposed in Table 5, we conclude that the farmer increases revenues as compared to costs from 1.055 to 1.149, even considering the additional cost for the crop diagnosis with drone and field advisory and consulting services. This is due to the fact that the technology allowed reducing on average the cost of the crop by saving fertilizer, in addition to increasing, on average, wheat yield.

**Table 5.** Profitability of wheat cultivation through traditional technology and Optimal Fertilization.

| Concept                                     | Traditional technology | Nitrogen dose reduction technology without Support | Nitrogen dose reduction technology with support |
|---|------------------------|--|---|
| Total Cost \$ per ha                        | 36,938.00              | 36,418.05  | 35,764.00                                       |
| 1. Cost per ha:<br>(of which Fertilization) | 36,938.00<br>15,747.00 | 35,502.05<br>14,311.05                             | 35,502.05<br>14,311.05                          |
| 2. Drone/ha                                 | -                      | 153.50   | 30.70   |
| 3. Advice/ha                                | -                      | 500.00   | 100.00  |
| 4. Consultancy/ha                           | -                      | 262.50   | 131.25  |
| Income \$ /ha                               | 38,967.50              | 41,834.20  | 41,834.20                                       |
| -Yield tn/ha                                | 7.15                   | 7.68   | 7.68  |
| -Price / tn                                 | 5,450.00               | 5,450.00   | 5,450.00  |
| B/C ratio                                   | 1.055                  | 1.149  | 1.170   |

1/ Traditional technology: Cost of cultivation ([www.FIRA.gob.mx](http://www.FIRA.gob.mx))

Price: Price per ton of crystalline wheat during harvest at the end of May/2023 (310 dis/tn)

## CONCLUSIONS

The adoption of new agricultural technologies is crucial for agricultural development, especially in Mexico, as it enhances nitrogen use reduction in wheat production in the Yaqui Valley and consequently improves overall agricultural productivity. However, the

decision and associated risks fall on farmers, which limits implementation. This study identified key adoption barriers, including lack of education, technical assistance, and financial resources. Farmers with higher education levels, access to credit, and technical support are more likely to adopt these technologies. at the adoption rate was 14.8%, but it could increase through strategies such as field demonstrations and specialized technical assistance.

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## REFERENCES

- Beman, J., Arrigo, K., & Matson, P. (2005). Agricultural runoff fuels large phytoplankton blooms in vulnerable areas of the ocean. *Nature*, 434, 211-214. . doi:<https://doi.org/10.1038/nature03370>
- Ben-Akiva, M., & Lerman, S. R. (1985). *Discrete choice Analysis: Theory and Application to Travel Demand*. Cambridge, MA: MIT Press.
- Cerutti, M. (2019). Trigo y revolución verde en el noroeste de México (1930-1970) (Vol. 20). *Mundo agrario*. doi:<https://doi.org/10.24215/15155994e103>
- CIMMYT. (2021). Los beneficios de eliminar las aplicaciones de nitrógeno durante la presiembra. Obtenido de Divulgación-CIMMYT: <https://www.cimmyt.org/es/noticias/los-beneficios-de-eliminar-las-aplicaciones-de-nitrogeno-durante-la-presiembra/>
- Cochran, W. G. (1977). *Sampling Techniques*. John Wiley & Sons.
- Crain, J., Ortiz-Monasterio, I., & Raun, B. (2012). Evaluation of a reduced cost active NDVI sensor for crop nutrient management. *Journal of Sensors*. doi:<https://doi.org/10.1155/2012/582028>
- Curry, G. N., Nake, S., Koczberski, G., Oswald, M., Rafflegeau, S., Lummani, J., & Nailina, R. (2021). Disruptive innovation in agriculture: Socio-cultural factors in technology adoption in the developing world. *Journal of Rural Studies* (88), 422-431. doi:<https://doi.org/10.1016/j.jrurstud.2021.07.022>
- Elizondo Flores, J. A., Montes-Rivera, F. Y., Valdivia-Alcalá, R., & Cruz-Betanzos, A. (2023). Agriculture 4.0: Is Mexico Ready? *Agro Productividad*. doi:<https://doi.org/10.32854/agrop.v15i4.2495>
- Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*, 33(2), 255-298.
- Gebremedhin, B., & Swinton, S. (2003). Investment in Soil Conservation in Northern Ethiopia: The Role of Land Tenure Security and Public Programs. *Agricultural Economics*, 29, 69-84. doi:10.1111/j.1574-0862.2003.tb00148.x.
- Knight, J., Weir, S., & Woldehanna, T. (2003). The role of education in facilitating risk-taking and innovation in agriculture. *The Journal of Development Studies*, 39, 1-22. doi:<https://doi.org/10.1080/00220380312331293567>.
- Lachman, J., Gómez-Roca, S., & López, A. (2022). Adopción de tecnologías de agricultura de precisión en los grupos CREA. *Serie Documentos de Trabajo del IIEP* (79), 1-43. doi:<https://ojs.econ.uba.ar/index.php/DT-IIEP/issue/view/427>
- Lapidus, D., Latane, A., Beach, R. H., & Ortiz-Monasterio, I. (2017). *The green seeker Handheld*. RTI Press.
- Matson, P. A., Naylor, R., & Ortiz-Monasterio. (1998). Integration of environmental, agronomic, and economic aspects of fertilizer management. *Science*. doi:10.1126/science.280.5360.112
- Mehrabi, Z., McDowell, M. J., Ricciardi, V., Levers, C., Martinez, J. D., Mehrabi, N., . . . Jarvis, A. (2021). The global divide in data-driven farming. *Nature Sustainability*, 154-160. doi:<https://doi.org/10.1038/s41893-020-00631-0>
- Millar, N., Urrea, A., Kahmark, K., Shcherbak, I., Robertson, G., & Ortiz, I. (2018). Nitrous oxide (N<sub>2</sub>O) flux responds exponentially to nitrogen fertilizer in irrigated wheat in the Yaqui Valley, Mexico. *Agriculture, Ecosystems & Environment*, 261, 125-132. doi:<https://doi.org/10.1016/j.agee.2018.04.003>.
- Mwangi, M., & Kariuki, S. (2015). Factors Determining Adoption of New Agricultural Technology by Smallholder Farmers in Developing Countries. *Journal of economics and sustainable development*, 6(5), 208-216.
- Ndiritu, S., Kassie, M., & Shiferaw, B. (2014). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, 49(1), 117-127. doi: <https://doi.org/10.1016/j.foodpol.2014.06.010>.

- Ortiz, I., & Raun, W. (2007). Reduced nitrogen and improved farm income for irrigated spring wheat in the Yaqui Valley, Mexico, using sensor based nitrogen management. *Journal of Agricultural Science*, 145, 215–222. doi:10.1017/S0021859607006995.
- Ruan, W., Solie, J., Stone, M., Martin, K., Freeman, K., Mullen, R., . . . Johnson, G. (2005). Optical Sensor Based Algorithm for Crop Nitrogen Fertilization. *Communications In Soil Science and Plant Analysis*, 36(19-20), 2759-2781. doi: 10.1080/00103620500303988.
- Ruzzante, S., Labarta, R., & Bilton, A. (2021). Adoption of agricultural technology in the developing world: A meta-analysis of the empirical literature. *World Development*, 146, 107384. doi:<https://doi.org/10.1016/j.worlddev.2021.105599>.
- Santillano, J., Lopez, Á., Ortiz, I., & Raun, W. (2013). Use of Optical Sensor Technology for the Fertilization of Wheat (*Triticum aestivum* L.). *Tierra Latinoamericana*, 31, 95-103.
- Schwab, K. (2017). The fourth industrial revolution. New York: Crown Publishing Group.
- Späti, K., Huber, R., & Finger, R. (2021). Benefits of Increasing Information Accuracy in Variable Rate Technologies. *Ecological Economics*, 185, 107047. doi:<https://doi.org/10.1016/j.ecolecon.2021.107047>
- Vyas, V. (1975). India's high yielding varieties programme in wheat 1966-67 to 1971-72. CIMMYT Studies in the Adoption of New Agricultural Technology. VIII, 28.



# Profitability and economic viability of the production of agave syrup

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## ABSTRACT

**Objective:** To quantify the income and production costs of agave syrup and their determining factors, as well as their potential to improve the competitiveness and profitability of agave production.

**Design/Methodology/Approach:** Three representative production units (URP) of agave syrup were designed through a cross-sectional mixed method, using semi-structured interviews and the producer panel method, as examples of typical production systems of the region. Economic indicators, such as economic and financial viability and benefit/cost ratio (B/C), were obtained.

**Results:** The three URP recorded financially positive net incomes; consequently, they are a viable alternative in the short-medium term. The three URP recorded 1.87, 1.74 and 1.08 B/C ratios.

**Study Limitations/Implications:** The results are not statistically significant; therefore, they cannot be extrapolated to the rest of the population.

**Findings/Conclusions:** To increase the competitiveness of agave syrup, sharing its functional properties is fundamental to develop a highly consolidated market where the sales of the producer are certain.

**Keywords:** Maguey, artisanal products, functional products.

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## INTRODUCTION

Functional foods have been drawing attention since the COVID-19 pandemic, because their active ingredients can be used to prevent and treat several diseases (Kim *et al.*, 2022). Regular consumption of nutrient-rich functional foods—particularly plant-based foods—can improve metabolic health, reduce inflammation, control weight, and potentially reduce sugar consumption. Consequently, functional foods improve the overall human health (Jurek, 2022). As a result of the interest of people in an improved lifestyle, functional foods are becoming increasingly popular and the related industry is rapidly growing. An example of these products is agave syrup, a sugar substitute. As a result of its nutraceutical



properties (Ozuna and Franco-Robles, 2022), agave syrup has recently become very popular in the health, organic, and functional markets, as well as food for patients with diabetes. Agave syrup (AS) is mainly produced with agave sap from the *Agave tequilana* and *A. salmiana* species. This vegan sweetener has been used to substitute conventional saccharine sweeteners. As a result of its nutritional value, AS has a higher content of minerals, vitamins, and polyphenols than other traditional sweeteners (Saraiva *et al.*, 2022; Yargatti and Muley, 2022). Unlike other natural syrups and honeys, AS is a great natural sweetener due to its prebiotic potential and low glycemic index (Mellado-Mojica and López-Pérez, 2013). In addition, AS has a great potential in international markets, where it can be used as an alternative to diversify products, improving the entry of agave producers into the said markets (Narváez-Suárez *et al.*, 2016). Studies about AS are scarce and have mainly focused on the biotechnology, food, and health areas (Mellado-Mojica and López-Pérez, 2013; Ozuna and Franco-Robles, 2022), as a consequence of its physical and chemical properties and its biological functionality. Therefore, the socioeconomic factors of this product have not been fully analyzed, leading to a lack of information about its basic indicators, such as profitability and benefit/cost ratio, which are fundamental to evaluate AS competitiveness.

Consequently, the objective of this study was to quantify the income and production costs of AS, to measure its competitiveness level, and to determine its potential as an economic viable alternative for both agave producers and potential investors.

## MATERIALS AND METHODS

The experiment consisted of a cross-sectional mixed method and a sample of 15 participants. Data were collected with semi-structured interviews and the producer panel method, adapted from the Delphi method, which consists of discussions and information exchange about technical management, prices, and product yield between experts and producers (Sagarnaga-Villegas *et al.*, 2014).

The study focused on three Representative Production Units (URP) of AS. These URP were used as models of the production systems frequently found in the home region of the participating producers. The URP were identified as IXAS10, THAS12, and CDAS800. The abbreviations referred to the study areas (IX: Ixtapaluca; TH: Teotihuacán; and CD: Cardonal, Hidalgo), the AS economic activity, and the monthly production scale (10, 12, and 800 liters). These URP were chosen based on the opinion of local experts. Fieldwork was carried out in January 2022. Based on the recognition of inflation of monetary and non-monetary assets (CINIF, 2020), the data from this study were updated to reflect 2024 values.

Economic and financial viability and the B/C ratio of the Mexican agricultural sector were determined using the modification proposed by Sagarnaga *et al.* (2014) to the method developed by the Agricultural & Applied Economics Association (AAEA, 2000) and the United States Department of Agriculture (USDA, 2013).

Total income was calculated based on the liters of AS sold multiplied by market price and other sources of income (bank transfers, self-consumption, etc.). Production costs included all the expenditures directly associated with the production of AS. According to

the methodology used in this study, three types of costs were identified: operational costs (OC), general costs (GC), and economic costs (EC).

Operational costs (OC) are directly related to production level (supplies, direct labor, and interest payments on short-term loans, etc.). Meanwhile, general costs (GC) do not depend on production level (payment of services, taxes, insurances, interest payment on long-term loans, etc.).

Economic costs (EC) consist of OC, GC, and opportunity costs from factors of production (capital invested in land and in extraordinary improvements, working capital, labor payment, and unpaid management).

B/C ratio is used to calculate profitability, dividing total income by total operational costs: a  $>1$  B/C indicates that the project is profitable; an  $=1$  B/C shows that the project is not viable; and, finally, a  $<1$  B/C indicates that the project is not profitable.

Financial viability measures the capacity of the company to tackle operational and general costs. Positive results indicates that the URP has a medium-term viability. Meanwhile, economic viability is the capacity of the company to pay opportunity costs from factors of production (land, workforce, and capital). Positive results indicate that factors of production are appropriately paid and, consequently, the company is viable and has a low chance of disappearing in the long-term, because producers will rarely find another highly profitable activity in which to invest the factors of production.

## RESULTS AND DISCUSSION

### Technical parameters and net income of URP

IXAS10 and THAS12 have an artisanal production system, using unpaid family labor and adapting home facilities. Fifty percent of producers pointed out that their main activity is agave cultivation. Producers sell pulque, pulque bread, leaves, distilled beverages, syrup, and other products. CDAS800 has a semi-industrialized production system. The URP has 4 employees working in the production process. It has specialized infrastructures and belongs to an organization of producers that only produce agave syrup.

In terms of agave sap yield, the three URP required 10 liters of sap to produce 1 liter of AS. These results match the findings of Vázquez-García *et al.* (2016), who reported that other producers obtained the same yield. Significant differences about production time and syrup standardization were recorded. Both artisanal processes resulted in a production of 2-4 liters per day, with substantial color and consistency differences. Meanwhile, the semi-industrialized process obtained up to 240 liters and the resulting agave syrup had the same color and consistency, due to the use of specialized machinery. According to Cechura and Hockmann (2014), the lack of homogeneity in artisanal food processing is the result of a low scale production and family labor, as well as a minimum use of machinery and a focus on traditional methods.

The three URP reported different prices, because producers establish their sell price based on market prices and the destination of their products. The price of CDAS800 was the closest to the actual price (\$221.00 MXN per kilogram) reported by Franco-Malvaíz *et al.* (2014). In the net cash flow and the financial analysis, income is determined by the direct syrup sales, while self-consumption is added to the total income to calculate the

income of the economic analysis. IXAS10, THAS12, and CDAS800 recorded a 10, 8.33, and 1% self-consumption, respectively (Table 1).

### Production costs

The purchase of agave sap accounted for 50-70% of the operational costs of the three URP. After the operation costs, bottling is the second major element in the costs of artisanal producers. Meanwhile, 75% of the sales of CDAS800 were buck sales and, consequently, bottling costs were not significant. The second major cost for this URP was labor, which accounted for 14% of the total operational costs. For their part, IXAS10 and THAS12 did not employ paid workforce, which therefore was not significant in their costs. According to Jiménez-Jiménez *et al.* (2014), this situation limits their competitiveness. This type of URP does not consider family labor among its supply costs.

The semi-industrialized CDAS800 had higher machinery and equipment depreciation costs than the artisanal IXAS10 and THAS12. The latter URP do not always have the equipment and machinery required for their processes and, consequently, do not include deterioration costs among their general costs. The general costs of the artisanal URP ranged from 1.5 to 4% of the total costs, while the general costs of the semi-industrialized URP (CDAS800) accounted for 20% of the same heading. This URP has a specialized structure and a higher machinery and equipment investment and, consequently, a high depreciation cost (Table 2). Meanwhile, IXAS10 and THAS12 recorded low depreciation costs, because they have minimum infrastructure, furniture, and equipment. These results match the findings of Barrera *et al.* (2018), who reported that rustic agricultural activities have low depreciation costs, as a result of the lack of infrastructure and equipment.

The opportunity costs were a key factor for IXAS10 and THAS12 (who produce their own syrup), accounting for 48 and 49.5% of the total economic costs, respectively. Consequently, unpaid labor was included in their economic analysis. Meanwhile, the unpaid labor of CDAS800 accounts only for 12% of the total economic cost. A factor that stood out in the economic analysis was the management opportunity cost: it was 50 times higher in the industrial process than in the artisanal process. These results match the reports of Esquivel-Marín *et al.* (2022), who found that primary production requires scarce or no management at all. However, it increases depending on the integration degree of the producers.

As a result of their artisanal production, the producers of IXAS10 and THAS12 sold their products through short commercialization chains and at their own farms. Nevertheless, this study took into account the rent of premises for the viability analysis,

**Table 1.** Technical parameters and annual net income in thousands of pesos (2024).

| URP     | Type of Technology | Production (lt) | Self-Use (lt) | Selling Price (MXN\$/lt) | Income    |           |
|---------|--------------------|-----------------|---------------|--------------------------|-----------|-----------|
|         |                    |                 |               |                          | Financial | Economic  |
| IXAS10  | Rustic             | 120             | 12            | 545                      | 65,364    | 71,901    |
| THAS12  | Rustic             | 144             | 12            | 409                      | 58,828    | 63,730    |
| CDAS800 | Industrial         | 5700            | 60            | 216                      | 1,229,129 | 1,242,066 |

Source: Table developed by the authors with information collected in the field.

**Table 2.** Annual productions costs in thousands of pesos (2024).

| <b>General Costs</b>         | <b>IXAS10</b> | <b>THAS12</b> | <b>CDAS800</b>   |
|------------------------------|---------------|---------------|------------------|
| Agave sap                    | 13,618        | 16,341        | 343,165          |
| Packaging                    | 9,532         | 5,760         | 70,812           |
| Labor                        | 0             | 0             | 163,412          |
| Other                        | 11,149        | 9,497         | 230,263          |
| <b>Operating costs</b>       | <b>34,299</b> | <b>32,375</b> | <b>807,652</b>   |
| Depreciation                 | 596           | 1,453         | 204,418          |
| General subtotal             | 596           | 1,453         | 204,418          |
| <b>Financial</b>             | <b>34,895</b> | <b>33,827</b> | <b>1,012,070</b> |
| Opportunity Cost of Location | 13,618        | 13,618        | 0                |
| Family Labor                 | 13,618        | 10,894        | 0                |
| Management                   | 2,724         | 2,451         | 137,771          |
| Working capital              | 4,219         | 4,224         | 96,918           |
| <b>Economic</b>              | <b>69,073</b> | <b>65,014</b> | <b>1,149,841</b> |

Source: Table developed by the authors with information collected in the field.

in case the producers wanted to sale their products in a permanent store. For its part, CDAS800 did not include rent costs in their sales, because they are distributors.

Given their use of intermediaries, the sale prices of THAS12 and CDAS800 were lower than IXAS10's. For its part, the policy of IXAS10 involves working with no more than one intermediary. This policy can be defined as a short commercialization chain (Ministerio de Agricultura, 2012). This strategy allowed them to capture most of the market value of the product, mainly in pulque and barbacoa establishments, as well as local fairs.

### **Competitiveness indicators**

The net income was financially positive for the three URP; consequently, they have a short- and medium-term viability. However, only IXAS10 and CDAS800 have an economically positive income and therefore have a long-term viability. Meanwhile, THAS12 had an economically negative income and, therefore, its long-term viability is in question. According to Domínguez-García *et al.* (2017), the factors of production could be more efficiently used in another more profitable production activity. Therefore, the ongoing operation of THAS12 is at risk. The financial and economic B/C ratio of IXAS10, THAS12, and CDAS800 were 1.87 and 1.04, 1.74 and 0.98, and 1.21 and 1.08, respectively. These results match the findings of Franco-Malvaíz *et al.* (2014), who reported a 1.85 financial B/C ratio, a very similar figure than the one obtained by IXAS10 and THAS12 (Table 3).

IXAS10 recovered its economic cost and obtained a 4% profit, CDAS800 obtained an 8% profit, and THAS12 did not recover its total costs and recorded a 2% economic loss. Although CDAS800 is economically viable, it could make a better use of its resources, because at the time it only operated at 10% of its capacity. Consequently, this situation has a negative impact on the unit production cost. CDAS800 has a semi-industrialized

**Table 3.** Competitiveness indicators of the URP.

| URP     | Viability |          | Benefit-Cost Ratio |          |
|---------|-----------|----------|--------------------|----------|
|         | Financial | Economic | Financial          | Economic |
| IXAS10  | Viable    | Viable   | 1.87               | 1.04     |
| THAS12  | Viable    | Unviable | 1.74               | 0.98     |
| CDAS800 | Viable    | Viable   | 1.21               | 1.08     |

Source: Table developed by the authors with information collected in the field.

production which results in a higher fixed assets investment that generates high economic costs, due to depreciation and opportunity costs resulting from the capital invested in machinery. These costs could be reduced adjusting the production infrastructure to the volume of the URP or increasing production.

Overall, other reports about the agave value chain reported a lower competitiveness in the production of AS. On the one hand, Fonseca-Varela and Chalita-Tovar (2022) found a 1.27 B/C ratio in mezcal production. On the other hand, Ávila-Lara *et al.* (2021) reported a 1.24 B/C ratio in the production of agave sap.

Taking into account the characteristics of the production of AS and the costs estimated in this study, the production of AS is a profitable activity for the three URP. However, the economic profitability indicator showed that THAS12 was inefficient and, consequently, its long-term permanence is not guaranteed. IXAS10 complemented its activities with the sale of other agave and local products, improving its profitability. Finally, CDAS800 can improve its economic benefits if it increases its production volume and its client portfolio.

## CONCLUSIONS

The production of AS is an important opportunity to diversify and increase the income of the agave primary production. In addition, it is attractive to investors interested in the elements of the production chain that follow the production of agave sap. The growth of the functional product markets drives the AS demand. The AS profitability can be optimized through three key strategies: improving technical efficiency, strengthening its marketing based on its beneficial properties, and forming strategic alliances with specialized shops and gourmet restaurants. These actions will not only increase the positive perception among consumers, but also will guarantee a more efficient and sustainable commercialization of AS.

## REFERENCES

- American Agricultural Economics Association Task Force. AAEA. (2000). Commodity Costs and Returns Estimation Handbook. A Report of the AAEA Task Force on Commodity and Returns February 1, 2000.
- Ávila-Lara, D. D., González-Montemayor, A. M., Espinoza-Arellano, J. J., Flores-Gallegos, A. C., & Rodríguez-Herrera, R. (2021). Rentabilidad de la producción de aguamiel en el sureste del estado de Coahuila, México: Un estudio de caso. *Investigación y Ciencia de la Universidad Autónoma de Aguascalientes*, 29(82), 61-71.
- Barrera-Perales, O. T., Sagarnaga-Villegas, L. M., Salas-González, J. M., Leos-Rodríguez, J. A., & Santos-Lavalle, R. (2018). Viabilidad económica y financiera de la ganadería caprina extensiva en San Luis Potosí, México. *Mundo Agrario*, 19(40), e077.

- Cechura, L., & Hockmann, H. (2014). Heterogeneity in technology and efficiency—specifics of the food processing industry in the Visegrád countries. International Congress, Ljubljana, Slovenia. DOI: 10.22004/ag.econ.182662
- Consejo Mexicano de Normas de Información Financiera. (2020). NIF B-10 Efectos de la Inflación. CINIF.
- Domínguez-García, I. A., Granados-Sánchez, M. D. R., Sagarnaga-Villegas, L. M., Salas-González, J. M., & Aguilar-Ávila, J. (2017). Viabilidad económica y financiera de nopal tuna (*Opuntia ficus-indica*) en Nopaltepec, Estado de México. *Revista mexicana de ciencias agrícolas*, 8(6), 1371-1382.
- Esquivel-Marín, N. H., Sagarnaga-Villegas, L. M., Barrera-Perales, O. T., Salas-González, J. M., & Burgos, A. L. (2022). Viabilidad económica y financiera de la cadena de valor flor de jamaica (*Hibiscus sabdariffa* L.). Estudio de caso: Cooperativas y Unión de productores de la Huacana, Michoacán. *Custos e Agronegocio*, 18(2), 22-43.
- Fonseca-Varela, M., & Chalita-Tovar, L. E. (2021). Evaluación financiera de producción de agave y mezcal: caso de estudio Caltepec, Puebla. *Revista mexicana de ciencias agrícolas*, 12(2), 263-273.
- Franco-Malvaíz, A. L., Bobadilla Soto, E. E., & Rebollar Rebollar, S. (2014). Viabilidad económica y financiera de una microempresa de miel de aguamiel en Michoacán, México. *Revista mexicana de agronegocios*, 35(2014), 957-968.
- Jiménez-Jiménez, R. A., Espinosa-Ortiz, V., & Soler-Fonseca, D. M. (2014). El costo de oportunidad de la mano de obra familiar en la economía de la producción lechera de Michoacán, México. *RIAA*, 5(1), 47-56.
- Jurek, J. (2022). Health Benefits of Functional Foods. *Journal of biomedical research & environmental sciences*, 3(11). DOI: 10.37871/jbres1598
- Kim, S. Y., Moon, D. H., & Kim, N. E. (2022). Factors Affecting the Profitability of Health Functional Foods Manufacturers. *Korean Journal of Agricultural Management and Policy*, 49(4) DOI: 10.30805/kjamp.2022.49.4.686
- Mellado-Mojica, E., & López-Pérez, M. G. (2013). Análisis comparativo entre jarabe de agave azul (*Agave tequilana* Weber var. azul) y otros jarabes naturales. *Agrociencia*, 47, 233-244.
- Ministerio de Agricultura. (2012). Canales Cortos de Comercialización en el Sector Agroalimentario.
- Narváez-Suárez, A.U., Jiménez-Velázquez, M.A., Martínez-Saldaña, T., Cruz-Galindo, B. (2016). Magüey pulquero (*Agave salmiana* Otto ex Salm-Dyck): opción para desarrollo rural. *Agro Productividad*, 9(10)
- Ozuna, C., & Franco-Robles, E. (2022). Agave syrup: An alternative to conventional sweeteners? A review of its current technological applications and health effects. *Lwt*, 162, 113434.
- Sagarnaga-Villegas, L. M., Salas-González, J. M. y Aguilar-Ávila, J. (2014). Ingresos y Costos de Producción 2013. Unidades Representativas de Producción. Trópico Húmedo 2013. Paneles de Productores. (CIESTAAM Centro de Investigaciones Económicas, Ed.) (Primera ed). México: Universidad Autónoma Chapingo/CIESTAAM.
- Saraiva, A., Carrascosa, C., Ramos, F., Raheem, D., & Raposo, A. (2022). Agave syrup: chemical analysis and nutritional profile, applications in the food industry and health impacts. *International Journal of Environmental Research and Public Health*, 19(12), 7022.
- United States Department of Agriculture (USDA). 2013. Commodity Costs and Returns [en línea] Disponible en: <http://www.ers.usda.gov/data-products/commodity-costs-and-returns> [fecha de consulta: enero 16 de 2024].
- Vázquez-García, A., Aliphat-Fernández, M. M., Estrella-Chulim, N. G., Ortiz-Torres, E., Ramírez-Juárez, J., & María Ramírez, A. (2016). El Magüey pulquero, una planta multifuncional y polifacética: Los usos desde una visión mestiza e indígena. *Scripta Ethnologica*, 38, 65-88.
- Yargatti, R., & Muley, A. (2022). Agave syrup as a replacement for sucrose: An exploratory review. *Functional Foods in Health and Disease*, 12(10), 590-600.



# Supplementation with coffee husk enhances lactational performance of piglets and IgG concentration in sow colostrum: A prepartum intervention

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## ABSTRACT

**Objective:** This study aimed to evaluate the effects of prepartum supplementation with coffee by-products specifically coffee husks on piglet performance, with a focus on weight gain and immunoglobulin G (IgG) concentrations in colostrum and milk.

**Design/methodology:** Coffee by-products were collected, dried, ground, and sieved, and caffeine content was quantified using high-performance liquid chromatography (HPLC). Between gestation days 110 and 112, 50 g of coffee husks mixed with feed were administered to the sows, delivering a total caffeine dose of 750 mg. Farrowing was induced on day 113 using cloprostenol. Piglets were weighed at birth and at weaning, and pre-weaning mortality was recorded. Additionally, colostrum and milk samples were analyzed for IgG concentrations using a Brix refractometer.

**Results:** While no significant differences were observed in birth weight, piglets from caffeine-supplemented sows exhibited significantly higher weaning weights and increased IgG concentrations in both colostrum and milk, indicating improved lactogenesis. Pre-weaning mortality was also markedly lower in the supplemented group (0.97%) compared to the control group (10.83%), suggesting enhanced neonatal vitality and reduced mortality risk. The incorporation of coffee by-products into animal diets offers potential sustainability and health benefits; however, possible anti-nutritional effects and regulatory challenges must be addressed for widespread application.

**Conclusions:** Prepartum supplementation of sows with coffee by-products enhances IgG levels in colostrum and milk, supporting the development of heavier piglets with reduced mortality. These outcomes contribute to improved productivity and profitability in small-scale swine production systems.

**Keywords:** Coffee husk, neonatal mortality, weaned piglets, caffeine.



## INTRODUCTION

Coffee is one of the most widely consumed commodities worldwide and ranks second only to petroleum in terms of raw material trade. Despite its global economic importance, coffee production generates over 23 million tons of by-products annually, primarily from the processing of coffee cherries into green coffee beans (Iriundo-DeHond *et al.*, 2020; Durán-Aranguren *et al.*, 2021; Lee *et al.*, 2023). These by-products including husks, pulp, parchment, mucilage, and silver skin are often discarded, contributing significantly to environmental waste. As approximately 90% of the coffee cherry becomes waste, this presents a critical environmental challenge and highlights the need for sustainable solutions, such as the valorization of these by-products through biotechnological applications (Iriundo-DeHond *et al.*, 2020; Klingel *et al.*, 2020; Bobková *et al.*, 2022). Coffee by-products are rich in bioactive compounds, including polyphenols, alkaloids, chlorogenic acid, antioxidants, carbohydrates, proteins, and dietary fiber. However, despite their high nutritional value, these compounds are often underutilized, exacerbating their environmental impact (Esquivel and Jiménez, 2012; Heeger *et al.*, 2016). In some cases, coffee by-products are repurposed as fertilizers or additives in animal feed. Nevertheless, their use as exclusive feed ingredients is limited due to the presence of anti-nutritional factors such as caffeine, tannins, and polyphenols which can reduce feed intake, impair nutrient absorption, and negatively affect weight gain in livestock species including tilapia, ruminants, and poultry (Durán-Aranguren *et al.*, 2021; Eckhardt *et al.*, 2022; Lee *et al.*, 2023). While the use of coffee by-products in monogastric animals, such as pigs, remains underexplored, existing research suggests caffeine may offer benefits in these species. Studies involving oral and injectable pharmaceutical-grade caffeine have shown its prophylactic and therapeutic potential in sows and their offspring. Doses ranging from 250 mg/sow/day to 6.4 g/sow have been administered without inducing nervous or behavioral disturbances, yielding improvements in thermoregulation, neonatal survival, lactation weight gain, gas exchange at birth, and overall weight gain during lactation especially in low-birth-weight piglets when combined with glucose (Superchi *et al.*, 2013; Dearlove *et al.*, 2018; Sanchez-Salcedo *et al.*, 2019; Jarrat *et al.*, 2023). Importantly, no adverse effects on maternal behavior were reported (Superchi *et al.*, 2016). The processing of 1 kg of coffee cherries produces approximately 430 g of by-products, which can contain between 3.4 and 18 mg of caffeine per gram. It is estimated that nearly 40% of the total caffeine is removed during processing and ends up in these by-products (Heeger *et al.*, 2016), making materials such as coffee husk a potentially sustainable source of caffeine.

Therefore, the aim of this study was to evaluate the effects of prepartum supplementation with coffee husk on piglet weight gain and immunoglobulin G (IgG) levels in colostrum and milk during parturition. We hypothesize that the caffeine present in coffee husk can enhance piglet health and performance, while also providing a sustainable strategy for repurposing waste from the coffee industry.

## MATERIALS AND METHODS

The experiment was conducted within a smallholder pig production system located in the central region of Veracruz, Mexico. A total of 223 piglets born to 20 multiparous sows

of hybrid Yorkshire-Landrace genetics (average weight:  $189.53 \pm 4.53$  kg; body condition score: 3; average previous litter size:  $13.5 \pm 1$  piglets) were included in the study. The sows were randomly assigned to two experimental groups: Control ( $n=11$ ) and Coffee Husk ( $n=9$ ). Group allocation was based on a prior statistical power analysis to ensure balanced baseline characteristics and sufficient sample sizes for detecting significant differences. All sows were multiparous (mean parity:  $2.66 \pm 0.12$ ). Individuals with compromised health or any condition likely to affect experimental outcomes were excluded. To minimize variability, 223 piglets were selected based on litter homogeneity within each group. Sows were housed individually in farrowing crates (1.5 m wide  $\times$  2.2 m long) beginning one week prior to the expected farrowing date. Environmental conditions were controlled, maintaining a temperature of  $27.8 \pm 0.46$  °C and relative humidity between 60-70%. Each farrowing crate was equipped with a piglet nest area containing an infrared heat lamp to ensure a postnatal temperature of 30 °C. All sows received a standard diet containing 13% crude protein, 3.2 Mcal ME/kg, and 18.6 g/day of lysine, with ad libitum access to water. Farrowing was induced in accordance with standard farm management practices, and all piglets were allowed immediate access to colostrum after birth. The experimental protocol was reviewed and approved by the Bioethics Committee of the Academic Program in Agricultural and Livestock Development at Universidad Veracruzana (approval code: MDA-BIO-002). All procedures were conducted in compliance with established national ethical guidelines.

### Sampling and analysis

**Coffee Husk Preparation:** The coffee husk used in this study was obtained via the wet processing method from a *Coffea robusta* plantation located in Cosautlán, Veracruz, Mexico ( $19^{\circ} 20' 00''$  N,  $96^{\circ} 59' 00''$  W). After collection, the husk was sun-dried for three days and subsequently oven-dried at 40 °C until a constant weight was achieved. The dried material was ground using an electric mill (Hamilton Beach model CM08) and sieved through a 500- $\mu$ m mesh. The processed husk was then vacuum-sealed and stored in biosafety chambers to prevent contamination.

**Reagents:** Analytical-grade reagents used included acetonitrile (HPLC grade, 99.9%), formic acid (HPLC grade, 98-100%), methanol (HPLC grade, 99.8%), and ethanol (99.5%, Tedia Brand, Control Técnico y Representaciones, S.A. de C.V., Monterrey, Nuevo León, Mexico). HPLC-grade water (18 m $\Omega$ ) was produced using a Milli-Q50 purification system (Millipore Corp., Bedford, MA, USA). Authentic standards of alkaloids and phenolic compounds commonly found in coffee and its by-products were purchased from Sigma-Aldrich, with the following purities: caffeine (99%), trigonelline (97.5-102.5%), theobromine (99%), theophylline (99%), chlorogenic acid (95%), neochlorogenic acid (>98%), 3,5-dicaffeoylquinic acid (95%), 3,4-di-O-caffeoylquinic acid (90%), protocatechuic acid (97%), and caffeic acid (98%).

**Extraction Conditions:** To determine the chemical composition of the coffee husk and quantify caffeine content, Soxhlet extraction was performed. A 12.5 g sample of coffee husk was refluxed with 250 mL of ethanol (solid/liquid ratio: 1:20) at its boiling point (78 °C) for 7 hours. Ethanol was selected as the solvent based on its proven effectiveness in

caffeine extraction over methylene chloride (Román-Montalvo *et al.*, 2024). The extraction process was carried out in triplicate. Resulting extracts were evaporated to dryness and analyzed via HPLC.

**HPLC-DAD Analysis:** The dried ethanolic extract was analyzed using a Varian ProStar 320 HPLC system (Polaris Series) equipped with a diode array detector (DAD) and a C18 HYPERSIL ODS column (125×4.6 mm, 5 μm particle size), maintained at 30 °C. The mobile phase consisted of solvent A (0.1% aqueous formic acid) and solvent B (acetonitrile), both filtered through a 0.45 μm membrane and sonicated for 10 minutes. A gradient elution program was employed: 5% B (0-2 min), 7% B (2-4 min), 10% B (4-8 min), 12% B (8-12 min), 13% B (12-16 min), 14% B (16-20 min), 16% B (20-22 min), 18% B (22-24 min), 22% B (24-26 min), 26% B (26-28 min), 28% B (28-30 min), 30% B (30-32 min), and 100% B (32-44 min), at a flow rate of 1.0 mL/min.

The alkaloids and phenolic compounds detection were performed at 280 and 340 nm. Metabolite identification was based on retention time and spectral comparison with authentic standards. Caffeine quantification was conducted using an external calibration curve, with results expressed in mg of caffeine per kg of dried coffee husk. The linearity of the method was assessed using the  $R^2$  coefficient, calculated by analyzing the relationship between caffeine concentration (0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09 and 0.10 mg/mL) and the corresponding peak area.

**Method Validation:** Linearity was assessed by plotting peak area against caffeine concentrations ranging from 0.01 to 0.10 mg/mL, and calculating the coefficient of determination ( $R^2$ ). Detection limit (DL) and quantification limit (QL) were established based on signal-to-noise ratios of 3 and 10, respectively, following Rada-Mendoza & Salazar S. (2011). Precision was determined by evaluating the repeatability of three area readings for a 0.05 mg/mL caffeine standard.

On the other hand, the accuracy was estimated in terms of the percentage of caffeine recovery (%R), similar to the method proposed by Tuesta-Hidalgo *et al.* (2024), but with some modifications. Briefly, 50 mg of caffeine standard (Caf) was added to 12.5 g of a coffee husk sample (fortified sample), which was then extracted using a Soxhlet, as described previously. The procedure was performed in duplicate. The result was calculated with the following equation:

$$\%R = \frac{\text{Quant. of Caf in the fortified sample} - \text{Natural Quant. of Caf}}{\text{Added amount of Caf}} \times 100$$

### Treatment administration

On day 110 of gestation (four days before the expected farrowing date on day 114), between 18:00 and 20:00 hours, 50 g of coffee husk mixed with the standard diet comprising broken yellow corn, sorghum, and commercial additives was offered to the sows for *ad libitum* consumption. This supplementation protocol was repeated on days 111 and 112, resulting in a total intake of 150 g of coffee husk and an estimated cumulative caffeine dose of 750 mg. On day 113, farrowing was induced at 9:00 a.m.

via intramuscular administration of 1 mL of cloprostenol (0.075 mg; InducelActive, Virbac, Mexico).

**Litter Weighing and Pre-Weaning Mortality:** All piglets were weighed immediately after birth and then returned to their respective pens. A second weighing was conducted at weaning, 21 days postpartum, using a mechanical floor scale. Pre-weaning mortality was calculated as the number of piglets that died before weaning divided by the number of live-born piglets, multiplied by 100 (Schodl *et al.*, 2019). After this, piglets were weaned, ear-tagged, and transferred to the weaning area, where they were grouped by weight following standard farm procedures.

**Colostrum and Milk Density Analysis:** Colostrum samples were collected manually approximately six hours after parturition from all teats in both the upper and lower rows of each sow. Samples were analyzed immediately using a Brix refractometer (Atago 3810 Pal-1, China), calibrated with distilled water before each set of measurements. A drop of colostrum was placed on the prism, and the Brix percentage was recorded to estimate IgG concentration, as described by Balzani *et al.* (2016). The same procedure was repeated for milk samples collected 24 hours postpartum.

### Statistical analysis

The analysis began with the sorting and classification of data obtained from the experimental procedures. Descriptive statistics and independent-sample t-tests were used to evaluate differences between groups, with birth weight, weaning weight, Brix percentage of colostrum and milk, and pre-weaning mortality serving as the dependent variables. A significance level of  $P \leq 0.05$  was established, and results were expressed as mean  $\pm$  standard error. Statistical analyses were conducted using the SigmaPlot 12 software package.

## RESULTS AND DISCUSSION

The use of coffee by-products as a food supplement for both human and animal consumption is not a novel concept. Initiatives in Europe and the Americas have been proposed to address the substantial volume of waste produced by the global coffee industry, which generates more than 23 million tons annually and is considered highly polluting (Eckhardt *et al.*, 2022). In this context and given the apparent lack of interest from major transnational corporations in effectively utilizing waste from coffee production systems (Rivera-Rojo, 2022) small-scale production systems present a viable alternative. To enhance their productivity and profitability, these systems must leverage accessible resources through a systems-based approach. Integrating surrounding agricultural activities can provide additional inputs or innovative methods to support farm operations (Ángel-Hernández *et al.*, 2021).

### Chemical coffee husk characterization

Six phenolic compounds and four alkaloids were identified in the chromatogram of the ethanolic extract of coffee husk: chlorogenic acid, neochlorogenic acid, 3,5-dicaffeoylquinic acid, 3,4-di-O-caffeoylquinic acid, caffeic acid, protocatechuic acid, theobromine, theophylline, trigonelline and caffeine. The calibration curve equation to

quantify caffeine was  $y=819052X-3778.4$  ( $R^2=0.9969$ ). DL and QL of the method were 0.011 and 0.038 mg/mL, respectively, whereas %R was  $91.18 \pm 3.37$  and precision was 2.08 %. The amount of caffeine found in the sample was  $4,962.67 \pm 816.52$  (mg of caffeine/Kg of dried coffee husk).

### Brix determination in colostrum and milk

All results for both experimental groups are presented in Table 1. Colostrum from sows supplemented with coffee husk showed significantly higher IgG concentrations, as estimated by Brix degrees, compared to the control group ( $t(18)=-2.258$ ,  $P=0.03$ ). This study revealed a slight but consistent increase of nearly 2.5 Brix degrees in the supplemented group, corresponding to approximately 2 to 3 mg/mL more IgG than in the colostrum of control sows. Given the moderate correlation between Brix degrees and IgG concentration ( $r=0.56$ ) as reported by Balzani (2016), Brix refractometry serves as an efficient and practical tool for on-farm estimation of immunoglobulin levels in colostrum. Similarly, milk samples collected 24 hours postpartum from supplemented sows also demonstrated significantly higher Brix values compared to the control group ( $t(18)=-2.929$ ,  $P=0.009$ ). The elevated IgG levels observed in both colostrum and milk from the supplemented group may be attributed to the biological effects of caffeine on mammary tissue.

Caffeine is known to promote mammary gland development by enhancing tissue sensitivity to mammatropic hormones and increasing intracellular cAMP levels, which in turn stimulates beneficial cellular activities. Additionally, caffeine inhibits phosphodiesterase, leading to cAMP accumulation in mammary epithelial cells, and influences pituitary hormone secretion by modulating neurotransmission (Li and Hacker, 1995). These mechanisms contribute to greater mammary gland development by stimulating expansion of the endoplasmic reticulum and growth of lobular structures, enabling enhanced fat globule accumulation and promoting lactogenesis (Segura *et al.*, 2020; Farmer *et al.*, 2006). Consequently, increased consumption of colostrum and milk combined with higher protein content in these secretions—is critical in the early life of piglets. It ensures greater intake of immunoglobulins, thereby enhancing passive immunity and reducing susceptibility to viral and bacterial infections (Superchi *et al.*, 2016).

### Lactational weight and preweaning mortality

Research has shown that caffeine is capable of crossing the placental barrier and can be detected in biological fluids such as colostrum and milk in pigs (Mazzoni *et al.*, 2012; Superchi *et al.*, 2013). In the present study, piglets born to sows supplemented with coffee husk alongside their regular diet showed no significant differences in birth weight compared to control piglets ( $t(221)=1.011$ ,  $P=0.31$ ;  $1.513 \pm 0.03$  kg *vs.*  $1.469 \pm 0.02$  kg,

**Table 1.** Brix degrees in colostrum and milk for both groups of sows.

| Density<br>(Brix degrees) | Colostrum (%)<br>6 h post-partum | Milk (%)<br>24 h post-partum | P-value |
|---------------------------|----------------------------------|------------------------------|---------|
| Control                   | $26.27 \pm 0.5$                  | $21.27 \pm 0.5$              | 0.030   |
| Coffee by-products        | $28.66 \pm 1.0$                  | $24.00 \pm 0.7$              | 0.009   |

for control and coffee husk groups, respectively). This outcome aligns with previous findings suggesting that caffeine administration during late gestation is safe, as the fetuses are already fully developed at that stage (Sánchez-Salcedo *et al.*, 2019; Superchi *et al.*, 2013).

However, at 21 days postpartum, piglets from the coffee husk-supplemented group exhibited significantly higher weaning weights ( $t(207) = -4.769$ ,  $P < 0.001$ ), averaging  $5.820 \pm 0.08$  kg compared to  $5.213 \pm 0.09$  kg in the control group. This outcome supports earlier research by Sánchez-Salcedo *et al.* (2019), who reported increased weaning weights in piglets following subcutaneous caffeine supplementation in sows during late gestation (Control:  $6.52 \pm 0.25$  kg *vs.* Caffeine:  $6.87 \pm 0.18$  kg,  $P < 0.05$ ). Conversely, Dearlove *et al.* (2018) found no significant effect on weaning weight with oral caffeine supplementation (6 g/day) starting on day 112 of gestation. The improved weight gain observed in this study likely results from caffeine's stimulatory effects, including enhanced colostrum and milk intake. Adequate colostrum consumption has been linked to increased daily weight gain during lactation and through weaning (Huting *et al.*, 2019; Quesnel and Farmer, 2019; Amatucci *et al.*, 2022). Caffeine is known to reduce lethargy by blocking adenosine receptors, thereby decreasing fatigue and increasing alertness. This heightened state of energy may encourage piglets to nurse more vigorously and frequently, promoting better nutrition (Dearlove *et al.*, 2018; Sanchez-Salcedo, 2019). Ensuring optimal development within the first 72 hours of life establishes a solid foundation for systematic feeding and adaptation, providing a developmental advantage over piglets not exposed to caffeine's stimulatory effects (Farmer *et al.*, 2006). Pre-weaning mortality is a key performance indicator in pig production systems, reflecting overall piglet and litter management, particularly in full-cycle farms. In this study, pre-weaning mortality was markedly lower in the caffeine-supplemented group (1 death; 0.97%) compared to the control group (13 deaths; 10.83%). Most piglet deaths were attributed to crushing by the sow. The significant reduction in mortality in the supplemented group is consistent with the positive effects of caffeine on neonatal vitality observed in previous studies (Dearlove *et al.*, 2018; Superchi *et al.*, 2016). Caffeine supplementation in sows, whether administered the day before induced farrowing (27 mg/kg) or for three days before natural farrowing (6 g/day), has been shown to reduce stillbirth rates and improve neonatal adaptation, including better thermoregulation, viability, and extended gestation by an average of 1.1 days (Dearlove *et al.*, 2015; Superchi *et al.*, 2013, 2016). In contrast, van Wettere *et al.* (2018) reported increased piglet mortality when sows received oral progesterone (0.4% w/v) and caffeine (2.4 g/kg feed) concurrently from days 111 to 113 of gestation. The authors suggested that the combined use of two uterine contractility inhibitors may have led to prolonged farrowing and increased mortality.

These findings support the hypothesis that improved nutrition and caffeine-induced stimulation enhance piglet reflexes and adaptive behavior, reducing risks such as asphyxia, dehydration, and crushing. Meanwhile, piglets from control sows may face early-life challenges linked to pain, stress, or inadequate care during and after farrowing, compromising their initial development and survival (Tummaruk and Kridtasak, 2012).

## CONCLUSIONS

This study demonstrates that supplementing pregnant sows with 150 g of coffee husk a natural source of caffeine —between days 110 and 112 of gestation effectively enhances piglet development without negatively impacting sow behavior or causing adverse outcomes such as abortion. The supplementation led to increased immunoglobulin G (IgG) concentrations in colostrum and milk, with levels 2 to 3 mg/mL higher than those observed in the control group. Additionally, piglets born to supplemented sows exhibited weight gains of up to 600 g more than those in the control group by weaning. Pre-weaning mortality at 21 days was also significantly reduced (0.97% in the coffee husk group *vs.* 10.83% in the control group).

These improvements in early piglet performance could enhance profitability in small-scale swine production systems and provide practical solutions to ongoing challenges in pig farming. However, to fully understand the role of caffeine administered through coffee husk, further pharmacokinetic and behavioral research is essential. Future studies should explore varying doses and administration durations to precisely determine the amount of caffeine transferred to piglets via colostrum and milk, as well as its potential effects on both sow and piglet physiology and development.

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## REFERENCES

- Amatucci, L., Luise, D., Correa, F., Bosi, P., & Trevisi, P. (2022). Importance of Breed, Parity and Sow Colostrum Components on Litter Performance and Health. *Animals*, *12*(10), 1230. <https://doi.org/10.3390/ani12101230>
- Angel-Hernández, A., García-Munguía, C. A., García- Munguía, A. M., Valencia-Posadas, M., Hernández Ruiz, J., & Velázquez-Madrado, P. A. (2022). Tipificación y caracterización del sistema de producción del cerdo criollo de la Región Centro, México. *Ecosistemas y Recursos Agropecuarios*, *8*(II). <https://doi.org/10.19136/era.a8n3.2777>
- Balzani, A., Cordell, H. J., & Edwards, S. A. (2016). Evaluation of an on-farm method to assess colostrum IgG content in sows. *Animal*, *10*(4), 643-648. <https://doi.org/10.1017/S1751731115002451>
- Bobková, A., Poláková, K., Demianová, A., Belej, L., Bobko, M., Jurčaga, L., Gálik, B., Novotná, I., Iriondo-DeHond, A., & Castillo, M. D. D. (2022). Comparative Analysis of Selected Chemical Parameters of *Coffea arabica*, from Cascara to Silverskin. *Foods*, *11*(8), 1082. <https://doi.org/10.3390/foods11081082>
- Dearlove, B. A., Kind, K. L., Gatford, K. L., & Van Wettere, W. H. E. J. (2018). Oral caffeine administered during late gestation increases gestation length and piglet temperature in naturally farrowing sows. *Animal Reproduction Science*, *198*, 160-166. <https://doi.org/10.1016/j.anireprosci.2018.09.015>
- Durán-Aranguren, D., Robledo, S., Gomez-Restrepo, E., Arboleda Valencia, J., & Tarazona, N. (2021). Scientometric Overview of Coffee By-Products and Their Applications. *Molecules*, *26*(24), 7605. <https://doi.org/10.3390/molecules26247605>
- Eckhardt, S., Franke, H., Schwarz, S., & Lachenmeier, D. W. (2022). Risk Assessment of Coffee Cherry (Cascara) Fruit Products for Flour Replacement and Other Alternative Food Uses. *Molecules*, *27*(23), 8435. <https://doi.org/10.3390/molecules27238435>
- Esquivel, P., & Jiménez, V. M. (2012). Functional properties of coffee and coffee by-products. *Food Research International*, *46*(2), 488-495. <https://doi.org/10.1016/j.foodres.2011.05.028>
- Farmer, C., Devillers, N., Rooke, J. N., & Dividich, J. L. (2006). Colostrum production in swine: From the mammary glands to the piglets. *CABI Reviews*. <https://doi.org/10.1079/PAVSNNR20061003>

- Heeger, A., Kosińska-Cagnazzo, A., Cantergiani, E., & Andlauer, W. (2017). Bioactives of coffee cherry pulp and its utilisation for production of Cascara beverage. *Food Chemistry*, 221, 969-975. <https://doi.org/10.1016/j.foodchem.2016.11.067>
- Huting, A. M. S., Sakkas, P., & Kyriazakis, I. (2019). Sows in mid parity are best foster mothers for the pre- and post-weaning performance of both light and heavy piglets1. *Journal of Animal Science*, 97(4), 1656-1670. <https://doi.org/10.1093/jas/skz062>
- Iriondo-DeHond, A., Iriondo-DeHond, M., & Del Castillo, M. D. (2020). Applications of Compounds from Coffee Processing By-Products. *Biomolecules*, 10(9), 1219. <https://doi.org/10.3390/biom10091219>
- Jarratt, L., James, S. E., Kirkwood, R. N., & Nowland, T. L. (2023). Effects of Caffeine and Glucose Supplementation at Birth on Piglet Pre-Weaning Growth, Thermoregulation, and Survival. *Animals*, 13(3), 435. <https://doi.org/10.3390/ani13030435>
- Klingel, T., Kremer, J. I., Gottstein, V., Rajcic De Rezende, T., Schwarz, S., & Lachenmeier, D. W. (2020). A Review of Coffee By-Products Including Leaf, Flower, Cherry, Husk, Silver Skin, and Spent Grounds as Novel Foods within the European Union. *Foods*, 9(5), 665. <https://doi.org/10.3390/foods9050665>
- Li, S., & Hacker, R. R. (1995). The effect of caffeine on mammary gland development and milk yield in primiparous sows. *Journal of Animal Science*, 73(2), 534-540. <https://doi.org/10.2527/1995.732534x>
- Lee, Y.-G., Cho, E.-J., Maskey, S., Nguyen, D.-T., & Bae, H.-J. (2023). Value-Added Products from Coffee Waste: A Review. *Molecules*, 28(8), 3562. <https://doi.org/10.3390/molecules28083562>
- Mazzoni, C., Sabbioni, A., Bertini, S., Menozzi, A., Piancastelli, C., Catelli, E., Zanardelli, P., Catelli, E., Zambini, E.M., Saleri R. & Superchi, P. (2012). Estudio preliminar de la utilización de la cafeína en las cerdas en el momento del parto. *Suís*, 90, 32-35.
- Quesnel, H., & Farmer, C. (2019). Review: Nutritional and endocrine control of colostrogenesis in swine. *Animal*, 13, s26-s34. <https://doi.org/10.1017/S1751731118003555>
- Rada-Mendoza, M. P., Salazar S, M.,(2011). La lactulosa, indicador de tratamiento térmico en leches enriquecida comerciales colombianas. *Biocología en el Sector Agropecuario y Agroindustrial*. 9(2) 74-84
- Rivera Rojo, C. R. (2022). Competitiveness of the Mexican coffee in international trade: A comparative analysis with Brazil, Colombia, and Peru (2000 -2019). *Análisis Económico*, 37(94), 181-199. <https://doi.org/10.24275/uam/azc/dcsh/ae/2022v37n94/Rivera>
- Román-Montalvo, D., Sánchez, A., Lorenzana-Licea, E., Domínguez, Z., Matus, M.H. (2024). Extraction of caffeine from coffee husk employing choline-based ionic liquids: Optimization of the process and theoretical study on solute-salts interactions. *Journal of Molecular Liquids*, 398, 124286. <https://doi.org/10.1016/j.molliq.2024.124286>
- Sánchez-Salcedo, J. A., Orozco-Gregorio, H., González-Lozano, M., Roldán-Santiago, P., González-Hernández, M., Ballesteros-Rodea, G., & Bonilla-Jaime, H. (2019). Caffeine administered to pregnant sows improves piglet vitality, gas exchange and body weight gain. *Animal Reproduction Science*, 208, 106120. <https://doi.org/10.1016/j.anireprosci.2019.106120>
- Schodl, K., Revermann, R., Winckler, C., Fuerst-Waltl, B., Leeb, C., Willam, A., Knapp, P., & Pfeiffer, C. (2019). Assessment of Piglet Vitality by Farmers—Validation of A Scoring Scheme and Estimation of Associated Genetic Parameters. *Animals*, 9(6), 317. <https://doi.org/10.3390/ani9060317>
- Segura, M., Martínez-Miró, S., López, M. J., Madrid, J., & Hernández, F. (2020). Effect of Parity on Reproductive Performance and Composition of Sow Colostrum during First 24 h Postpartum. *Animals*, 10(10), 1853. <https://doi.org/10.3390/ani10101853>
- Superchi, P., Mazzoni, C., Zanardelli, P., Piancastelli, C., Zambini, E. M., Beretti, V., & Sabbioni, A. (2013). Effects of oral caffeine administration to sows with induced parturition on hypoxia in piglets. *Livestock Science*, 157(1), 372-377. <https://doi.org/10.1016/j.livsci.2013.08.003>
- Superchi, P., Saleri, R., Farina, E., Cavalli, V., Riccardi, E., & Sabbioni, A. (2016). Effects of oral administration of caffeine on some physiological parameters and maternal behaviour of sows at farrowing. *Research in Veterinary Science*, 105, 121-123. <https://doi.org/10.1016/j.rvsc.2016.01.023>
- Tuesta-Hidalgo, O. A., Tuesta-Hidalgo, J. C., Morante-Alanya, G., Fermin-Vega, B. J., Rodríguez-Hamamura, N., Nureña-Hidalgo, M. A. & Barbachan-Ruales, E. A. (2024). Validación de una metodología de cuantificación de cafeína por cromatografía líquida (UHPLC/DAD). *Revista Peruana de Investigación Agropecuaria*, 3(1), e56. <https://doi.org/10.56926/repia.v3i1.56>
- Tummaruk, P., & Sang-Gassanee, K. (2013). Effect of farrowing duration, parity number and the type of anti-inflammatory drug on postparturient disorders in sows: A clinical study. *Tropical Animal Health and Production*, 45(4), 1071-1077. <https://doi.org/10.1007/s11250-012-0315-x>
- van Wettere, W.H.E.J., Toplis, P. & Miller, H.M. (2018). Effect of oral progesterone and caffeine at the end of gestation on farrowing duration and piglet growth and survival. *Animal*, 12(8): 1638-1641. <https://doi.org/10.1017/S175173111700310X>



# Influence of endogenous heat load or cooling on thermoregulation plasticity of hair sheep and meat goats at extreme heat

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## ABSTRACT

**Objective:** To compare the influence of endogenous heat load or cooling on thermoregulation plasticity between hair sheep and meat goats at extreme heat.

**Design/methodology/approach:** Mature ewes and does of contrasting coat color were subject to endogenous heat load from animal activity, heat increment from feeding, and heat dissipation by shower to compare the changes on their core body temperature as a proxy of thermoregulation plasticity at extreme heat.

**Results:** Endogenous heat load from activity increased core body temperature in both treatment groups similarly, however, ewes showed slower heat dissipation response which extended cooling phase time. The heat increment of feeding affected core body temperature greater in ewes than in does within the first postprandial hour with no difference on heat dissipation response thereafter. Cooling by shower increased heat load dissipation and reduced core body temperature similarly in both groups of animals, however, wetting does triggered an increase in the behavior of basking in the sun.

**Limitations on study/implications:** Does lost endogenous heat load from activity faster and had a lower heat increment due to feeding than ewes. Cooling by shower helped keep ewes' core body temperature lower longer than in does who looked for sunshine to rewarm themselves.

**Findings/conclusions:** Meat goat slightly overperformed to hair sheep on thermoregulation plasticity when challenged with endogenous heat load at extreme heat. Cooling by shower improved the thermal comfort of hair sheep at extreme heat but limited benefits were observed in meat goats. The red coat color did not increase thermal heat gain in meat goats.

**Keywords:** Hair sheep; Meat goats; Extreme heat; Thermoregulation.

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## INTRODUCTION

A recent rise in average ambient temperature was greater for the northern extratropics (90 N-23.6 N) and tropics (23.6 N-23.6 S) than southern extratropics, leading to the highest



ambient temperature on record in the northern hemisphere (NASA, 2024). These record-breaking temperatures threaten livestock performance and the lives of people living in those regions (Sejian *et al.*, 2018). Most sheep and goat dwell in tropical and subtropical regions with the highest density in the Sub-Saharan region and India (FAO, 2022) where they rely on rangeland for feed. In doing so, they face scorching temperatures (Sejian *et al.*, 2018). Animal activity and feeding induces endogenous heat load on top of the impact of solar radiation, which oftentimes surpasses animals' heat dissipation capacity (Mitchell *et al.*, 2018). The core body temperature ( $T_c$ ) or body's inner tissue mean temperature is commonplace represented by rectal temperature (IUPS Thermal Commission, 2001), which reflects the balance between heat gain and loss (NRC, 1971; Gupta & Mondal, 2021). Small ruminants may be more tolerant to extreme heat compared to other livestock (Joy *et al.*, 2020) apart from camel. Research has demonstrated that hair sheep and goats are the most heat resistant among sheep (Mcmanus *et al.*, 2020; Dearborn *et al.*, 2023) and livestock (Gaughan *et al.*, 2019; Nair *et al.*, 2021), respectively. Thermotolerance is dependent on many factors, with pervasive misconceptions persisting, such as linking coat color to thermoregulation (Mcmanus *et al.*, 2020) which remains elusive to explain (Stuart-Fox *et al.*, 2017). We hypothesize that meat goats have greater thermoregulation plasticity at extreme heat compared to hair sheep. The objective was to compare the influence of endogenous heat load from activity, feeding, and cooling on core body temperature of hair sheep and meat goats at extreme heat.

## MATERIALS AND METHODS

A set of trials were performed under climatic conditions during summer months at two locations: The Sheep Research Unit at Instituto de Ciencias Agrícolas at Universidad Autónoma de Baja de California and at a goat production unit "Los Pequeños Agricultores" located 1.5 km apart from one another. The locations were within the Sonoran Desert characterized for extreme heat waves during summer months. Four adult ewes ( $46.3 \pm 8.0$  kg; Dorper  $\times$  Pelibuey  $\times$  Katahdin; solid-white coat color; *Ovis aries* L.) and four does ( $45.8 \pm 7.5$  kg; Kalahari red; red coat color; *Capra hircus* L.) in non-pregnant and non-lactating stage were used to evaluate the influence of endogenous heat load or cooling on thermoregulation plasticity at extreme heat. Ewes and goats were group-housed in  $10 \text{ m} \times 5 \text{ m}$  open-lot pens with  $14 \text{ m}^2$  of shade. Ewes and does were fed 1.2 kg of low-quality 50:50 alfalfa-grass hay mixture 50:50 in the morning (0940 h) and evening (1930 h). The animals had free access to drinking water. The three treatments were endogenous heat load from activity (EHA), heat increment from feeding (HIF), and cooling by shower (CSH). EHA was generated by pushing ewes and does around for 5 min at regular walking pace. HIF was induced by supplementing 0.30 kg of concentrated feed (0.7% of shrunk BW) per animal per day; concentrated feed consisted of steam flaked corn, distillers grain with solubles, alfalfa and sudangrass hay, molasses, tallow, urea and minerals. CSH was done by soaking animals with running water during 5 min. All treatment effects were evaluated at the hottest part of the day (1555 h; solar radiation  $>850 \text{ W/m}^2$ ;  $>40.0 \text{ }^\circ\text{C}$ ) for three consecutive days. The ambient temperature and relative humidity were recorded throughout the entire experimental period at 10-min interval using a wireless environmental data logger (Kestrel

Drop D2, Kestrel Instruments, Miami, FL). The temperature-humidity index (THI) was calculated by the formula

$$THI = ((1.8 * T) + 32) - [(0.55 - 0.0055 * RH) * (1.8 * T) - 2.8]$$

where  $T$ =temperature, °C and  $RH$ =relative humidity (NRC, 1971).

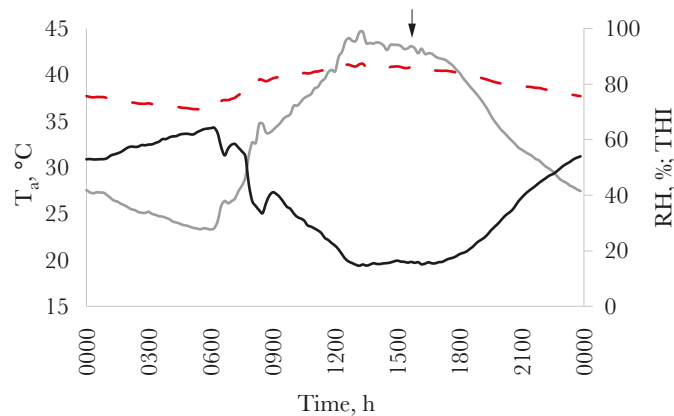
Vaginal temperature was recorded at 10-min interval with the help of a temperature data logger (Thermotracker BT; iButtonLink LLC, Whitewater, WI) fixed onto a washed (hormone-depleted) controlled internal drug releasing device (CIDR 330 sheep & goat insert, Zoetis). The CIDR was aseptically inserted five days before the beginning of the trials. Inspections for vaginal irritation, vaginal discharge, or displaced devices were conducted daily. The trial was analyzed as a generalized randomized block design using linear mixed model for analysis of repeated measures (SAS Inst. Inc., Cary, NC; Version 9.1). Covariance structure (selected for minimum AIC, AICC and BIC) was unstructured. Differences of least square means were compared by Tukey test.

## RESULTS AND DISCUSSION

### Ambient conditions

The magnitude of thermal stress on homeotherms depends on humidity and ambient temperature ( $T_a$ ) which could be estimated by the temperature-humidity index (THI; NRC, 1971). The  $T_a$  and THI during trials are shown in Figure 1. Treatments were applied in the afternoon where  $T_a$  and ground radiation remained high such that for an animal in the sun on a typical summer day receives 662 kcal/m<sup>2</sup>h (NRC, 1971).

The average THI values preceding animal activity, feed supplementation and cooling were 86.13, 84.84 and 87.77, respectively, which all were over the threshold at which small ruminants suffer hyperthermia (THI>84.4; Srivastava *et al.*, 2021). Animal adaptation to extreme heat (EH) involves physiological fluctuations within the body that have trade-offs such as poor productive and reproductive performance and health. All animals originated



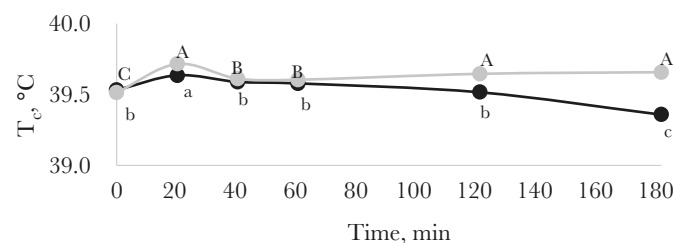
**Figure 1.** Daily ambient conditions during trials;  $T_a$ =Ambient Temperature;  $RH$ =Relative Humidity;  $THI$ =Temperature Humidity Index; arrow indicates treatments application time. Gray, dark, and dashed line indicate  $T_a$ ,  $RH$ , and  $THI$ , respectively.

from local herds already were acclimated as demonstrated by goats which were mated and succeed reproductively.

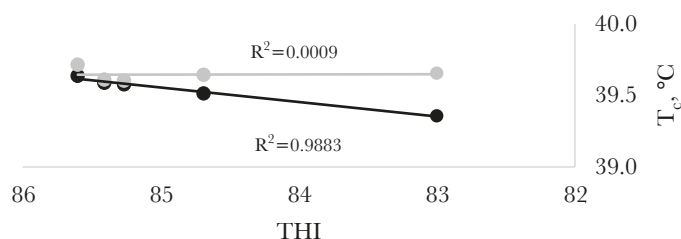
### Influence of endogenous heat load from activity on thermoregulation

The influence of endogenous heat load from activity (EHA) on core body temperature ( $T_c$ ) in ewes and does is shown in Figure 2. There was an interaction between animal group and time for  $T_c$  ( $P < 0.01$ ). Heat-acclimated ewes and does did not have different ( $P > 0.10$ )  $T_c$  (39.53 vs. 39.51°C) at extreme heat (EH; THI=86.13) during pretreatment even though the THI was above the threshold (84.40) at which small ruminants suffer hyperthermia (Srivastava *et al.*, 2021). Similar results were reported from hair sheep adapted to EH (Pulido-Rodríguez *et al.*, 2021). The activity increased  $T_c$  numerically, though not statistically ( $P > 0.10$ ) between both groups of animals at 20-, 40-, 60- or 120-min following treatment. However, there was a  $T_c$  reduction ( $P < 0.01$ ) in does (-0.3 °C) at 180-min after treatment.  $T_c$  in both groups of animals peaked ( $P < 0.01$ ) at 20-min following treatment.

However, at 40-min post-treatment, does showed better heat dissipation capacity than ewes, whose  $T_c$  slightly increased for the remainder of the 180-min post-treatment period. A simple linear regression of THI and  $T_c$  of ewes and does from peak  $T_c$  onwards are shown in Figure 3. This model explains ( $P < 0.001$ ) most variation ( $R^2 = 0.99$ ) of  $T_c$  in goats but not in ewes ( $P > 0.10$ ) whose  $T_c$  did change ( $R^2 = 0.001$ ) as ambient thermal load went down and where does were able to shed heat. Controlling  $T_c$  in a narrower range and timeframe in does could be an indicative of greater thermoregulation plasticity which is an advantage when grazing at EH (Nair *et al.*, 2021). EHA added on top of high ambient heat load caused heterothermy, or larger amplitude of  $T_c$  rhythm, in ewes, which is another response of heat-acclimated mammals to save water at EH (Hemet *et al.*, 2010), a condition called “adaptive heterothermy” (Schmidt-Nielsen *et al.*, 1957).



**Figure 2.** Performance of  $T_c$  following activity in small ruminants as a function of time; gray light and dark line indicate  $T_c$  in ewes and does, respectively.



**Figure 3.** Performance of  $T_c$  in small ruminants at cooling phase as a function of THI; gray light and dark line indicate ewes and does  $T_c$ , respectively.

It is likely that the animals used here were already heat-acclimated, similar to reports of wool sheep kept into climatic chambers (THI=82 for 49 d) not having different  $T_c$  compared to sheep in the control group (Bernabucci *et al.*, 2009). Sun-resistant animals express different ways to cope with EH, which would be worth further exploration.

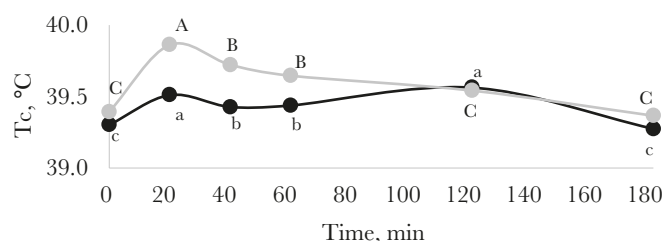
### Influence of heat increment of feeding on thermoregulation

The influence of treatment effects on  $T_c$  in ewes and does at EH is shown in Figure 4. Environmental conditions were harsh (THI=84.84) for the animals at treatment time. There was an interaction between animal group and time ( $P<0.0001$ ) following treatments. Concentrate supplementation at 0.7% of shrunk BW increased ( $P<0.05$ )  $T_c$  at 20-, 40-, and 60-min following treatment. This heat increment of feeding (HIF) comes from rumen fermentation, digestive process and nutrient metabolism (NRC, 1981). During the 20-, 40-, and 60-minutes following concentrate consumption, ewes demonstrated greater  $T_c$  than does, however there was no difference ( $P>0.10$ ) after 60-minutes.

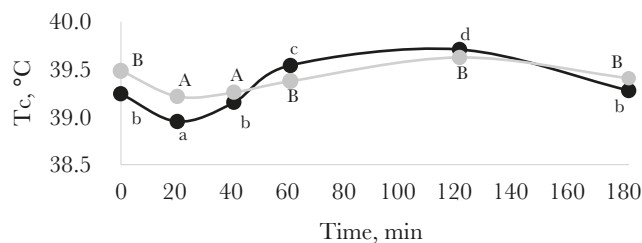
The basis of this is not known, but it could be ascribed to differences in rumen fermentation patterns between sheep and goats. The end-product of organic matter fermentation in the rumen are volatile fatty acids (VFA), predominantly acetic, propionic and butyric acid (Dijkstra, 1994). Rumen fermentation in sheep generates around 85% acetic acid compared to about 75% in goats (Craine and Hansen, 1952). Acetic acid itself generates greater heat loss which was estimated to be around 60% compared to just 16% for all VFA combined, approximately. The theoretical greater acetic acid production during rumen fermentation in sheep (Armstrong and Blaxter, 1956) and its greater heat loss may be the cause of larger amplitude of postprandial  $T_c$  rhythm in sheep. Consistently, does showed narrowed amplitude of postprandial  $T_c$  rhythm which could be an advantage while foraging at EH.

### Effect of cooling by shower on thermoregulation

Evaporative cooling systems are an effective method to mitigate heat load in livestock in hot/dry environments (Chen *et al.*, 2016). The current trial was conducted at the greatest temperature and THI (THI=87.77) among thermoregulation trials where non-sun resistant goats are at danger of hyperthermia (Srivastava *et al.*, 2021). The influence of cooling on  $T_c$  in ewes and does at extreme heat are shown in Figure 5. Before treatment with water ewes had greater  $T_c$  ( $P=0.006$  compared to does (39.49 vs. 39.25 °C, respectively) at EH. Interestingly, the difference on thermoregulation



**Figure 4.** Postprandial  $T_c$  in small ruminants as a function of time; gray light and black line indicate  $T_c$  in ewes and does, respectively.



**Figure 5.**  $T_c$  in cooled small ruminants as a function of time; gray light and black line depict  $T_c$  in ewes and does, respectively.

plasticity at such EH conditions did not prevent the heat-acclimated animals in the study from maintaining their  $T_c$  within the range observed at thermoneutral conditions (Bernabucci *et al.*, 2009; Mcmanus *et al.*, 2020). Even though providing shade reduces solar radiation it does not eliminate the large heat load ( $\text{THI} > 87.00$ ) caused by reflected solar radiation (Mitchell *et al.*, 2018), which was a heavier burden for ewes' heat dissipation mechanisms.

Showering the animals with water reduced  $T_c$  in both groups of animals similarly (Chen *et al.*, 2016) right after cooling. However, the reduction (0.25 °C) of  $T_c$  in wetted does triggered the behavioral change of basking in the sun, a passive rewarming ectothermic strategy in many species to reduce the need of endogenous heat production (Signer *et al.*, 2011; Stachowicz *et al.*, 2019). Basking in the sun at such high solar radiation rapidly increased thermal head load (Mitchell *et al.*, 2018) which surpassed pre-treatment  $T_c$  at 40-min post-treatment. The increase in  $T_c$  from basking plateaued 60-min post-treatment. Does basked in the sun until  $T_c$  reached 39.71 °C, at which point they ceased the behavior. This could be an indication of greater thermoregulation plasticity. The basis of this is not certain, however the behavioral change adopted by does might indicate a preference to stay dry and reduce their internal heat load using other mechanisms (Stachowicz *et al.*, 2019). Conversely, ewes treated with a shower of water remained cooler for 40 min post-treatment, rewarmed slowly, and reached pre-treatment  $T_c$  at 60-min following the treatment. This timeframe could be used as a reference for a programmed cycle cooling in sheep (Chen *et al.*, 2016). However, showering does with water at EH does not have a positive impact as it triggers behaviors that counter any cooling benefits.

### **The controversial view of coat color on thermoregulation in livestock**

A fraction of inflow heat comes from solar radiation within the visible reflectance wavelength, while half comes from outside the visible reflectance wavelength. Solar radiation from the visible reflectance wavelength is depending on coat color (COC; Dawson *et al.*, 2014). Dark COC Santa Ines sheep showed similar thermoregulation characteristics than their crosses with whiter COC at EH (Pulido-Rodríguez *et al.*, 2021), in which other heat exchange channels such as dry heat exchange and evaporative heat transfer played a bigger role (Mitchell *et al.*, 2018). The Kalahari red goat which has a fully pigmented skin and red coat color and is considered sun resistant (OSU, 2024), contradicts the misconception that lighter COC results in improved thermoregulation (Stuart-Fox *et al.*, 2017). When

Kalahari red goats experience increased extreme heat, their coats get thinner and darker red, not lighter.

## CONCLUSIONS

Fully pigmented skin red coat color meat goats had improved thermoregulation at EH when challenged by endogenous heat load compared to solid-white coat hair sheep. Cooling hair sheep by showering with water reduced  $T_{c}$ , however showering did not benefit goats long term. Skin and coat color play a minor role compared to other physiological and behavioral mechanism to cope with heat load. Small ruminant breeds and biotypes resilient to extreme heat are more likely to provide a much-needed animal food-source for human nutrition under limited environmental accommodations.

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## REFERENCES

- NASA. (2024). National Aeronautics and Space Administration. GISS surface temperature analysis (v4). Goddard Institute for space studies. Washington, DC, US. Available at: [https://data.giss.nasa.gov/gistemp/graphs\\_v4/](https://data.giss.nasa.gov/gistemp/graphs_v4/).
- Sejian, V., Bhatta, R., Gaughan, J. B., Dunshea, F. R., & Lacetera, N. (2018). Review: Adaptation of animals to heat stress. *Animal*, 12(s2), S431–S444. <https://doi.org/10.1017/S1751731118001945>
- FAO. 2022. Goats 2020 in Gridded livestock of the world. Available at: [https://data.apps.fao.org/catalog/dataset/cfaa6aab-a8d0-41b9-a4a9-dd2da7449599/resource/5bac1cf8-b968-48c2-8dc1-a2f89d4db020/download/2\\_Gt\\_2020\\_Da.png](https://data.apps.fao.org/catalog/dataset/cfaa6aab-a8d0-41b9-a4a9-dd2da7449599/resource/5bac1cf8-b968-48c2-8dc1-a2f89d4db020/download/2_Gt_2020_Da.png).
- Mitchell, D., Snelling, E. P., Hetem, R. S., Maloney, S. K., Strauss, W. M., & Fuller, A. (2018). Revisiting concepts of thermal physiology: Predicting responses of mammals to climate change. *Journal of Animal Ecology*, 87(4), 956–973. <https://doi.org/10.1111/1365-2656.12818>
- UPS Thermal Commission. (2001) Glossary of terms for thermal physiology. Third ed. Revised by The Commission for Thermal Physiology of the International Union of Physiological Sciences. *The Japanese Journal of Physiology*. 51, 245-280.
- NRC. 1971. A guide to environmental research on animals. National Academy of Sciences, Washington, DC
- Gupta, M., & Mondal, T. (2021). Heat stress and thermoregulatory responses of goats: a review. *Biological Rhythm Research*, 52(3), 407-433. <https://doi.org/10.1080/09291016.2019.1603692>
- Joy, A., Dunshea, F. R., Leury, B. J., Clarke, I. J., Digiacomio, K., & Chauhan, S. S. (2020). Resilience of small ruminants to climate change and increased environmental temperature: A review. *Animals*, 10(5). <https://doi.org/10.3390/ani10050867>
- McManus, C. M., Faria, D. A., Lucci, C. M., Louvandini, H., Pereira, S. A., & Paiva, S. R. (2020). Heat stress effects on sheep: Are hair sheep more heat resistant? *Theriogenology*, 155, 157-167. <https://doi.org/10.1016/j.theriogenology.2020.05.047>
- Dearborn, L., Abdul-Rahmaan, B., Pesato, M., Memili, E., & Rios, L. (2023). Hair sheep in the Americas: economic traits and sustainable production. *Frontiers in Animal Science*, 4(December), 1-9. <https://doi.org/10.3389/fanim.2023.1195680>
- Gaughan, J., Sejian, V., Mader, T. L., & Dunshea, F. R. (2019). Adaptation strategies: ruminants. *Animal Frontiers*, 4(1), 47-53. <https://doi.org/10.1093/af/vfy029>
- Nair, M. R. R., Sejian, V., Silpa, M. V., Fonsêca, V. F. C., de Melo Costa, C. C., Devaraj, C., Krishnan, G., Bagath, M., Nameer, P. O., & Bhatta, R. (2021). Goat as the ideal climate-resilient animal model in tropical environment: revisiting advantages over other livestock species. *International Journal of Biometeorology*, 65(12), 2229-2240. <https://doi.org/10.1007/s00484-021-02179-w>
- Stuart-Fox, D., Newton, E., & Clusella-Trullas, S. (2017). Thermal consequences of colour and near-infrared reflectance. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 372(1724). <https://doi.org/10.1098/rstb.2016.0345>

- Srivastava, A., Yadav, P., Mahajan, A., Anand, M., Yadav, S., Madan, A. K., & Yadav, B. (2021). Appropriate THI model and its threshold for goats in semi-arid regions of India. *Journal of Thermal Biology*, 96(January), 102845. <https://doi.org/10.1016/j.jtherbio.2021.102845>
- Pulido-Rodríguez, L. F., Titto, C. G., Bruni, G. de A., Froge, G. A., Fuloni, M. F., Payan-Carrera, R., Henrique, F. L., Geraldo, A. C. A. P. de M., & Pereira, A. M. F. (2021). Effect of solar radiation on thermoregulatory responses of Santa Inês sheep and their crosses with wool and hair Dorper sheep. *Small Ruminant Research*, 202(June). <https://doi.org/10.1016/j.smallrumres.2021.106470>
- Hetem, R. S., Strauss, W. M., Fick, L. G., Maloney, S. K., Meyer, L. C. R., Shobrak, M., Fuller, A., & Mitchell, D. (2010). Variation in the daily rhythm of body temperature of free-living Arabian oryx (*Oryx leucoryx*): Does water limitation drive heterothermy? *Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology*, 180(7), 1111–1119. <https://doi.org/10.1007/s00360-010-0480-z>
- Schmidt-Nielsen, K., Schmidt-Nielsen, B., Jarnum, S. A., & Houpt, T. R. (1957). Body temperature of the camel and its relation to water economy. *The American Journal of Physiology*, 188(1), 103-112. <https://doi.org/10.1152/ajplegacy.1956.188.1.103>
- Bernabucci, U., Lacetera, N., Danieli, P. P., Bani, P., Nardone, A., & Ronchi, B. (2009). Influence of different periods of exposure to hot environment on rumen function and diet digestibility in sheep. *International Journal of Biometeorology*, 53(5), 387-395. <https://doi.org/10.1007/s00484-009-0223-6>
- NRC. (1981). Nutritional energetics of domestic animals and glossary of energy terms. Washington, DC. The National Academies Press. <https://doi.org/10.17226/1670>
- Dijkstra, J. (1994). Production and absorption of volatile fatty acids in the rumen. *Livestock Production Science*, 39(1), 61-69. [https://doi.org/10.1016/0301-6226\(94\)90154-6](https://doi.org/10.1016/0301-6226(94)90154-6)
- Craine, E. M., & Hansen, R. G. (1952). The short-chain fatty acids of the peripheral blood of goats. *Journal of Dairy Science*, 35(7), 631-636. [https://doi.org/10.3168/jds.S0022-0302\(52\)93748-X](https://doi.org/10.3168/jds.S0022-0302(52)93748-X)
- Armstrong, D. G. & Blaxter, R. L. (1956). Heat increment of feeding in ruminants. *Nature*, 177, 1183-1184.
- Chen, J. M., Schütz, K. E., & Tucker, C. B. (2016). Cooling cows efficiently with water spray: Behavioral, physiological, and production responses to sprinklers at the feed bunk. *Journal of Dairy Science*, 99(6), 4607-4618. <https://doi.org/10.3168/jds.2015-10714>
- Signer, C., Ruf, T., & Arnold, W. (2011). Hypometabolism and basking: The strategies of Alpine ibex to endure harsh over-wintering conditions. *Functional Ecology*, 25(3), 537-547. <https://doi.org/10.1111/j.1365-2435.2010.01806.x>
- Stachowicz, J., Lanter, A., Gygax, L., Hillmann, E., Wechsler, B., & Keil, N. M. (2019). Under temperate weather conditions, dairy goats use an outdoor run more with increasing warmth and avoid light wind or rain. *Journal of Dairy Science*, 102(2), 1508-1521. <https://doi.org/10.3168/jds.2018-14636>
- Dawson, T. J., Webster, K. N., & Maloney, S. K. (2014). The fur of mammals in exposed environments; do crypsis and thermal needs necessarily conflict? The polar bear and marsupial koala compared. *Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology*, 184(2), 273–284. <https://doi.org/10.1007/s00360-013-0794-8>
- OSU (2024). Oklahoma state university. Breed of Goats - Breeds of livestock. (Breeds of Livestock, Department of Animal Science). Available at: <https://breeds.okstate.edu/goats/kalahari-red-goats.html>

# Diversity of terrestrial mammals visiting artificial water sources at the Technological University of Calakmul, Campeche, México

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## ABSTRACT

**Objective:** To evaluate the diversity of terrestrial mammals visiting artificial drinking troughs in the conservation zone of the Technological University of Calakmul, as well as their conservation status, activity patterns and behavior at these sites.

**Methodology:** Four artificial water sources were installed in strategic locations, each equipped with a camera trap station to record the species using the water sources and document their behavior in five categories: passing through, feeding, foraging, hydration, and temperature regulation. The data were analyzed using accumulation curves and ecological interaction networks.

**Results:** Twelve species were recorded, highlighting the use of water as a fundamental resource, especially during dry periods. Among the observed species, the jaguar and puma stood out as key predators in the ecosystem.

**Limitations:** This study was limited to a small conservation area within UTC and would benefit from greater sampling coverage.

**Conclusions:** Artificial water sources are an effective strategy for maintaining the availability of water during critical periods and provide important interaction points for wildlife. The data obtained in this study suggest that university conservation areas are crucial for protecting biodiversity and the academic training of students.

**Key words:** conservation, activity patterns, monitoring

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## INTRODUCTION

Green areas and peri-urban forests are essential for the sustainability of cities, due to the various environmental benefits they provide such as noise mitigation, air purification, water infiltration, soil erosion reduction, and helping regulate the microclimate (Al-paidze and Salukvadze, 2023). These areas are of utmost importance for biodiversity, as they offer habitats and resources for the subsistence of native species (Verdú-Vázquez *et al.*, 2021).



Universities have green areas that in most cases accurately represent the local biodiversity. These areas function as conservation sites that host a high diversity of wildlife and in recent years have gained increased relevance as they serve as ideal laboratories to study the effects of urbanization on biodiversity (MacGregor-Fors, 2005; Lin *et al.*, 2020). Authors such as Faggi and Perepelizin (2006) state that species richness is lower in urban areas than in suburban peripheries. Therefore, these spaces can be reservoirs of unexplored biodiversity in different institutions and their green areas or peri-urban ecosystems.

Water is essential for all living organisms and its availability can influence the spatial distribution of wildlife to varying degrees (Paredes *et al.*, 2017). Climate change has become a topic of great importance in research, encompassing predictable climate fluctuations, impacts and adaptive or resilience responses observed in diverse ecosystems and human communities in Calakmul (Revollo and Ríos, 2023).

The implementation of artificial water sources in strategic locations is a positive measure to mitigate human-wildlife conflicts and can serve as an accessible alternative for animals in need of hydration (Contreras-Moreno *et al.*, 2024a,b). These water sources play a crucial role in mitigating the effects of drought on wildlife.

In the Calakmul Region, water is a major concern during the dry season, and the implementation of artificial drinking stations for wildlife is a common management practice (Contreras-Moreno *et al.*, 2024b). Therefore, these drinking stations may have a positive impact on the conservation of certain species; however, it is crucial to consider how their presence might influence the overall ecosystem and the diversity of species present (Hernández-Gómez *et al.*, 2020). Therefore, the objective of this study was to assess the diversity and conservation status of terrestrial mammals visiting the artificial drinking stations in two different vegetation types within the forest area of the Universidad Tecnológica de Calakmul (UTC).

Since the green areas of UTC are adjacent to the Voluntarily Designated Conservation Area (Área Destinada Voluntariamente a la Conservación, ADVC) Xpujil, and, in turn, to the central zone of the Calakmul Biosphere Reserve, it is expected that the mammals visiting the UTC drinking stations will be medium to large-sized species, some of which may be classified as environmentally threatened according to Mexican environmental regulations.

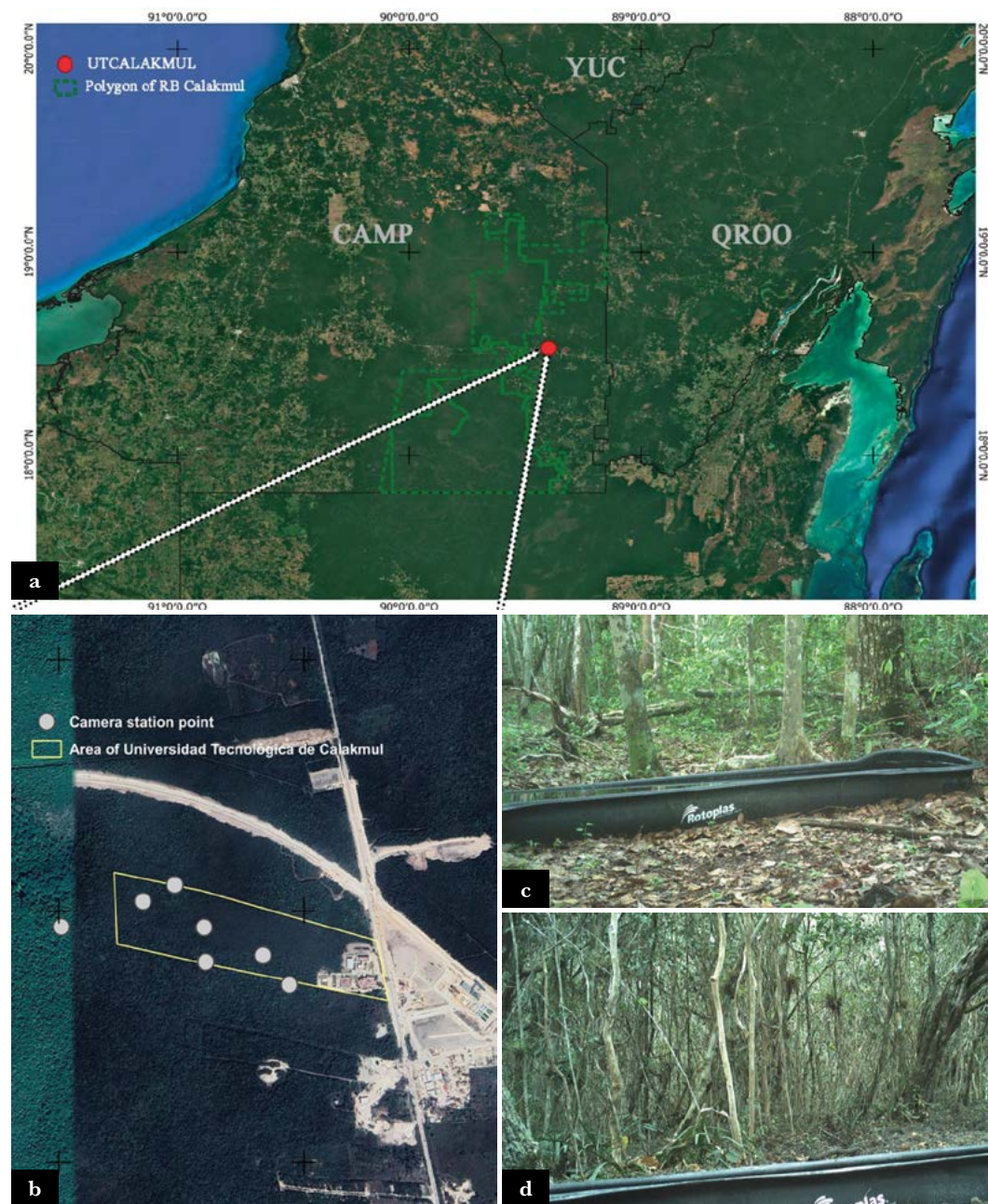
## **MATERIALS AND METHODS**

### **Study Area**

The study was conducted within the conservation zone of the Universidad Tecnológica de Calakmul (18° 31' 36.96" N, 89° 23' 59.57" W), located in the town of Xpujil, in the municipality of Calakmul, Campeche (Figure 1). The area is situated near the Calakmul Biosphere Reserve (REBICA) and the Voluntarily Designated Conservation Area (ADVC) Xpujil, which together cover over 20,000 km<sup>2</sup> (Reyna-Hurtado *et al.*, 2019). It includes 20 hectares of seasonally flooded lowland semi-evergreen forest and semi-deciduous medium-height forest. The area is located at an elevation of 242 meters above sea level, with an average annual temperature of 26 to 27 °C (INEGI, 2024).

### Installation of Drinking Stations

Four artificial waters troughs made of black plastic (Rotoplas® brand), each with a capacity of 300 liters, were installed (Contreras-Moreno *et al.*, 2024a). These stations were distributed along the access road to the institution's forest conservation area, maintaining a minimum distance of 350 meters between each station. Their purpose was to provide water for the wildlife inhabiting the surrounding forest areas (Figure 1).



**Figure 1.** Geographical location. a) Location of the Technological University of Calakmul on the Yucatan Peninsula, b) polygon of the university and sampling sites, c) artificial water trough in medium sub evergreen forest, d) artificial water trough in seasonally flooded lowland forest.

### Statistical analysis

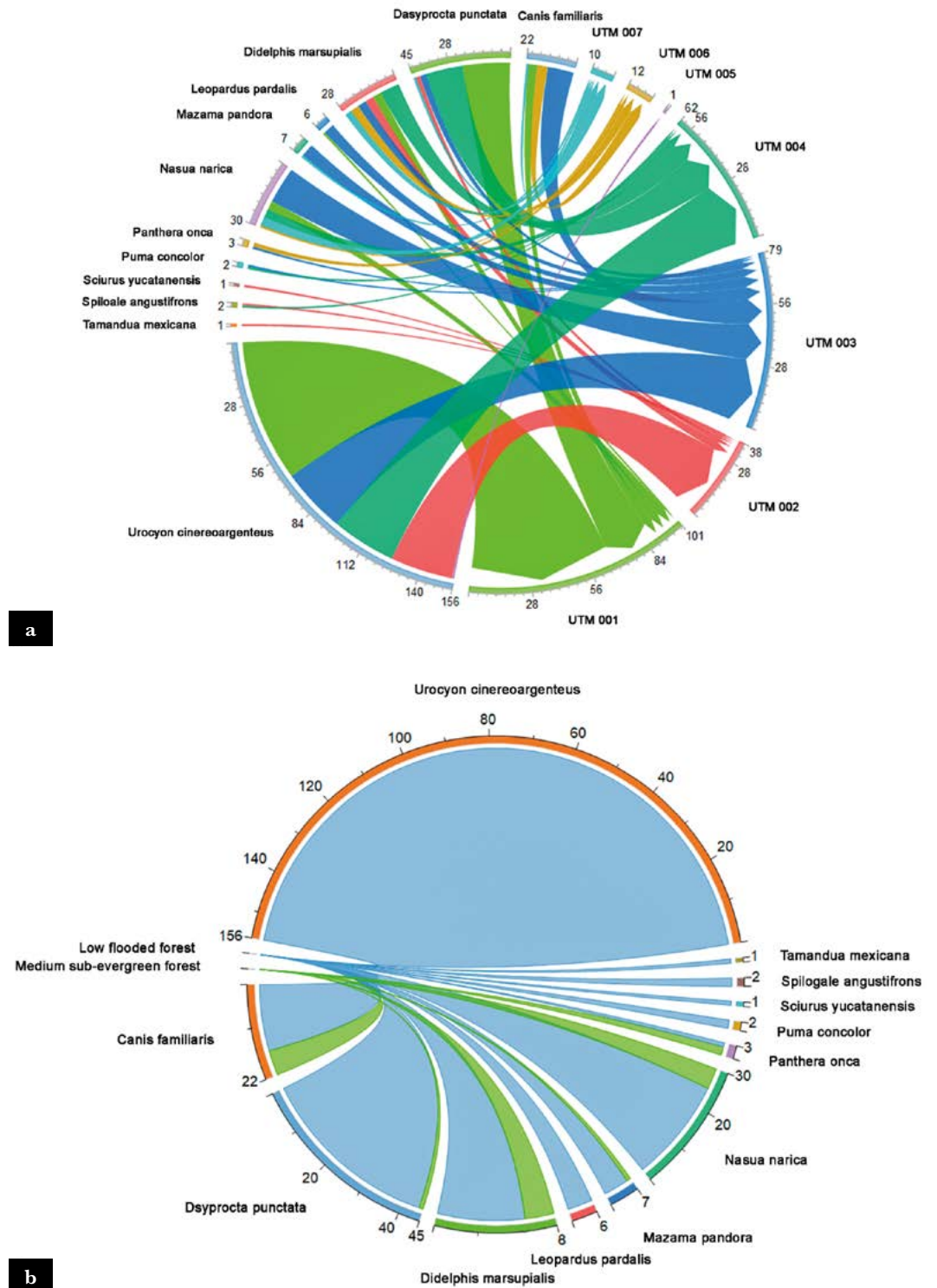
To assess sampling completeness, accumulation and extrapolation curves were generated using the iNEXT software in its different orders (Chao *et al.*, 2016). To determine the reasons for visiting the drinking troughs by terrestrial mammals, ecological interaction networks were performed in the Rstudio software using the Bipartite interface (Dormann *et al.*, 2008). Mammal activities were categorized based on photographic evidence into five behavioral types: passing, feeding, foraging, hydration, and temperature regulation. Similarly, to identify the abundance of mammal species and their presence across camera trap stations and vegetation types, chord diagrams were creating using OriginPro software (OriginPro, 2023). Finally, to determine the conservation status of the recorded species, the Mexican Official Standard NOM-059-SEMARNAT-2010 (SEMARNAT, 2010) and the IUCN Red List of Threatened Species (IUCN, 2022) were consulted, and a systematized list was generated.

### RESULTS AND DISCUSSION

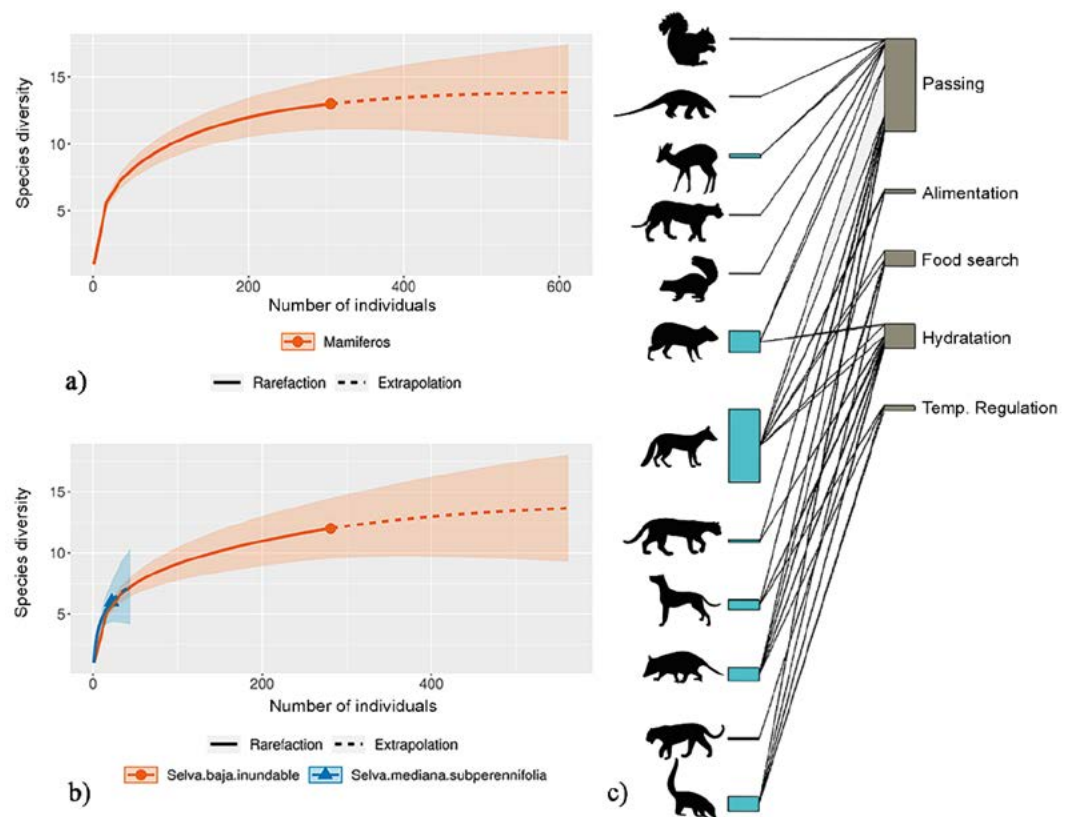
With a sampling effort of 155 nights/trap, 12 species of medium and large terrestrial mammals were identified, representing six orders and nine families. The most diverse family was Felidae, with three species: jaguar (*Panthera onca* Linnaeus), puma (*Puma concolor* Linnaeus), and ocelot (*Leopardus pardalis* Linnaeus). In contrast, Myrmecophagidae and Sciuridae were the least diverse, each represented by a single species. The species with the highest number of records was the gray fox (*Urocyon cinereoargenteus* Schreber) (n=156), followed by the sereque (*Dasyprocta punctata* Gray) (n=24). In contrast, the species with the fewest records were the Yucatan squirrel (*Sciurus yucatanensis* J. A. Allen) (n=1) and the anteater (*Tamandua mexicana* Saussure) (n=1) (Figure 2a). The vegetation type with the greatest mammal diversity was seasonally flooded lowland forest, with a total of 13 species, compared to the semi-evergreen medium-height forest, where only four species were recorded (Figure 2b).

The results of this study confirms that artificial water troughs is a functional alternative to ensure water availability for wildlife in the Calakmul region (Contreras-Moreno *et al.*, 2024a). Although the sampling effort was significantly lower than that of Contreras-Moreno *et al.* (2024a, b), the detection of ecologically important and elusive species, such as jaguar and puma, suggests that the UTC conservation area maintains exceptional conditions with a high degree of conservation. The presence of three of the region's large felids —puma, jaguar, and ocelot— underscores the conservation value of the area and the urgent need to ensure its continued protection.

The species accumulation and extrapolation curve show asymptotes for the forest conservation area, with the lowland flooded forest exhibiting a higher sampling effort, while the medium sub-evergreen forest does not reach its asymptote (Figure 3a and b). The species interaction networks and their activity at the artificial watering troughs reveal that a total of 11 species visit the troughs in a passing manner, followed by seven species classified under the hydration category, with the gray fox being the species with the highest number of visits (Figure 3c).



**Figure 2.** String diagrams. a) abundance of individuals in the different camera trap stations, b) abundance in vegetation types.



**Figure 3.** Accumulation curves and interaction networks. a) Species accumulation curve for the study site, b) species accumulation curve for the two vegetation types, and c) ecological interaction network of species and their visitation activity at the watering holes.

The presence of seven species from the carnivore group detected in this study highlights a spatial coexistence between these species. Coexistence among large predators has primarily been studied along three axes: feeding, space, and time (Ávila-Nájera *et al.*, 2016). The fact that these species coexist in the UTC conservation area suggests that the region likely maintains a sufficient availability of prey, which helps sustain the ecological balance. In this regard, it has been suggested that coexistence between top predator species is mediated by the selection of prey with different activity patterns (Hernández-Sánchez and Santos-Moreno, 2020).

Of the 12 species recorded, some are listed under different protection categories according to NOM-059-SEMARNAT-2010. In total, 33.33% of the species are considered at risk, including felines such as the ocelot and jaguar, which are classified as Endangered (Table 1; Figure 3).

Access to water is a matter of life and death for wildlife in the Maya Forest, as it has been observed that the lack of water can lead to dehydration and death in large animals such as jaguars, tapirs, and white-lipped peccaries (Gandiwa *et al.*, 2016). In this regard, the use of artificial drinking troughs serves as an alternative to ensure water availability during the dry season for predators and other species (Mandujano-Rodríguez and Hernández, 2019), thus helping to mitigate the issue of water scarcity.

**Table 1.** List of registered terrestrial mammal species. NOM-059-SEMARNAT-2010 categories: endangered (P), threatened (A), subject to special protection (SP). IUCN category: endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC), not assessed (NA). Vegetation type: lowland flooded forest (LFF) and medium sub evergreen forest (MSEF).

| Family          | Specie                          | NOM-059 | IUCN | LFF | MSEF |
|-----------------|---------------------------------|---------|------|-----|------|
| Canidae         | <i>Canis familiaris</i>         | —       | —    | 22  | —    |
|                 | <i>Urocyon cinereoargenteus</i> | —       | LC   | 146 | 9    |
| Cervidae        | <i>Mazama pandora</i>           |         | VU   | 5   | 2    |
| Dasyproctidae   | <i>Dasyprocta punctata</i>      | —       | LC   | 45  | —    |
| Didelphidae     | <i>Didelphis marsupialis</i>    | —       | LC   | 28  | —    |
| Felidae         | <i>Leopardus pardalis</i>       | A       | NT   | 6   | —    |
|                 | <i>Panthera onca</i>            | P       | NT   | 3   | —    |
|                 | <i>Puma concolor</i>            |         | LC   | 1   | 1    |
| Mephitidae      | <i>Spilogale angustifrons</i>   | —       | DD   | 2   | —    |
| Myrmecophagidae | <i>Tamandua mexicana</i>        | —       | LC   | 1   | —    |
| Procyonidae     | <i>Nasua narica</i>             | —       | LC   | 30  | 1    |
| Sciuridae       | <i>Sciurus yucatanensis</i>     | Pr      | LC   | 1   | —    |



**Figure 4.** Photographic record of species. a) *Didelphis marsupialis* Linnaeus, b) *Mazama pandora* Merriam, c) *Urocyon cinereoargenteus* calves, d) female and calf of *Urocyon cinereoargenteus* Schreber, e) *Dasyprocta punctata* Gray, f) *Nasua narica* Linnaeus, g) *Leopardus pardalis* Linnaeus, and h) *Panthera onca* Linnaeus.

The high diversity of species that continuously visit the troughs during the dry season in the Maya Forest underscores the effectiveness of the water supply strategy provided by artificial troughs in the UTC conservation zone. In addition to allowing individuals to access water, the troughs facilitate interactions among individuals from different populations, which could be considered a site for socialization (Contreras-Moreno *et al.*, 2024a).

Based on the results obtained, it is expected that there will be increased interest in conducting research at sites near urban areas, such as botanical or ethnobiological gardens, and green areas within educational institutions.

## CONCLUSIONS

This study demonstrated that the UTC conservation area supports mammal species of high ecological value. Maintaining the habitat quality of this area could serve as a functional refuge for large mammals, especially if water is supplied through artificial drinking troughs during the dry season.

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## REFERENCES

- Alpaidze, L., & Salukvadze, J. (2023). Green in the city: estimating the ecosystem services provided by urban and peri-urban forests of Tbilisi municipality, Georgia. *Forests*, *14*(1): 121. <https://doi.org/10.3390/f14010121>
- Ávila-Nájera, D. M., Chávez, C., Lazcano-Barrero, M. A., Mendoza, G. D., & Perez-Elizalde, S. (2016). Traslape en patrones de actividad entre grandes felinos y sus principales presas en el norte de Quintana Roo, México. *Therya*, *7*(3):439-448.
- Chao, A., Ma, K. H., & Hsieh, T. C. (2016). User's guide for iNEXT online: Software for interpolation and extrapolation of species diversity. Institute of Statistics. Recuperado de [http://chao.stat.nthu.edu.tw/wordpress/software\\_download](http://chao.stat.nthu.edu.tw/wordpress/software_download).
- Contreras-Moreno, F. M. (2020). Crisis de los tapires en Calakmul, un efecto del cambio climático. *Revista Hypatia*, *53*:10-14.
- Contreras-Moreno, F. M., Jesús-Espinosa, D., Cruz-Romo, L., Sanchez-Pinzon, K. G., Mendez-Tun, J. M., Perez-Mendez, F., Tamay-Yah, L., Gutierrez-Cortes, E., Duque-Moreno, V. D., Diaz-Ruiz, Y., Servin-Camacho, D. Y., Mendez-Saint, M. G., Simá-Pantí, D., & Bautista-Ramírez, P. (2024a). Water supply in artificial troughs: A strategy to mitigate the impacts of climate change in the Maya Forest. *AgroProductividad*, *17*(4):69-77. doi: 10.32854/agrop.v17i4.2647
- Contreras-Moreno, F. M., Jesús-Espinosa, D., Sánchez, K., Méndez-Tun, J., & Cruz-Romo, L. (2024b). Use of artificial water troughs by deer in the Maya Forest, México. *Therya*, *15*(1):103-111.
- Dormann, C. F., Gruber, B., & Fründ, J. (2008). Introducing the bipartite package: Analysing ecological networks. *Interaction*, *1*(0.2413793).
- Faggi, A., & Perepelizin, V. (2006). Riqueza de aves a lo largo de un gradiente de urbanización en la ciudad de Buenos Aires. *Museo Argentino de Ciencias Naturales Bernardino Rivadavia*, *8*(2):289-297.
- Gandiwa, E., Heitkónig, I. M., Eilers, P. H., & Prins, H. H. (2016). Rainfall variability and its impact on large mammal populations in a complex of semi-arid African savanna protected areas. *Tropical Ecology*, *57*(2):163-180.
- Hernández-Gómez, C. A., Andrade-Ponce, G. P., Velásquez-C, K. L., & Mandujano, S. (2020). Uso de bebederos artificiales por pequeños roedores en un bosque tropical seco en Oaxaca, México. *Mammalogy Notes*, *7*(2):179-182.

- Hernández-Sánchez, A., & Santos-Moreno, A. (2020). Activity patterns in a feline assemblage in south-west Mexico, and their relationship with prey species. *Journal of Tropical Ecology*, 36(5):225-233.
- Lin, P., Yang, L., & Zhao, S. (2020). Urbanization effects on Chinese mammal and amphibian richness: A multi-scale study using the urban-rural gradient approach. *Environmental Research Communications*, 2(12):125002. doi: 10.1088/2515-7620/abd1c5
- MacGregor-Fors, I., Avendaño-Reyes, S., Bandala, V. M., Chacón-Zapata, S., Díaz-Toribio, M. H., González-García, F., & Escobar, F. (2015). Multi-taxonomic diversity patterns in a neotropical green city: A rapid biological assessment. *Urban Ecosystems*, 18:633-647.
- Mandujano-Rodríguez, S., & Hernández, C. (2019). Uso de bebederos artificiales por venado cola blanca en una UMA extensiva en la reserva de biosfera Tehuacán-Cuicatlán, México. *AgroProductividad*, 12(6):37-42.
- Origin(Pro), Version (2023). OriginLab Corporation, Northampton, MA, USA.
- Revollo, D., & Ríos, A. (2023). Presente y futuro de las Aguadas de Calakmul, México: Un análisis de las instituciones formales e informales de los habitantes frente al cambio climático. *Sobre México: Revista Sobre México*, 2(4):114-130.
- Reyna-Hurtado, R., Sima-Pantí, D., Andrade, M., Padilla, A., Retana-Guaiscón, O., Sánchez-Pinzón, K., & Domínguez, N. A. (2019). Tapir population patterns under the disappearance of freestanding water. *Therya*, 10(3):353-358.
- SEMARNAT [Secretaría de Medio Ambiente y Recursos Naturales]. (2010). Norma Oficial Mexicana NOM-059-SEMARNAT-2010, Protección Ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-lista de especies en riesgo. Diario Oficial de la Federación. Segunda Sección. D.F., México.
- UICN [Unión Internacional para la Conservación de la Naturaleza]. (2024). IUCN 2024. The IUCN Red List of Threatened Species. Version 2024-2. <<https://www.iucnredlist.org>>. <https://www.iucnredlist.org> [Consultado en octubre de 2024].
- Verdú-Vázquez, A., Fernández-Pablos, E., Lozano-Diez, R. V., & López-Zaldívar, Ó. (2021). Green space networks as natural infrastructures in peri-urban areas. *Urban Ecosystems*, 24, 187-204. <https://doi.org/10.1007/s11252-020-01019-w>





# Analysis of the impact of the Sembrando Vida program in agricultural production in Mexico

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## ABSTRACT

**Objective:** To determine the impact of the Sembrando Vida program on corn and bean production in the eight states where the program began to be implemented.

**Design/methodology/approach:** A total of 64 structural analysis tests were carried out with dichotomous variables (using control variables) to determine the impact of the Sembrando Vida program on corn and bean production in Puebla, Durango, Veracruz, Tabasco, Chiapas, Campeche, Quintana Roo and Yucatán, in the years 2019, 2020, 2021 and 2022. This type of test allows determining whether a variable changed its trend or its intercept or both, due to an event.

**Results:** The Sembrando Vida program has not been successful in impacting corn production in seven of the eight states examined and, in the case of beans, it did not impact in six of the eight states analyzed. The exception in corn was the state of Quintana Roo in 2022; and, in the case of beans, it was Quintana Roo in 2019 and 2022 and Durango in 2019, 2021 and 2022.

**Limitations on study/implications:** Fruit trees were not examined; each state was not characterized; and the states to which the program was expanded were not analyzed.

**Findings/conclusions:** The objective of the study was achieved because it was determined that, in general, the Sembrando Vida program did not impact the production of corn and beans (with exceptions); and that it is necessary to restructure government programs so that they have a greater effect.

**Keywords:** government programs; econometric analysis; agricultural production; and social support.

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## INTRODUCTION

The programs destined to the agricultural sector take on relevance due to the importance of this sector for countries, since that is where the foods that society demands are produced, and it is a relevant economic sector. Some examples of these programs are the National Plan for Integrated Agriculture in Thailand or the International Fund for Agricultural Development in China (Zhu *et al.*, 2024; Yunez, 2020; García *et al.*, 2018; Hanpongpanth, 2003; Brambila *et al.*, 2014; Méndez, 2011; OCDE-FAO, 2011; Terrones and Sánchez, 2010; Hewitt, 2007).

Among the programs destined to the agricultural sector, there are the following: social, which are focused on improving the wellbeing of people in this sector; and those destined to improving or increasing production in the agricultural sector. These programs have the

purpose of generating a structural change in the production or the standards of living of recipients of the program (SADER, 2024; Gallardo *et al.*, 2020; Gómez and Tacuba, 2017).

In Mexico, various programs for the agricultural sector have been implemented since 1900, such as: Fertilizers for Wellbeing (*Fertilizantes para el Bienestar*), and Program for Support to Small-Scale Producers (*Programa de Apoyo a Pequeños Productores*). These programs have had different objectives, such as increasing the production, productivity and competitiveness of the agricultural sector; or social, such as contributing to improve the standards of living of people from the agricultural sector (Arriaga *et al.*, 2023; Gallardo *et al.*, 2020; Secretaría de Desarrollo Social, 2014; Gómez and Tacuba, 2017).

Likewise, to achieve these objectives, these programs have implemented different strategies, such as backing for producers to modernize the sector through the purchase of machinery; and, increasing their productivity by giving out fertilizers (Arriaga *et al.*, 2023; Gallardo *et al.*, 2020; Secretaría de Desarrollo Social, 2014). The social objectives of these programs destined to agricultural areas are the most important, especially poverty reduction. This is because it has been pointed out that in rural zones the percentage of poverty is higher than in urban areas (SADER, 2024; CIMMYT, 2023; Baca and Cuevas, 2018; Briceño, 2010; CONEVAL, 2024).

Additionally, the agricultural sector in Mexico has other challenges, such as: a group of producers lacks economic resources that allow them to modernize and increase their production, and that it is the most vulnerable to economic crises such as the one in 2008 (Ríos, 2020; Ayala and Chapa, 2017; Guzmán *et al.*, 2012; Becerril *et al.*, 2011; De Grammont, 2010).

The programs in Mexico destined to the agricultural sector have received criticism. Such was the case of the National Program for Farmland Modernization (*Programa Nacional de Modernización del Campo*), which was examined by Gómez and Tacuba (2017); the authors mention that the program did not improve the competitiveness of the sector. Another program studied is that of Fertilizers for Wellbeing, which has been called out for providing fertilizers that are more toxic than those habitually used (Díaz, 2008). For their part, Martínez (2023) and López-Villafañe (2020) have analyzed the Bienpesca programs directed to the fishing sector and Production for Wellbeing directed at the agricultural sector. They indicate that, in both programs, the expenditure on the operation is higher than the benefits they have caused. In turn, Delta (2019) indicates that the programs have had a significant impact because they increased agricultural productivity by 20%.

Specifically, Sembrando Vida was one of the proposals from President López Obrador in 2018, under a modality of plots of corn, bean and fruit trees. It seeks to generate employment for the population at risk of migration, by promoting agricultural productivity and improving the rural per capita income. Likewise, it is a program that is included in the proposal from 2018 called Integral Development Plan for Central America. The program consists of generating jobs offering a wage of \$6,000 pesos and giving benefits such as a savings register and fund. Sembrando Vida started in 2019 in Campeche, Chiapas, Durango, Puebla, Quintana Roo, Tabasco, Veracruz and Yucatán. By 2022, it had nearly 450,000 employees and at the end of 2023 it already operated in 21 states (SADER, 2024;

Arriaga *et al.*, 2023; López, 2021; Gallardo *et al.*, 2020; Santiago, 2023; Montes and Sánchez, 2024; Ortiz and Sánchez, 2024; Santiago, 2023).

This program was a change in the federal government's policy in Mexico compared to prior periods. Since the reform to Article 27 and the entry into force of the North America Free Trade Agreement in 1994, this sector has suffered disloyal competition, lack of support and an increase in poverty. One of the novelties is that the Sembrando Vida program covers several areas, seeking to create employment, give technical support, and include women (Montes and Sánchez, 2024; Santiago, 2023).

In this sense, Montes and Sánchez (2024), Cortez *et al.*, (2022), Santiago (2023), and Ortiz and Sánchez (2024) conclude that the Sembrando Vida program has the novelty of placing peasants at the core; it offers monthly backing; it is necessary to improve the registration requirements; the people have a good perception of the program; problems with technical support and for inputs persist; the impact in the socioeconomic area is negative; the resources granted are not sufficient to achieve the goals of the program and to cover its basic needs; and it should encompass beyond the rural level to address the predicament of migration.

Therefore, the objective proposed for this study is to determine the impact of the Sembrando Vida program on the production of corn and beans in the eight states where the program started to be implemented. Likewise, the research hypothesis is that the Sembrando Vida program impacted corn and bean production in the eight states where it started to be implemented.

## MATERIALS AND METHODS

To reach the objective of the study and to test the hypothesis, 64 structural analysis tests with dichotomous variables were conducted. These tests, according to Gujarati and Porter (2009) and Wooldridge (2010), allow to determine if a variable changed its trend or its intercept, or both, because of an event. That is, with these tests, it will be possible to establish whether the Sembrando Vida program caused a change in the trend or in the intercept of corn and bean production in the eight states where it started to be implemented.

The databases that were used in this study are the agricultural production from the eight states where the program started to be implemented (Puebla, Durango, Veracruz, Tabasco, Chiapas, Campeche, Quintana Roo and Yucatán) and the yield per hectare of the eight states, which were extracted from the Agrifood and Fishing Information Service (*Servicio de Información Agroalimentaria y Pesquera*, SIAP) website (SIAP, 2024).

In addition, the Trimester Index of State Economic Activity (*Índice Trimestral de Actividad Económica Estatal*, ITAEE) was used, which was obtained from the National Institute of Statistics and Geography (*Instituto Nacional de Estadística y Geografía*, INEGI) website (INEGI, 2024). The three databases have a temporality of 1980 to 2022, they are annual data (an annual average was obtained for ITAEE), and there are 43 data.

Regarding the databases, according to Gujarati and Porter (2009) and Wooldridge (2010), it is necessary to have a broad database for this type of tests that require conducting regressions. This is because, according to the authors, based on the Gauss Márkov theorem and the assumption of normality, which allow, among other things, for a model to be a

best unbiased estimator (BUE) and to conduct hypothesis tests. In this sense, because the production data are only in annual data, and to fulfill the test requirements, the decision was made to use the temporality available from SIAP (2024), which was 1980 to 2022.

**Structural analysis tests**

To analyze the impact of the Sembrando Vida program on corn and bean production in the eight states where it started to be implemented, 64 structural analysis tests with dichotomous variables were used. To conduct them, the methodology presented by Gujarati and Porter (2009) and Wooldridge was employed. With this methodology, the existence of a structural change could be determined, and whether that change was in the intercept, the slope or both.

In this sense, and according to the authors, the dates when the event took place should be chosen, and with that determine where the tests will be applied. Because the program started to be implemented in 2019, the tests for 2019 would be applied; however, considering the delay that the effect of the program could have on corn and bean production, the tests for 2020, 2021 and 2022 were conducted.

It should be noted that, as indicated before, these tests require conducting regressions and therefore it is necessary to have abundant robust data. Likewise, because the data are annual, the temporality available was used, which is 1980 to 2022 (there are only 43 data). The information from the 64 tests that will be made is summarized in Table 1.

Table 1 shows that for each of the eight states examined (Puebla, Durango, Veracruz, Tabasco, Chiapas, Campeche, Quintana Roo and Yucatán), two tests will be conducted because there are two products which are analyzed (corn and bean), and four years will be examined (2019, 2020, 2021 y 2022). Therefore, the 64 structural analysis tests that will be conducted will have the form of Equation 1.

$$Y = \alpha_1 + \alpha_2 D_t + B_1 T + B_2 (D_t T) + x_1 B_3 + x_2 B_4 + \mu_1 \tag{1}$$

Where:  $Y$ =corn or bean production from one of the eight states;  $\alpha_1$ =intercept value;  $\alpha_2$ = differential intercept value;  $D_t$ =dichotomous variable, where 0 are the observations before the cut and 1 after the cut (see Table 1);  $B_1$ =beta value of time;  $T$ =time;  $B_2$ =differential slope;  $x_1$ =Trimester Index of State Economic Activity (*Índice Trimestral de Actividad Económica Estatal*, ITAEE);  $B_3$ =Beta value of the ITAEE control variable;  $x_2$ =Yield of one of the eight states (UDM/HA);  $B_4$ =Beta value of the control variable, yield;  $\mu_1$ =stochastic error.

**Table 1.** Information about structural analysis tests that will be conducted.

| Independent variables  | Independent variable                         | Years that were examined | Cut   |
|--|--|--------------------------|---|
| Time   | Corn and bean production from                | 2019                     | 0 before the year examined and 1 after the year examined. |
| Trimester Index of State Economic Activity ( <i>Índice Trimestral de Actividad Económica Estatal</i> , ITAEE). | Puebla, Durango, Veracruz, Tabasco,          | 2020                     |   |
| Yield (UDM/HA)   | Chiapas, Campeche, Quintana Roo and Yucatán. | 2021                     |   |
|  |  | 2022                     |   |

Source: Prepared by the authors.

The 64 structural analysis tests that have the form of Equation 1 will be made according to what was described by Gujarati and Porter (2009) and Wooldridge (2010), and the Excel software will be used. Likewise, Equation 1 indicates that two control variables were added with the aim of obtaining more robust results.

This is how, in the 64 tests that will be made, the intercept ( $\alpha_2$ ) and the differential slope ( $B_2$ ) will be reviewed, with the aim of establishing the presence of a structural change in corn and bean production in the eight states examined during the years 2019, 2020, 2021 and 2022.

In this sense, when only the  $p$  value of the differential intercept ( $\alpha_2$ ) is lower than 0.05, then there is a structural change in the intercept; on the other hand, in the case where only the  $p$  value of the differential slope ( $B_2$ ) is lower than 0.05, then there is a structural change in the slope; lastly, in the case that both values are lower than 0.05, then there is a structural change in the slope and in the intercept. If both values are higher than 0.05, there is no structural change.

## RESULTS AND DISCUSSION

Based on the methodology, the results from the 32 structural analysis tests with dichotomous variables of corn in the eight states examined in the years 2019, 2020, 2021 and 2022, are presented in Table 2.

The results from the structural analysis tests for corn production presented in Table 2 show that a structural change was not present in seven of the eight states examined in the periods 2019, 2020, 2021 and 2022, since in these tests the  $p$  values of the intercept ( $\alpha_2$ ) and of the differential slope ( $B_2$ ) are higher than 0.05 in every case. This means that there was not a structural change in corn production in the years 2019, 2020, 2021 and 2022, in the states of Puebla, Durango, Veracruz, Tabasco, Chiapas, Campeche and Yucatán. The only exception is the state of Quintana Roo, where it was found that corn production suffered a structural change in the differential intercept ( $\alpha_2$ ) in the year 2022, since its  $p$  is lower than 0.05.

Now, the results from the 32 structural analysis tests with dichotomous variables of bean from the eight states examined in the years 2019, 2020, 2021 and 2022 are presented in Table 3.

The structural analysis tests of bean production presented in Table 3 show that there was no structural change in six of the eight states examined in the periods 2019, 2020, 2021 and 2022, since in these tests, the  $p$  values of the intercept ( $\alpha_2$ ) and of the differential slope ( $B_2$ ) are higher than 0.05 in every case. This means that there was no structural change in bean production in the years 2019, 2020, 2021 and 2022, in the states of Puebla, Veracruz, Tabasco, Chiapas, Campeche and Yucatán.

The exceptions are the state of Quintana Roo, where it was found that in the years 2019 and 2022, bean production suffered a structural change in the differential slope ( $\alpha_2$ ), since the  $p$  value is lower than 0.05 in both years; and Durango, where it was found that in the year 2019 there was a structural change in the slope ( $B_2$ ) and in the differential intercept ( $\alpha_2$ ), because the  $p$  value is lower than 0.05 in both cases, and in the

**Table 2.** Structural analysis tests with dichotomous variables of corn.

| Year | Corn                      | Puebla  | Durango | Veracruz | Tabasco | Chiapas | Campeche | Quintana Roo | Yucatán |
|------|---------------------------|---------|---------|----------|---------|---------|----------|--------------|---------|
|      |                           | p-value |         |          |         |         |          |              |         |
| 2019 | Interception              | 0.99    | 0.25    | 0.24     | 0.04    | 0.11    | 0.01     | 0.00         | 0.88    |
|      | Differential intercept    | 0.75    | 0.38    | 0.26     | 0.40    | 0.70    | 0.51     | 0.27         | 0.59    |
|      | X                         | 0.95    | 0.66    | 0.69     | 0.02    | 0.07    | 0.00     | 0.95         | 0.19    |
|      | Differential slope        | 0.75    | 0.34    | 0.25     | 0.40    | 0.72    | 0.47     | 0.32         | 0.59    |
|      | Economic activity (ITAEE) | 0.85    | 0.95    | 0.20     | 0.77    | 0.04    | 0.13     | 0.79         | 0.20    |
|      | Yield                     | 0.00    | 0.00    | 0.00     | 0.84    | 0.00    | 0.00     | 0.00         | 0.04    |
| 2020 | Interception              | 1.00    | 0.26    | 0.16     | 0.06    | 0.12    | 0.01     | 0.00         | 0.83    |
|      | Differential intercept    | 0.89    | 0.29    | 0.50     | 0.77    | 0.83    | 0.41     | 0.17         | 0.89    |
|      | X                         | 0.96    | 0.67    | 0.49     | 0.03    | 0.08    | 0.00     | 0.95         | 0.20    |
|      | Differential slope        | 0.89    | 0.51    | 0.11     | 0.60    | 0.90    | 0.81     | 0.96         | 0.94    |
|      | Economic activity (ITAEE) | 0.86    | 0.99    | 0.11     | 0.96    | 0.04    | 0.15     | 0.85         | 0.20    |
|      | Yield                     | 0.00    | 0.00    | 0.00     | 0.84    | 0.00    | 0.00     | 0.00         | 0.04    |
| 2021 | Interception              | 1.00    | 0.31    | 0.27     | 0.04    | 0.11    | 0.01     | 0.00         | 0.90    |
|      | Differential intercept    | 0.86    | 0.09    | 0.94     | 0.62    | 0.55    | 0.52     | 0.17         | 0.58    |
|      | X                         | 1.00    | 0.76    | 0.75     | 0.02    | 0.07    | 0.00     | 0.95         | 0.21    |
|      | Differential slope        | 0.86    | 0.66    | 0.48     | 0.37    | 0.70    | 0.24     | 0.96         | 0.46    |
|      | Economic activity (ITAEE) | 0.82    | 0.91    | 0.23     | 0.79    | 0.04    | 0.12     | 0.85         | 0.22    |
|      | Yield                     | 0.00    | 0.00    | 0.00     | 0.84    | 0.00    | 0.00     | 0.00         | 0.03    |
| 2022 | Interception              | 0.95    | 0.28    | 0.28     | 0.06    | 0.10    | 0.01     | 0.00         | 0.91    |
|      | Differential intercept    | 0.77    | 0.07    | 0.87     | 0.85    | 0.47    | 0.21     | 0.01         | 0.72    |
|      | X                         | 0.97    | 0.69    | 0.77     | 0.03    | 0.06    | 0.00     | 0.81         | 0.21    |
|      | Differential slope        | 0.77    | 0.17    | 0.44     | 0.54    | 0.53    | 0.69     | 0.37         | 0.58    |
|      | Economic activity (ITAEE) | 0.85    | 0.93    | 0.25     | 0.89    | 0.03    | 0.14     | 0.96         | 0.22    |
|      | Yield                     | 0.00    | 0.00    | 0.00     | 0.84    | 0.00    | 0.00     | 0.00         | 0.04    |

Source: Prepared by the authors.

years 2021 and 2022 where only the differential slope changed ( $B_2$ ) because the value is lower than 0.05 in both cases.

Therefore, the results from the research are similar to the findings by Gómez and Tacuba (2017), who indicate that the programs *Fertilizantes para el Bienestar* and *Programa Nacional de Modernización del Campo*, did not have a significant impact, which they attribute to deficiencies in their design.

The latter is indicated by Ortiz and Sánchez (2024), Cortez *et al.* (2022) and Santiago (2023), authors who analyzed the impact of *Sembrando Vida*, signaling some deficiencies, such as: the resources granted are not enough to achieve the goals of the program and to cover their basic needs; it should go beyond rural zones, and give technical support and inputs; it is necessary to improve the registration requirements; and it should encompass beyond the rural level.

**Table 3.** Structural analysis tests with dichotomous variables of bean.

| Año  | Frijol                    | Puebla  | Durango | Veracruz | Tabasco | Chiapas | Campeche | Quintana Roo | Yucatán |
|------|---------------------------|---------|---------|----------|---------|---------|----------|--------------|---------|
|      |                           | p-value |         |          |         |         |          |              |         |
| 2019 | Interception              | 0.05    | 0.19    | 0.92     | 0.50    | 0.20    | 0.01     | 0.57         | 0.01    |
|      | Differential intercept    | 0.44    | 0.04    | 0.76     | 0.94    | 0.67    | 0.94     | 0.06         | 0.80    |
|      | X                         | 0.49    | 0.31    | 0.24     | 0.43    | 0.95    | 0.07     | 0.05         | 0.89    |
|      | Differential slope        | 0.38    | 0.04    | 0.70     | 0.89    | 0.63    | 0.91     | 0.04         | 0.80    |
|      | Economic activity (ITAEE) | 0.89    | 0.13    | 0.52     | 0.63    | 0.18    | 0.03     | 0.07         | 0.37    |
|      | Yield                     | 0.00    | 0.00    | 0.05     | 0.00    | 0.00    | 0.00     | 0.12         | 0.56    |
| 2020 | Interception              | 0.07    | 0.24    | 0.99     | 0.50    | 0.23    | 0.01     | 0.79         | 0.01    |
|      | Differential intercept    | 0.67    | 0.94    | 0.46     | 0.38    | 0.55    | 0.58     | 0.86         | 0.93    |
|      | X                         | 0.57    | 0.39    | 0.22     | 0.41    | 0.86    | 0.07     | 0.03         | 0.89    |
|      | Differential slope        | 0.62    | 0.40    | 0.59     | 0.95    | 0.92    | 0.95     | 0.15         | 0.95    |
|      | Economic activity (ITAEE) | 0.99    | 0.18    | 0.46     | 0.63    | 0.21    | 0.03     | 0.04         | 0.38    |
|      | Yield                     | 0.00    | 0.00    | 0.05     | 0.00    | 0.00    | 0.00     | 0.20         | 0.56    |
| 2021 | Interception              | 0.04    | 0.25    | 0.90     | 0.51    | 0.20    | 0.01     | 0.53         | 0.01    |
|      | Differential intercept    | 0.92    | 0.69    | 0.27     | 0.28    | 0.64    | 0.49     | 0.64         | 0.91    |
|      | X                         | 0.33    | 0.37    | 0.25     | 0.43    | 0.94    | 0.07     | 0.07         | 0.88    |
|      | Differential slope        | 0.94    | 0.04    | 0.78     | 0.93    | 0.65    | 0.90     | 0.14         | 0.80    |
|      | Economic activity (ITAEE) | 0.77    | 0.15    | 0.54     | 0.65    | 0.18    | 0.03     | 0.09         | 0.36    |
|      | Yield                     | 0.00    | 0.00    | 0.05     | 0.00    | 0.00    | 0.00     | 0.16         | 0.56    |
| 2022 | Interception              | 0.04    | 0.24    | 0.88     | 0.49    | 0.18    | 0.01     | 0.42         | 0.01    |
|      | Differential intercept    | 0.13    | 0.92    | 0.20     | 0.23    | 0.67    | 0.42     | 0.70         | 0.93    |
|      | X                         | 0.33    | 0.42    | 0.27     | 0.41    | 0.97    | 0.07     | 0.12         | 0.87    |
|      | Differential slope        | 0.94    | 0.03    | 0.83     | 0.85    | 0.51    | 0.93     | 0.02         | 0.75    |
|      | Economic activity (ITAEE) | 0.77    | 0.18    | 0.56     | 0.61    | 0.16    | 0.03     | 0.22         | 0.36    |
|      | Yield                     | 0.00    | 0.00    | 0.05     | 0.00    | 0.00    | 0.00     | 0.04         | 0.56    |

Source: Prepared by the authors.

The deficiencies pointed out by the authors can explain why, in general, no evidence was found in the study of a structural change caused by the Sembrando Vida program. Therefore, according to the results and the study, it is necessary to address these deficiencies of the program.

On the other hand, there are authors that have found evidence that the government programs have had a significant impact, as in the case of De Ita (2019), who indicates that Bienpesca and Production for Wellbeing, have had a significant impact because they increased agricultural productivity by 20% in the states where the program was applied like Guerrero, Veracruz and Chiapas.

About this, Montes and Sánchez (2024) and Santiago (2023) indicate that the Sembrando Vida program has some characteristics that make it stand out over previous programs. They are that: it seeks to cover several areas; it seeks to create jobs; give technical support; include women; place peasants at the center of the program; and offer monthly support.

This is why even when these programs do not achieve their aim, it is necessary to continue supporting the agricultural sector in Mexico. This is because the agricultural sector has multiple problems, such as the poverty of people in the agricultural sector and the lack of modernization of a large part of agricultural producers (Ríos, 2020; Baca and Cuevas, 2018; Ayala and Chapa, 2017; Guzmán *et al.*, 2012; Becerril *et al.*, 2011; De Grammont, 2010). Because of this, the study suggests continuing to support the agricultural sector in Mexico, although restructuring the program for it to have a more significant impact.

## CONCLUSIONS

The results indicate that the Sembrando Vida program has not been successful in impacting corn production in seven of the states examined, and in the case of bean, it did not impact in six of the eight states analyzed. The exception in corn was the state of Quintana Roo in the year 2022; and in the case of bean, it was Quintana Roo in the years 2019 and 2022, and Durango in the years 2019, 2021 and 2022. This allows establishing that the Sembrando Vida program did not have a significant impact on the production of two crops. This can be attributed to deficiencies of the program. Some limitations of the study are that fruit trees were not examined.

## REFERENCES

- Arriaga Morales, M. M., Acosta Calderón, J. A., González Santiago, M. V. (2023). Sembrando Vida: Entre lo Diáfano y Profano. *EDUCATECONCIENCIA*, 31(42). <https://doi.org/10.58299/6wej9y08>
- Arriaga Morales, M. M., Acosta Calderón, J. A., González Santiago, M. V. (2023). Sembrando Vida: entre lo diáfano y profano. *EDUCATECONCIENCIA, Volumen Especial: Epistemología, Género e Impactos en el Medio Rural*, 31(42), 1-24. <https://doi.org/10.58299/etc.v31i42.707>
- Ayala, E. y Chapa, F. (2017). Impacto de la influenza AH1N1 en el mercado mexicano de la carne de puerco. *Estudios Económicos*, 1(32), 3-25.
- Baca del Moral, J., y Cuevas Reyes, V. (2018). Desvinculación de las políticas públicas en el campo mexicano. *Andamios*, 15(38), 319-338. <https://doi.org/10.29092/uacm.v15i38.662>
- Becerril-Torres, O., Rodríguez-Licea, G., y Ramírez-Hernández, J. (2011). Eficiencia técnica del sector agropecuario de México: Una perspectiva de análisis envolvente de datos. *Economía*, (31), 85-110.
- Borja Bravo, M., y García Salazar, J. (2022). El Programa de Fertilizantes para el Bienestar y el mercado de frijol en México. *Agronomía Mesoamericana*, 33(2), 1-12. DOI: <http://dx.doi.org/10.15517/am.v33i2.47216>
- Brambila J, Martínez M, Rojas M, Pérez V. 2014. El valor de la producción agrícola y pecuaria en México: fuentes del crecimiento, 1980-2010. *Revista mexicana de ciencias agrícolas*, 5(4): 619-631.
- Briceño Ruiz, J. (2010). La iniciativa del Arco del Pacífico latinoamericano. *Nueva Sociedad*, 228, 44-59.
- Centro Internacional de Mejoramiento de Maíz y Trigo (2023). La agricultura sustentable, una herramienta para reducir la pobreza rural. CIMMYT.
- Consejo Nacional de Evaluación de la Política de Desarrollo Nacional (CONEVAL). (2024). Pobreza Rural. Obtenido de Lo que se mide se puede mejorar: [chro-me-extension://efaidnbmnnnibpcajpcgiclfndmkaj/https://www.coneval.org.mx/Medicion/MP/Documents/PATP/Pobreza\\_rural.pdf](https://efaidnbmnnnibpcajpcgiclfndmkaj/https://www.coneval.org.mx/Medicion/MP/Documents/PATP/Pobreza_rural.pdf)
- Cortez Egremy, J. G., Baca del Moral, J., Uribe Gómez, M., Teodoro, G. H., y Valdés Velarde, E. (2022). La multifuncionalidad de la agricultura como herramienta de análisis de políticas agrarias: el caso del programa Sembrando Vida en Chahuities, Oaxaca. *Acta Universitaria*, 32, 1-18. <http://doi.org/10.15174.au.2022.3339>
- De Grammont HC. (2010). La evolución de la producción agropecuaria en el campo mexicano: concentración productiva, pobreza y pluriactividad. *Andamios*, 7(13): 85-117.
- De Ita, A. (2019). AMLO: claroscurios de propuestas para el campo. *El Cotidiano*, 34(213), 56-66.
- Díaz José, J. (2008). Los programas gubernamentales para promover el desarrollo agrícola: estudio del caso del programa de fertilizantes 2007 en el Estado de Guerrero. Institución de enseñanza e investigación en ciencias agrícolas.

- Gallardo López, F., Hernández Chontal, M. A., Linares Gabriel, A., Morales Narváez, O. A. (2021). Reinterpretaciones y transformaciones en la aplicación del programa Sembrando Vida en México desde la voz de los actores. Ediciones Comunicación Científica.
- García-Salazar JA, Borja-Bravo M., Rodríguez-Licea G. (2018). Consumo de fertilizantes en el sector agrícola de México: Un estudio sobre los factores que afectan la tasa de adopción. *Interciencia*, 43(7): 505-510.
- Gómez Oliver, L., y Tacuba Santos, A. (2017). La política de desarrollo rural en México. ¿Existe correspondencia entre lo formal y lo real? *Economía unam*, 14(42), 93-117. <https://doi.org/10.1016/j.eunam.2017.09.004>
- Gujarati DN, Porter DC. (2010). *Econometría* (5a.ed.). México: McGraw Hill.
- Guzmán E, De la Garza M, García J, Hernández J, Rebollar S. (2012). Determinantes de la oferta de maíz grano en México. *Agronomía mesoamericana*, 23(2): 269-279.
- Hanpongpanth, S. (2003). Diversificación del Desarrollo Rural en Tailandia. Banco Interamericano de Desarrollo. <http://dx.doi.org/10.18235/0012058>
- Hewitt de Alcántara, C. (2007). Ensayo sobre los obstáculos al desarrollo rural en México. Retrospectiva y prospectiva. *Desacatos*, (25), 79-100.
- Instituto Nacional de Estadística y Geografía (INEGI). (2024). Sistema de Cuentas Nacionales de México. Indicador Trimestral de la Actividad Económica Estatal. Año Base 2018. Serie del primer trimestre de 1980 al tercer trimestre de 2023. <https://www.inegi.org.mx/temas/itacee/#tabulados>
- López-Villafañe, V. (2020). AMLO en el poder: la hegemonía política y el desarrollo económico del nuevo régimen. Grupo Editor Orfila Valentini.
- Martínez Espinoza, M. I. (2023). Política social y pobreza en la 4T. *Revista mexicana de sociología*, 85(1), 41-69. <http://dx.doi.org/10.22201/iis.01882503p.2023.0.60448>
- Méndez-Reyes, J. (2011). El cooperativismo y la financiación agrícola en Baja California, México (1930-1950). Una aproximación inicial. *Mundo Agrario*, 11(22).
- Montes Ramírez, K. A., y Sánchez Juárez, G. K. (2024). Programa Sembrando Vida en el municipio San Miguel Talea de Castro, Oaxaca, México. *Estudios Sociales, Revista de Alimentación Contemporánea y Desarrollo Regional*, 34(63), 1-24. <https://doi.org/10.24836/es.v34i63.1420>
- OCDE-FAO 2011. Perspectivas de la agricultura 2011-2020. OECD Publishing y FAO. DOI: [https://doi.org/10.1787/agr\\_outlook-2011-es](https://doi.org/10.1787/agr_outlook-2011-es)
- Ortiz Timoteo, J., y Sánchez Sánchez, O. (2024). El programa Sembrando Vida: una aproximación sobre su implementación en el sur de Veracruz, México. *Estudios Sociales, Revista de Alimentación Contemporánea y Desarrollo Regional*, 34(64), 1-32. <https://doi.org/10.24836/es.v34i64.1487e241487>
- Ríos, D. (2020). COVID-19 y cadena de suministro de alimentos: estatus y perspectivas. *Investigaciones y Estudios-UNA*, 11(2), 43-55. <https://doi.org/10.47133/IEUNA2025>
- Santiago Cruz, M. de J. (2023). “Sembrando Vida” y la migración desde el Triángulo Norte de Centroamérica (TNCA). *Revista de Fomento Social*, 78(3), 347-371.
- Secretaría de Agricultura y Desarrollo Rural (SADER). (2024). Programa sembrando vida. <https://www.gob.mx/bienestar/acciones-y-programas/programa-sembrando-vida>
- Secretaría de Desarrollo Social. (2014). Lineamientos básicos para la elaboración de programas nuevos de desarrollo social. Obtenido de Poder Ejecutivo: [chro-me-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://www.ordenjuridico.gob.mx/Documentos/Estatal/Colima/wo99541.pdf](http://www.ordenjuridico.gob.mx/Documentos/Estatal/Colima/wo99541.pdf)
- Servicio de Información Agroalimentaria y Pesquera (SIAP). (2024). [Conjunto de datos]. Recuperado el 2024, de Anuario Estadístico de la Producción Agrícola: <https://nube.siap.gob.mx/cierreagricola/>
- Terrones CA, Sánchez T. (2010). Demandas de insumos de la producción agrícola en México 1975-2011. *Universidad y Ciencia Trópico Húmedo*, 26(1): 81-91.
- Wooldridge, J. (2010). *Introducción a la Econometría, Un enfoque moderno* (7a.ed.). México, DF: Cengage Learning Editores.
- Yunez Naude, A. (2020). Las transformaciones del campo y el papel de las políticas públicas: 1929-2008. El Colegio de México, 729-756.
- Zhu, R., Zhang, Y., Huang, Y. (2024). Research On Global Equity Based on Contribution-Welfare Model. *Highlights in Business, Economics and Management*, 25, 55-65. <https://doi.org/10.54097/0rs7nc61>



# Farmers perceive that the application of vermicompost enhances plant growth and strengthens resistance to diseases

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## ABSTRACT

**Objective:** To identify the factors influencing growers in the municipalities of Fresnillo, Río Grande, and Zacatecas to either incorporate or refrain from incorporating available cattle manure into vermicompost production, trade, and use.

**Design/methodology/approach:** A questionnaire comprising 59 items was designed to assess human, social, physical, and economic factors related to vermicompost use in agricultural plots. The questionnaire was administered to 30 growers. The resulting dataset was analyzed using Principal Component Analysis (PCA) and Cluster Analysis (CA) to identify dominant factors and to classify growers.

**Results:** Both PCA and CA enabled the identification of key factors within each domain and facilitated the classification of growers.

**Limitations on study/implications:** The sample size is relatively small due to the limited number of growers using vermicompost in the study region.

**Findings/conclusions:** Among growers using vermicompost, three distinct groups were identified: the first group (10 growers) perceives improvements in soil fertility and contamination reduction; the second group (9 growers) values enhanced plant nutrition and increased soil microorganism activity; and the third group (11 growers) reports better plant growth and greater disease resistance.

**Keywords:** Human capital, Social capital, Physical capital, Economic capital.

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## INTRODUCTION

The increase in agricultural production has driven the adoption of improved seeds and the intensive use of agrochemical products (Deepak, 2019). As a result, farmers have faced declining profits and rising input costs (Deepak, 2019). In response to this situation, they have sought to incorporate treated organic materials to produce environmentally friendly fertilizers (Enebe & Erasmus, 2023), such as vermicompost-derived products. Vermicomposting is a viable alternative due to its simple production techniques and the ecological and economic benefits it offers (Deepak, 2019).

Vermicomposting is a biological process in which earthworms decompose organic matter, transforming it into a nutrient-rich (Thirunavukkarasu *et al.*, 2022) and microbe-enriched fertilizer (Enebe & Erasmus, 2023). The resulting product, known as vermicompost, contains essential nutrients such as carbon, nitrogen (N), phosphorus (P), and potassium (K), as well as microorganisms, enzymes, plant growth regulators, and hormones (Gupta & Garg, 2008). Various sources of organic waste can be used in the vermicomposting process, including animal manure, sewage sludge, food production waste, kitchen waste, and horticultural residues, among others (Thirunavukkarasu *et al.*, 2022).

The potential benefits of using vermicompost include stimulating plant growth, reducing the incidence of diseases, and increasing soil porosity and microbial activity (Padilla *et al.*, 2021). In other words, vermicompost promotes soil biology improvement, which leads to enhanced crop productivity (Enebe & Erasmus, 2023), including nutrient absorption and plant growth. Recently, Keskin *et al.* (2025) reported that vermicompost induces increases in root biomass and leaf area. These effects can be attributed to the role of vermicompost in increasing organic carbon in the soil, as well as its capacity to improve soil water retention, aeration, and porosity (Haque & Biswas, 2021; Liu *et al.*, 2020; Wang *et al.*, 2018).

The use of vermicompost produced from bovine manure has generated growing interest in the dairy industry (Padilla *et al.*, 2021); however, dairy farmers face several issues regarding manure management (Padilla *et al.*, 2021); this implies the need for guidance on the proper management and use of vermicompost through the organization of various training and outreach activities (Sharma & Garg, 2019).

In the case of the state of Zacatecas, Mexico, some farmers and companies produce and market vermicompost. However, the evident issue is the lack of information regarding production systems, products (vermicomposts and leachates), as well as their composition, quality, storage, packaging, transportation, and distribution. In this context, the municipalities of Fresnillo (16,890.80 thousand liters), Río Grande (15,226.20 thousand liters), and Miguel Auza (23,014.70 thousand liters) are the top producers of cow's milk (SIAP, 2021); this implies that these municipalities have the highest number of dairy cattle farms and greater manure production due to the confinement of the animals.

Therefore, it is essential to understand the challenges, issues, and problems faced by farmers who have access to dairy cattle manure in adopting vermicomposting technology (Padilla *et al.*, 2021). Thus, the objective of this research was to identify the reasons why farmers with access to bovine manure in the municipalities of Fresnillo, Río Grande, and Miguel Auza, Zacatecas either incorporate or do not incorporate this raw material for the production, marketing, and use of vermicompost.

## **MATERIALS AND METHODS**

A data generation/collection instrument was designed with semi-structured statements, considering a first section about the respondent's data, such as the production unit profile, infrastructure, equipment, and input acquisition. The second section of the instrument included 59 items based on the Likert scale. These items addressed technical and productive

aspects within the human (14 items), social (19 items), physical (15 items), and economic (11 items) domains, in accordance with the Mexico's Sustainable Rural Development Law (DOF, 2019). The response scale consisted of five agreement categories. The categories were: Disagree, Partially Disagree, Neither Agree nor Disagree, Agree, and Strongly Agree (Likert, 1932). The information generated through the application of semi-structured questionnaires can be useful for estimating their reliability using the Cronbach's alpha statistic (Añorve-Guillén, 1991).

The application of the semi-structured questionnaire was carried out from November 2022 to May 2023. The instrument was administered to farmers in the municipalities of Fresnillo, Río Grande, and Miguel Auza, Zacatecas. Visits to the involved farmers were conducted to inform them about the study and obtain their consent as informants. Once consent was obtained, the questionnaire was provided to them in printed form so they could answer it at their convenience, ensuring their responses were not influenced.

### Data Collection and Analysis

The data collected from the surveys were entered into a Microsoft Excel<sup>®</sup> spreadsheet, classified by human, social, physical, and economic capitals. Values from 1 to 5 were assigned to the Likert scale levels. This approach made it possible to calculate basic statistical estimators and verify whether the sample ( $n=30$ ) was representative. The reliability of the questionnaire was confirmed through Cronbach's alpha coefficient ( $\alpha$ ). This statistical estimator evaluates the internal consistency of a set of items. The  $\alpha$  is used to determine the reliability of a survey that uses a measurement scale, as it reflects the correlations between the variables. The higher the  $\alpha$  value, the greater the internal consistency of the questionnaire.

A principal component analysis (PCA) was carried out with the aim of identifying the items that explain the largest portion of the variance in the data matrix. The principal components (PCs) allowed for the identification of the variables (items) that best describe the structure of each component, thus facilitating the ordination of the involved farmers. Additionally, a multivariate cluster analysis (CA) was performed to classify the farmers based on the structure of the Principal Components (*i.e.*, the coefficients of the Principal Components) that together explained >60% of the total variation. Overall, this analysis confirmed the groups identified through the PCA. The statistical analyses were performed using MINITAB 16<sup>®</sup> software.

### RESULTS

All the farmers who participated in answering the questionnaire were men ( $n=30$ ) (Table 1). The sample was found to be representative. Regarding age distribution, 40% of the respondents are 60 years or older; 30% are between 50 and 59 years old; 23.33% are between 40 and 49 years old; and 6.67% are between 30 and 39 years old. Concerning educational level, 86.67% of the farmers completed only basic education (primary and secondary), while 13.33% reached higher secondary education. Additionally, 66.67% of the farmers reported using vermicompost.

**Table 1.** Statistical Estimators of the Farmers (n=30) who answered the questionnaires in the municipalities of Fresnillo, Río Grande, and Miguel Auza, Zacatecas, Mexico.

| Age class        | Percentage       |       |
|------------------|------------------|-------|
| 18 to 29 years   | DNA <sup>1</sup> |       |
| 30 to 39 years   | 2                | 6.67  |
| 40 to 49 years   | 7                | 23.33 |
| 50 to 59 years   | 9                | 30    |
| >60 years        | 12               | 40    |
| Schooling        |                  |       |
| Elementary       | 15               | 50    |
| Secondary        | 11               | 36.67 |
| High             | 4                | 13.33 |
| Bachelor         | NA               | NA    |
| Other            | NA               | NA    |
| Use Vermicompost |                  |       |
| Yes              | 20               | 66.67 |
| No               | 10               | 33.33 |

<sup>1</sup>DNA: Does not apply.

### Reliability of the Questionnaire

The Cronbach's Alpha values for the Human Capital ( $\alpha=0.819$ ), Social Capital ( $\alpha=0.826$ ), and Physical Capital ( $\alpha=0.802$ ) indicate good reliability. Additionally, the value of this coefficient for Economic Capital ( $\alpha=0.935$ ) suggests excellent internal consistency. Therefore, the information generated through the application of the questionnaire is sufficiently reliable. For example, the error associated with the information about the Human Capital of the farmers is 0.329 (*i.e.*,  $0.819 \times 0.819 = 0.670$ ;  $1 - 0.670 = 0.329$ ).

### Human Capital

The PCA conducted based on 14 items about Human Capital showed that the first four components explain 67% of the total variance (Table 2). CP1 (31%) reflects the farmers' perception of soil improvement and the importance of training. CP2 (15.6%) focuses on knowledge about plant nutrition and the vermicomposting process. CP3 (12.3%) highlights the use of leachate as a fertilizer and plant disease resistance, while CP4 (8.1%) is based on ease of use and improvements in seed germination and soil aeration.

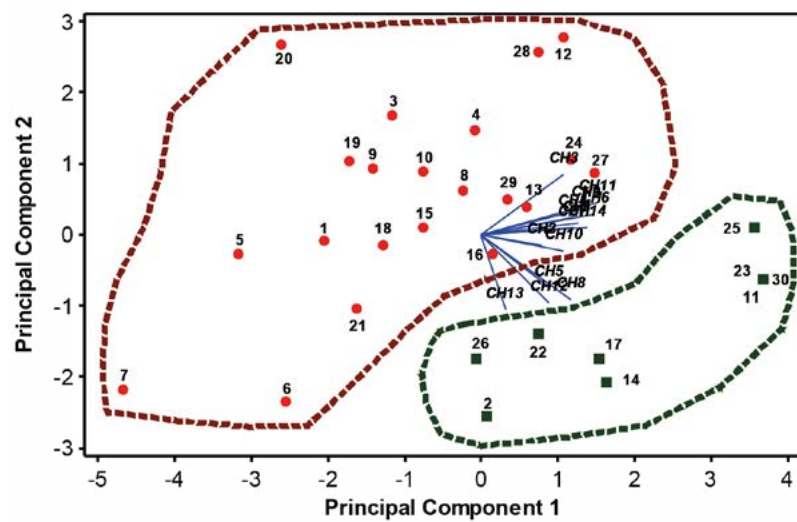
**Table 2.** Eigenvalues, proportions of explained variance, and cumulative variance associated with the first four principal components (PCs) corresponding to 14 items on Human Capital regarding the use of vermicompost based on the perceptions of 30 surveyed farmers.

|                        | PC1    | PC2    | PC3    | PC4    |
|------------------------|--------|--------|--------|--------|
| Eigenvalue             | 4.3422 | 2.1792 | 1.7150 | 1.1387 |
| Proportion of variance | 0.310  | 0.156  | 0.123  | 0.081  |
| Accumulated variance   | 0.310  | 0.466  | 0.588  | 0.670  |

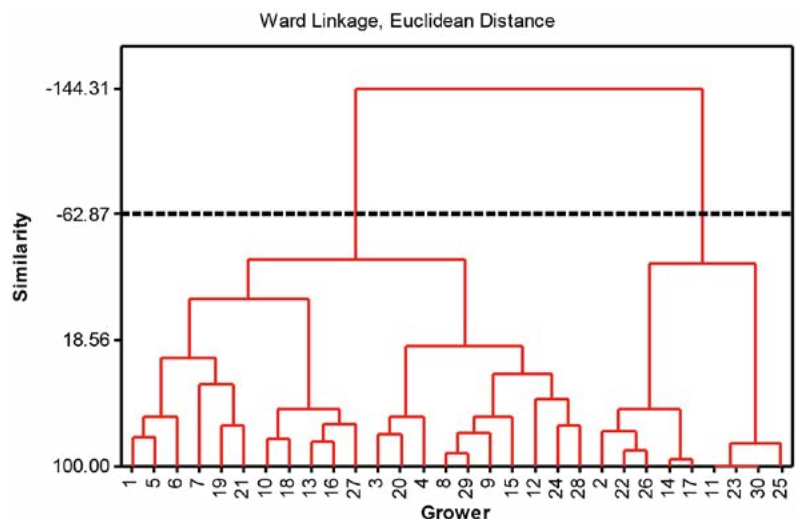
Both the PCA results (Figure 1) and CA results through the Euclidean Distance = -62.87 (Figure 2) identify two groups of farmers. The first group (farmers 2, 11, 14, 17, 22, 23, 25, 26, and 30) agrees that vermicompost is easy to apply, improves plant nutrition and disease resistance, and uses technical instructions; the second group (remaining farmers) highlighted improvements in germination, roots, and soil aeration, and considers training to be important.

**Social Capital**

The Principal Component Analysis (PCA) on Social Capital (19 items) showed that the first five principal components explained 61.6% of the total variability. CP1 (25.5%)



**Figure 1.** Position of the 30 farmers according to their perception, considering 14 items on Human Capital regarding the use of vermicompost in the orthogonal plane defined by the first two Principal Components.



**Figure 2.** Dendrogram of 30 farmers based on their perception, considering 14 items on Human Capital regarding the use of vermicompost as variables.

is related to recommendations from suppliers to improve soil fertility; CP2 (10.3%) is associated with the reduction of chemical fertilization and technical support; CP3 (10%) is linked to soil aeration and plant tolerance to stress; CP4 (9%) is associated with germination and yield; and CP5 (6.8%) is related to plant nutrition and root growth.

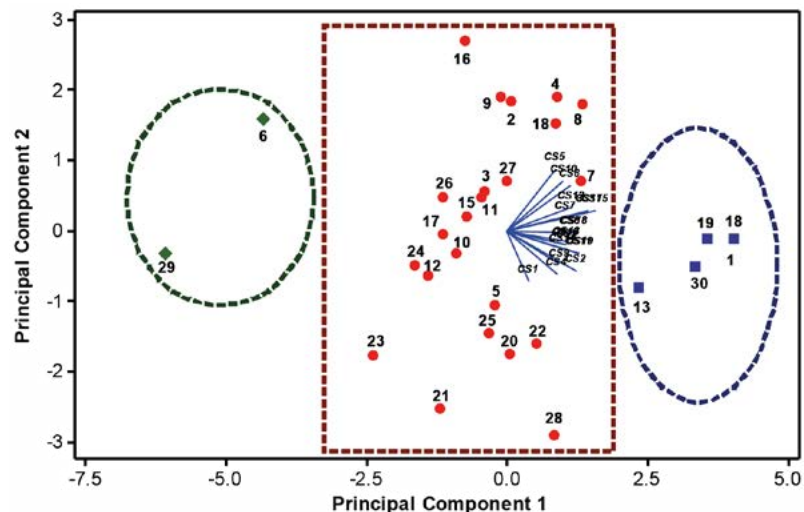
Three groups of farmers were identified based on their perception of vermicompost usage recommendations (Figure 3). The multivariate cluster analysis (CA) confirmed these groups through Ward’s method and Euclidean Distance = -10.46.

**Physical Capital**

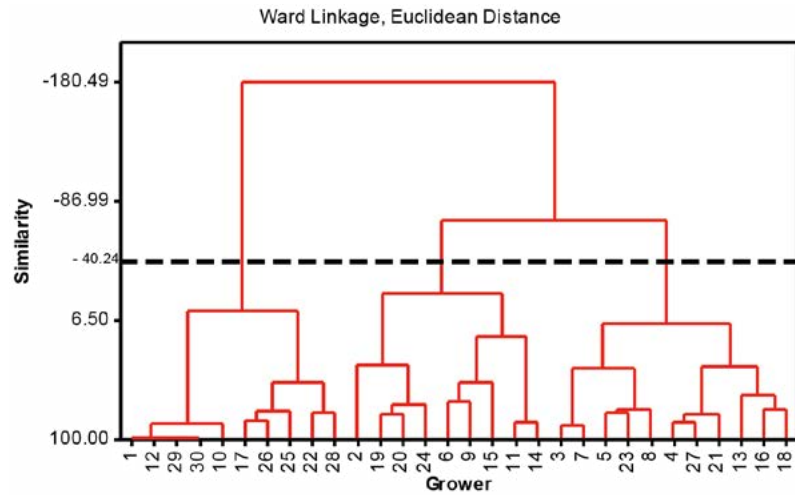
The PCA on Physical Capital, based on the perception of 30 farmers, revealed that the first four components explain 68.3% of the total variation. CP1 emphasizes soil fertility and nutrition. CP2 is more related to plant growth improvement and soil aeration. CP3 highlights that fertility and photosynthesis are enhanced. CP4 refers to how vermicompost facilitates germination and induces stress tolerance. In the plane defined by CP2 vs. CP1, three groups of farmers were identified (not shown). The first group perceives improvements in soil fertility and reduced pollution; the second values soil nutrition and microorganisms; and the third observes plant growth and resistance. The hierarchical cluster analysis confirmed these groups through a Euclidean Distance = -40.24 (Figure 4).

**Economic Capital**

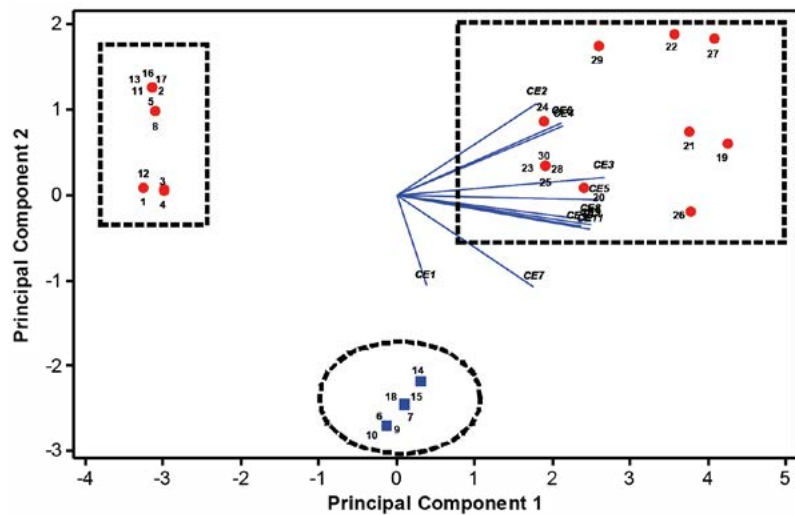
The PCA of 11 items on Economic Capital, based on the perceptions of 30 farmers, showed that the first two components explain 87.8% of the total variation. CP1 highlights the reduction of costs in fertilizers, root growth enhancers, plant nutrition, and pest control, while CP2 emphasizes the use of machinery and specialized labor, as well as the reduction in chemical fertilizer quantities and increased yield. In the CP2 vs. CP1 plane, three groups of farmers were identified (Figure 5). The first



**Figure 3.** Position of 30 farmers according to their perception considering 19 items of Social Capital on the use of vermicompost in the orthogonal plane defined by the first two Principal Components.



**Figure 4.** Dendrogram of 30 farmers based on their perception of 23 items regarding Physical Capital on the use of vermicompost as variables.



**Figure 5.** Position of 30 farmers according to their perception, considering 11 items of Economic Capital on the use of vermicompost in the orthogonal plane defined by the first two Principal Components.

group does not perceive cost savings or the need for machinery; the second disagrees with the reduction of chemical fertilizers and hormones but perceives an increase in income; the third perceives reductions in fertilization and plant nutrition costs. The multivariate cluster analysis (CA) confirmed these groups using Ward’s method and a Euclidean distance of  $-139.13$ .

## DISCUSSION

### Human Capital

The PCA and the CA identified two groups of farmers based on 14 statements related to Human Capital. The first group, composed of 8 respondents, agrees that vermicompost leachate is a useful foliar fertilizer. This aligns with Kmet’ová & Kováčik (2014), who argue

that using leachate can increase crop productivity. This effect is attributed to the humic acid in the leachate, which provides nutrients such as calcium, iron, potassium, sulfur, and phosphorus (Adhikary, 2012). The second group, made up of 22 farmers, understands that vermicompost enriches the soil with microorganisms. Edwards *et al.* (1984) observed significant populations of Gram-negative Enterobacteriaceae, protozoa, and fungi in vermicompost substrate. Additionally, they noted that worms, by digesting organic matter, increase the surface area of the material, promoting microbial colonization and the decomposition of organic matter.

### **Social Capital**

When analyzing 19 items on Social Capital, three groups of farmers were identified. The first group, consisting of 5 farmers, agrees that technical advisors and suppliers frequently recommend the use of vermicompost to improve the aggregation of soil mineral particles. According to Ansari & Ramnarain (2020), the application of vermicompost increases microbial activity, enzymes, and humic acid content, which improve soil aggregation, stability, and aeration. The second group, made up of 23 farmers, agrees that vermicompost improves plant nutrition. Several studies (*e.g.*, Atiyeh *et al.*, 2000; Ozores-Hampton & Vavrina, 2002) have shown that a growing medium with 10 to 20% vermicompost enhances plant growth. Finally, the third group (2 farmers) notes that technical advisors and suppliers recommend the use of vermicompost to improve root growth and structure. McClintock (2004) states that vermicompost improves the physical structure, fertility, and microbiological properties of the soil, promoting plant growth both in transplants and field crops.

### **Physical Capital**

Analysis of 15 items on Physical Capital identified three groups of farmers. The first group, consisting of 10 farmers, agrees that the vermicomposting process requires four to six months, although some researchers indicate that vermicomposting can require 40 to 45 days (*e.g.*, Ansari & Ramnarain, 2020). The second group (9 farmers) agrees that vermicompost improves soil fertility. Ansari & Ramnarain (2020) note that its application improves soil properties such as organic matter content, nitrogen, phosphorus, potassium, sulfur, zinc, and boron, which favor crop yields such as cereals. The third group (11 farmers) agrees that vermicompost provides disease resistance. In this regard, vermicompost based on sludge and bovine manure reduces infection by pathogens causing root rot in tomatoes (Szczech & Smolinska, 2001). Other studies (*e.g.*, Ascianto *et al.*, 2006) also indicate that vermicompost controls various species of *Phytophthora* and *Rhizoctonia*, through biological disease-suppression mechanisms (Simsek-Ersahin *et al.*, 2009).

### **Economic Capital**

Analysis of the 11 items on economic capital identified three groups of farmers. The first group (11 farmers) disagrees with the idea that the use of vermicompost reduces costs associated with disease control and the application of rooting agents. This perception contradicts the fact that vermicompost contains humic acids (Atiyeh *et al.*, 2002), as well

as auxins, gibberellins, and cytokinins (Singh *et al.*, 2008); these compounds are growth regulators that enhance plant growth, and improve productivity in various crops (Atiyeh *et al.*, 2002). The second group, consisting of 7 farmers, disagrees with the idea that vermicompost reduces the amount of chemical fertilizer required; this partially aligns with the findings of Jeyabal & Kuppaswamy (2001), who found that the combination of vermicompost and nitrogen fertilizer increases productivity more than the fertilizer alone. The third group, made up of 12 farmers, agrees that using vermicompost can reduce costs associated with chemical fertilizers. In this regard, Guo *et al.* (2015) demonstrated that although the initial costs of the vermicomposting process are higher than those of traditional composting, the production of worms and the use of cow manure vermicompost increase crop yields, such as maize, resulting in economic benefits.

## CONCLUSIONS

When vermicompost is used in production units, one group of farmers (10) perceives improvements in soil fertility and reduced contamination; a second group (9) values soil nutrition and microorganisms; and a third group (11) observes better plant growth and disease resistance. Therefore, it is recommended to foster collaboration among farmers, technicians, and public servants, as this could promote the development of capabilities regarding agroecological practices to enhance the production, commercialization, and use of vermicompost to improve agricultural productivity.

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## REFERENCES

- Adhikary, S. (2012) Vermicompost, the story of organic gold: A review. *Agricultural Sciences*, 3, 905-917. doi: 10.4236/as.2012.37110.
- Ansari, A.A., Ori, L., Ramnarain, Y.I. (2020). An effective organic waste recycling through vermicompost technology for soil health restoration. In: Meena, R. (eds.) *Soil Health Restoration and Management*. Springer, Singapore. [https://doi.org/10.1007/978-981-13-8570-4\\_3](https://doi.org/10.1007/978-981-13-8570-4_3)
- Añorve-Guillén, M. A. (1991). La fiabilidad en la entrevista: La entrevista semi estructurada y estructurada, un recurso de la encuesta. *Investigación Bibliotecológica: Archivonomía, Bibliotecología e Información*, 5(10), 29-37. <http://dx.doi.org/10.22201/iibi.0187358xp.1991.10>
- Asciutto, K., Rivera, M. C., Wright, E. R., Moriguie, D., & López, M. V. (2006). Effect of vermicompost on the growth and health of impatiens wallerana. *Phyton Int. J. Exp. Bot.* 75, 115-123. [https://cdn.techscience.cn/files/phyton/2006/v75nall/20181010082532\\_31906.pdf](https://cdn.techscience.cn/files/phyton/2006/v75nall/20181010082532_31906.pdf)
- Atiyeh, R.M., Lee, S.S., Edwards, C.A., Arancon, N.Q., & Metzger, J. (2002). The influence of humic acid derived from earthworm-processed organic waste on plant growth. *Bioresour. Technol.* 84, 7-14. doi:10.1016/S0960-8524(02)00017-2
- Atiyeh, R.M., N. Arancon, C.A. Edwards, & J.D. Metzger. (2000). Influence of earthworm-processed pig manure on the growth and yield of greenhouse tomatoes. *Bioresource Technology* 75, 175-180.
- Diario Oficial de la Federación (DOF). (2019). Ley de Desarrollo Rural Sustentable (LDRS). Diario Oficial de la Federación. Consultado el 2 de septiembre de 2022. [http://www.diputados.gob.mx/LeyesBiblio/pdf/235\\_120419.pdf](http://www.diputados.gob.mx/LeyesBiblio/pdf/235_120419.pdf).
- Deepak, C., R. D. (2019). Capacity Building Toolkit Module 7. Business Model: Vermicomposting. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). New Delhi, India. 28 p. <https://birdlucknow.nabard.org/wp-content/uploads/2020/03/17-Vermicompost-BM.pdf>

- Edwards, C.A., I. Burrows, K.E. Fletcher, and B.A. Jones. 1984. The use of earthworms for composting farm wastes. In: J.K.R. Gasser (ed.) *Composting of Agricultural and Other Wastes*. Elsevier Applied Science Publishers, London.
- Enebe, M. C., & Erasmus, M. (2023). Vermicomposting technology-A perspective on vermicompost production technologies, limitations and prospects. *Journal of Environmental Management*, 345, 118585. <https://doi.org/10.1016/j.jenvman.2023.118585>
- Guo, L., Wu, G., Li, C., Liu, W., Yu, X., Cheng, D., & Jiang, G. (2015). Vermicomposting with maize increases agricultural benefits by 304%. *Agronomy for Sustainable Development* 35, 1149-1155. <https://doi.org/10.1007/s13593-015-0307-0>
- Gupta, R., & Garg, V. K. (2008). Stabilization of primary sewage sludge during vermicomposting. *Journal of Hazardous Materials*, 153(3), 1023-1030. <https://doi.org/10.1016/j.jhazmat.2007.09.055>
- Haque, M. M., & Biswas, J. C. (2021). Emission factors and global warming potential as influenced by fertilizer management for the cultivation of rice under varied growing seasons. *Environmental Research*, 197, 111156. <https://doi.org/10.1016/j.envres.2021.111156>
- Jeyabal, A., & Kuppaswamy, G. (2001). Recycling of organic wastes for the production of vermicompost and its response in rice-legume cropping system and soil fertility. *European Journal of Agronomy*, 15(3), 153-170. [https://doi.org/10.1016/S1161-0301\(00\)00100-3](https://doi.org/10.1016/S1161-0301(00)00100-3)
- Keskin, B., Akhoundnejad, Y., Dasgan, H. Y., & Gruda, N. S. (2025). Fulvic Acid, Amino Acids, and Vermicompost Enhanced Yield and Improved Nutrient Profile of Soilless Iceberg Lettuce. *Plants*, 14(4), 609. <https://doi.org/10.3390/plants14040609>
- Kmetová, M., & Kováčik, P. (2014). The impact of vermicompost application on the yield parameters of maize (*Zea mays* L.) observed in selected phenological growth stages (BBCH-SCALE). *Acta Fytotechnica et Zootechnica*, 17(4), 100-108. <https://doi.org/10.15414/afz.2014.17.04.100-108>
- Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, 140, 1-55. Consultado el 20 de diciembre de 2022 en: <https://psycnet.apa.org/record/1933-01885-001>
- Liu, N., Liao, P., Zhang, J., Zhou, Y., Luo, L., Huang, H., & Zhang, L. (2020). Characteristics of denitrification genes and relevant enzyme activities in heavy-metal polluted soils remediated by biochar and compost. *Science of the Total Environment*, 739, 139987. <https://doi.org/10.1016/j.scitotenv.2020.139987>
- McClintock, N. C. (2004). Production and use of compost and vermicompost in sustainable farming systems. Thesis for the Degree of Master in Sciences. North Carolina State University. Consultado el 30 de abril de 2024, en: <https://efaidnbmnnnibpajpcgglefindmkaj/https://repository.lib.ncsu.edu/server/api/core/bitstreams/534a3b90-a49e-4888-a48c-839aaf8f7c83/content>
- Ozores-Hampton, M., and C.S. Vavrina. 2002. Worm castings: an alternative to sphagnum peat moss in organic tomato (*Lycopersicon esculentum* Mill.) transplant production. *Proc. Intl. Composting and Compost Sci.* Symposium, Columbus, Ohio, USA.
- Padilla, N. E., Payne, J. A. G., Lapastura, R. J. S., & Cadelina, E. J. A. (2021). Awareness on the benefits of the adoption of dairy vermicomposting technology in selected cooperatives in Region 02. *Journal of Agricultural Research*, 9(6), 258-265. <https://doi.org/10.13189/ujar.2021.090604>
- Sharma, K., & Garg, V. K. (2019). Vermicomposting of waste: a zero-waste approach for waste management. In: *Sustainable Resource Recovery and Zero Waste Approaches* (pp. 133-164). Elsevier. <https://doi.org/10.1016/B978-0-444-64200-4.00010-4>
- Sistema de Información Agroalimentaria y Pesquera (SIAP). Secretaría de Agricultura y Desarrollo Rural. Gobierno de México. (2021). Estadística de la producción pecuaria de 2021. Consultado el 3 de septiembre de 2022, en: [http://infosiap.siap.gob.mx/gobmx/datosAbiertos\\_p.php](http://infosiap.siap.gob.mx/gobmx/datosAbiertos_p.php)
- Simssek-Ersahin, Y., Haktanir, K., & Yanar, Y. (2009). Vermicompost from agricultural wastes suppress *Rhizoctonia Solani* Kuhn in cucumber seedlings. *J. Plant Dis. Prot.* 116:182-188. <https://doi.org/10.1007/bf03356308>
- Singh, R., Sharma, R.R., Kumar, S., Gupta, R.K., Patil, R.T. (2008). Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry (*Fragaria × ananassa* Duch.). *Bioresour. Technol.* 99, 8507-8511. doi:10.1016/j.biortech.2008.03.034
- Szczzech, M.M., & Smolinska, U. (2001). Comparison of suppressiveness of vermicomposts produced from animal manures and sewage sludge against *Phytophthora nicotianae* Breda de Haan var. nicotianae. *J. Phytopathol.* 149, 77-82. <https://doi.org/10.1046/j.1439-0434.2001.00586.x>
- Thirunavukkarasu, A., Nithya, R., Kumar, S. M., Priyadharshini, V., Kumar, B. P., Premnath, P., Sivashankar, R., & Sathya, A. B. (2022). A business canvas model on vermicomposting process: key insights onto technological and economical aspects. *Bioresource Technology Reports*, 18, 101119. <https://doi.org/10.1016/j.biteb.2022.101119>
- Wang, C., Liu, J., Shen, J., Chen, D., Li, Y., Jiang, B., & Wu, J. (2018). Effects of biochar amendment on net greenhouse gas emissions and soil fertility in a double rice cropping system: A 4-year field experiment. *Agriculture, Ecosystems & Environment*, 262, 83-96. <https://doi.org/10.1016/j.agee.2018.04.017>

# Factors explaining price decrease of chicken meat in Mexico

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## ABSTRACT

**Objective:** to determine the main factors that explain the decrease in the real price of chicken meat for the producers in Mexico during the period 1994-2021.

**Design/ Methodology/Approach:** an inverse supply function was used to determine the percentage change in the price of chicken meat when the factors that determine this variable vary.

**Results:** it was proved that technological change was the main variable explaining the decrease in the price of this white meat. Other factors, such as decrease in the price of competitive products and the inputs used as feed for broilers, also favored price drop.

**Study limitations/ Implications:** a limitation of the study is that only Mexico's domestic data were used.

**Findings/Conclusions:** a drop in the price of chicken meat to the producer in Mexico is explained by the behavior of the factors that determine chicken meat supply in the period analyzed. Such factors were technological development, as well as the decrease in the prices of the inputs used in production, and other competitive goods, which explain price drop to the producer.

**Keywords:** chicken meat, price to the producer, technological change, inverse supply function, flexibility.

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## INTRODUCTION

The decrease in the price of chicken meat in Mexico in recent decades has contributed to one of the main objectives of domestic economy policy, this is to keep the inflation rate in single digits. According to Mexico's Agrifood and Fisheries Information Service (SIAP, 2022), chicken, beef, pork and eggs had a 5% share in the National Consumer Price Index in November 2022; which allow us to assume that the 26.3% decrease in the real price to the producer of chicken meat that was experienced from 1994 to 2021 has caused also a decrease in the real price of this meat to the consumer, thus reducing inflationary pressure on the Mexican economy and increasing the overall purchasing power of Mexicans.

The decrease in the price of chicken meat brought benefits for consumers of this meat, the first of which was a consumption increase. The Organization for Economic Cooperation and Development (OCDE, 2018) states that in the last 40 years there has



been an increase in the production and consumption of several types of meat, chicken meat industry has been the most successful in this expansion. This agency adds that the price of this meat is lower than that of other types of meat, so the evolution of the price of chicken meat has been lower than the evolution experienced in the National Consumer Price Index. If the prices of January 1990 are taken as reference, overall prices increased 1083% up to January 2016; whereas chicken unit price increased by 662%.

Due to the decrease in price, the amount of chicken meat consumed in Mexico experienced growth in the same period, from 1.25 million tons (Megagrams, Mg) in 1994 to 4.48 million Mg in 2021; this means a growth of 258.5% in the period of analysis, with a 4.8% average annual growth. The consumption of chicken meat was supplied with national production and imports. From 1994 to 2021, the amount of chicken meat produced in Mexico increased 2.54 million Mg, from 1.1 to 3.7 million Mg produced in the cited period (SIAP, 2024), this means a 225.8% growth rate and a 4.31% average annual growth.

The growth of chicken meat in recent years seems to indicate that the decrease in the price of chicken meat is due to a growth in the supply of this industry, which would mean a shift of the supply curve to the right, according to economic theory. Tomek & Kaiser (2014) indicated that the supply of a good is a function of the price of the good, the price of goods that compete for resources (competitive goods), the price of goods related to the product under analysis, and technological development, among others. Therefore, in the period 1994-2021 there are factors that increased the supply of chicken meat and explain price drop of this meat.

To address the high consumption of chicken meat in Mexico, the objective of this research was to determine the factors that explain the decrease in the real price of this meat to the producer. In particular, considering the quantity of chicken meat produced, the real price of balanced feed for broilers, the real price of pork meat to the producer, and technological development. The main hypothesis considers that the real price of chicken meat to the producer will be determined mainly, by technological development and by the real price of the balanced feed used for chicken meat production.

## MATERIALS AND METHODS

If we observe that consumption has increased, then demand is excluded as a factor explaining price drop of chicken meat. Therefore, the decrease is due to the shift in the supply curve, caused by the behavior of factors that affect supply, such as technological change and the price of inputs used in feeding chicken. The model to determine those factors that explain price drop in chicken meat is an inverse supply function that allows determining the percentage of change in the price of chicken meat when the factors that determine this variable vary.

To obtain the model, the following supply function is used:

$$QPCP_t = f(PPCP_t, PPCC_t, PRAB_{t-1}, CA_t) \quad (1)$$

where  $QPCP_t$  is the quantity of carcass chicken produced in a year  $t$  in Mg;  $PPCP_t$  is the real producer price of carcass chicken in year  $t$  in Mexican pesos (MXN \$) per Mg;  $PPCC_t$

is the real price to the producer of carcass pork in year  $t$  in MXN \$ Mg<sup>-1</sup>;  $PRAB_{t-1}$  is the real price of broilers feed in year  $t-1$ , in MXN \$ Mg<sup>-1</sup>; and  $CA_t$  is the feed conversion in year  $t$ , in g of carcass chicken per kg of balanced feed.

The model was formulated based on microeconomic theory, which stipulates that changes in the quantity supplied of a product will be determined by A) observed changes in its price; B) price of inputs; C) price of goods that compete with the targeted factors of production; and D) technological development, which determines the efficiency of production, therefore, its production costs (Tomek & Kaiser, 2014).

Then you get the  $QPCP$  differential:

$$dQPCP = \frac{\partial QPCP}{\partial PPCP} dPPCP + \frac{\partial QPCP}{\partial PPCC} dPPCC + \frac{\partial QPCP}{\partial PRAB} dPRAB + \frac{\partial QPCP}{\partial CA} dCA \quad (2)$$

and divide both members of the supply function by  $QPCP$  and multiply the four independent variables of this function by  $PPCP/PPCP$ ,  $PPCC/PPCC$ ,  $PRAB/PRAB$  and  $CA/CA$ . So, the resulting equation,

$$\begin{aligned} \frac{dQPCP}{QPCP} &= \frac{\partial QPCP}{\partial PPCP} \frac{PPCP}{QPCP} \frac{dPPCP}{PPCP} + \frac{\partial QPCP}{\partial PPCC} \frac{PPCC}{QPCP} \frac{dPPCC}{PPCC} + \frac{\partial QPCP}{\partial PRAB} \frac{PRAB}{QPCP} \frac{dPRAB}{PRAB} \\ &+ \frac{\partial QPCP}{\partial CA} \frac{CA}{QPCP} \frac{dCA}{CA} \end{aligned} \quad (3)$$

can be expressed in percentage terms (—) as follows:

$$\overline{QPCP} = \varepsilon_1 \overline{PPCP} + \varepsilon_2 \overline{PPCC} + \varepsilon_3 \overline{PRAB} + \varepsilon_4 \overline{CA} \quad (4)$$

where (—) indicates percentage change of the variables of the model;  $\varepsilon_1$  is the proper price elasticity of supply;  $\varepsilon_2$  is the cross-price elasticity of supply;  $\varepsilon_3$  is the elasticity that relates the quantity of chicken meat produced to the price of the balanced feed; and  $\varepsilon_4$  is the elasticity that relates the supply of chicken meat and feed conversion and where  $\varepsilon_1, \varepsilon_4 > 0$ ; y  $\varepsilon_2$  y  $\varepsilon_3 < 0$ .

The inverse supply function can be obtained by expressing the price as a function of the quantity supplied; this is:

$$\overline{PPCP} = +\frac{1}{\varepsilon_1} \overline{QPCP} - \frac{\varepsilon_2}{\varepsilon_1} \overline{PPCC} - \frac{\varepsilon_3}{\varepsilon_1} \overline{PRAB} - \frac{\varepsilon_4}{\varepsilon_1} \overline{CA} \quad (5)$$

Since,

$$\frac{\varepsilon_2}{\varepsilon_1} = \frac{\frac{\partial QPCP}{\partial PPCC} \frac{PPCC}{QPCP}}{\frac{\partial PPCC}{\partial PPCP} \frac{PPCC}{PPCP}} = \frac{\partial PPCP}{\partial PPCC} \frac{PPCC}{PPCP} = \gamma_2 \quad (6)$$

and it is considered for the other independent variables that relations similar to the one expressed by equation 6 can be obtained; Then, equation 5 can be expressed as follows:

$$\overline{PPCP} = +\gamma_1 \overline{QPCP} + \gamma_2 \overline{PPCC} + \gamma_3 \overline{PRAB} - \gamma_4 \overline{CA} \quad (7)$$

where  $\gamma_1, \gamma_2, \gamma_3$  and  $\gamma_4$  measure the percentage change in  $PPCP$  when it varies by 1%  $QPCP$ ,  $PPCC$ ,  $PRAB$  and  $CA$ , respectively; and with the consideration of the sign of the elasticities, then  $\gamma_1$  and  $\gamma_4 > 0$  and  $\gamma_2$  and  $\gamma_3 < 0$ .

Therefore,  $PPCP$  is expected to react directly to changes in  $PPCC$ ,  $PRAB$  and  $QPCP$ ; and conversely with  $CA$ . This indicates that a decrease in  $QPCP$ ,  $PPCC$  and  $PRAB$  would drive the same effect as a shift of the supply curve to the right causing a decrease in the price, and an increase in  $CA$  would have the same effect.

The information used in the model was obtained from the sources mentioned below. Supply-related elasticities of chicken meat came from Nochebuena-Molina *et al.* (2023). The growth rates shown in the model equation 7 were calculated using information in the periods 1994-1996 and 2019-2021. From SIAP (2024) the quantity of carcass chicken produced; the producer price of a Mg of chicken meat; the producer price of one Mg of pork; and the producer prices of corn and soybeans were obtained. The values in real terms were obtained by dividing the independent variable by the 2018 value of the National Consumer Price Index, as it was reported by INEGI (2024).

The actual price of broiler feed ( $PRAB$ ) was obtained as follows: A) the amount of corn and soybeans used in the production of feed constitutes 92.4% of a Mg of balanced feed; B) if the share of both inputs is established as 100%, it is obtained that corn constitutes 50.8% of the balanced feed and soybeans have a participation of 49.2%; C) a weighted average of the real producer prices of corn ( $PM_t$ ) and soybeans ( $PS_t$ ) was calculated to obtain the price of the balanced feed, that is,

$$PRAB = (PM_t * 0.508) + (PS_t * 0.492)$$

The time series referring to feed conversion ( $CA$ ), the variable used here to represent technological development, was calculated as follows. A) The initial value for 1985 reported by Rigolin (2014) was used, this is 2.5 kg of balanced feed were necessary to obtain one kg of chicken meat in carcass; B) the final value reported by the National Union of Poultry Farmers (UNA, 2022) for 2021 was taken, where 1.75 kg of balanced feed were necessary to obtain one kg of chicken meat in carcass; C) the decision to use the indicator reported by the UNA (2022) as the final value was done because the

indicator reported previously by Rigolin (2014) is updated every 10 years. D) for the years between 1994 and 2021, the amount of balanced feed needed to obtain one kg of chicken meat was estimated with the equation 8; E) if this rate is applied to the value reported for 1985, the estimated value for 1986 is obtained, repeating the process until the value reported by the UNA in 2022 is obtained; and finally F) in order to observe whether technological development in the chicken meat industry has contributed to obtain more meat from one kg of balanced feed, the inverse of what was previously obtained was calculated, thus finding the amount of chicken meat in kg that is obtained from one kg of balanced feed.

The formula to obtain the growth rates of the independent variables in the model was as follows:

$$r = \left( \left( \frac{VF}{VI} \right)^{1/(n-1)} - 1 \right) * 100 \quad (8)$$

where  $r$  is the growth rate,  $VF$  is the final value,  $VI$  is the initial value, and  $n$  is the number of years in the time series.

## RESULTS AND DISCUSSION

Table 1 presents the results of the model. Supply price flexibility measures the percentage change in the price to the producer when a 1% change occurs in the quantity supplied, *ceteris paribus*. This interpretation is similar for each independent variable used in the model. The estimated flexibilities are also shown in Table 1. It can be observed that the flexibility relating the price and supply of chicken meat was 5.26; this indicates that in the event of a 1% increase in the quantity offered, the price of chicken meat will increase by 5.26%; a response more than proportional to the unit increase in the quantity offered. In the period under analysis, chicken meat supply experienced a growth of 107.9%, which explains the partial growth of the price by 568.1%.

**Table 1.** Factors that explain the change in the price of chicken meat in Mexico.

| Variable             | Supply function<br>QPCP=f(PPCP) |                                |                        | Inverse supply function<br>PPCP=f(QPCP) |                                |                        |
|----------------------|---------------------------------|--------------------------------|------------------------|---|--------------------------------|------------------------|
|                      | Elasticity                      | Change in independent variable | Partial change in QPCP | Flexibility                             | Change in independent variable | Partial change in PPCP |
| PPCP                 | 0.19                            | -13.1                          | -2.5                   | -                                       | -                              | -                      |
| PPCC                 | -0.48                           | -8.0                           | 3.8                    | 2.53                                    | -8.0                           | -20.2                  |
| PRAB                 | -0.21                           | -8.3                           | 1.7                    | 1.11                                    | -8.3                           | -9.1                   |
| CA                   | 3.79                            | 27.7                           | 104.9                  | -19.95                                  | 27.7                           | -551.9                 |
| QPCP                 | -                               | -                              | -                      | 5.26                                    | 107.9                          | 568.1                  |
| Total change in PPCP | -                               | -                              | -                      | -                                       | -                              | -13.1                  |
| Total change in QPCP | -                               | -                              | 107.9                  | -                                       | -                              | -                      |

As a competitive product, the flexibility that relates the producer price of chicken meat with the producer price of pork was 2.53; This means a 1% increase in the real price to the producer of pork will cause an increase of 2.53% in the real price of chicken meat to the producer. Regarding the price of goods that compete for the use of resources and according to information from SIAP (2024) and INEGI (2024), the real producer price of pork in Mexico decreased by MXN \$5359.25  $\text{Mg}^{-1}$  between 1994 and 2021, with a growth rate of 11.85% and an average annual decrease of 0.47%. This would imply, according to economic theory, that at similar conditions of both supply and demand, chicken meat production is more competitive than that of pork meat, since the decrease experienced in the chicken meat industry was greater than that experienced in the pork industry.

The flexibility corresponding to the real price of balanced feed was 1.11, which caused a positive response in the price of chicken meat. This is, facing a 1% increase in the price of balanced broilers feed, the price of chicken meat will increase by 1.11%; That is a more than proportional response to the increase in the price of balanced feed. In relation to the price of feeds used for livestock feed such as corn and soybeans, the Organization for Economic Cooperation and Development-OECD (OCDE, 2018) stated that balanced feed for broilers is a mixture of corn (which provides energy), soybeans (which provides protein), oils, fats, supplements and vitamins. Nochebuena-Molina *et al.* (2023) indicated that one Megagram of balanced feed for broilers contains 469 kg of corn and 459.91 kg of soybeans (jointly supplying 92.4% of total inputs).

As a technological variable, feed conversion presented a flexibility of  $-19.95$ , which means that, in the event of a 1% increase in this indicator, the price of chicken meat will decrease by 19.95%. This inverse effect of the technological variable (feed conversion) on the price of chicken meat is the most determining to the price of chicken meat in Mexico. Innovation by market participants can provide a number of desirable outcomes, such as increased production efficiency that can lead to decreased costs, improvements in product quality, a greater variety of products, and improvements in product safety (OECD, 2016).

In regard to technological change, Barbut (2015) stated that the decrease in chicken meat prices has its origin in improvements on genetics, health, breeding and processing. The selection of more efficient breeds in terms of meat production has resulted in better feed efficiency (*i.e.* the amount of balanced feed needed to obtain one kg of meat). In 1925 this index was 4.7, whereas in 2010 it was 1.92; which means that using balance feed promoted a more efficient use of resources, decreasing production costs in the chicken meat industry, so making it more competitive.

The value of the flexibilities and the growth rate of the independent variables allow us to analyze what has been the factor that explains the decrease observed in the price, which during the period of analysis was  $-13.1\%$ . The independent variables QPCP, PPCC, PRAB and CA showed a growth of 107.9,  $-8.0$ ,  $-8.27$  and 27.7% in the period 1994/96-2019/21. The decrease in the producer price of pork made the production of this meat less profitable and the resources were then channeled to chicken meat. In such a way that the fall in PPCC caused a 3.8% growth in chicken meat production, causing

a price drop of  $-20.2\%$  in the price of chicken meat to the producer, that made it more competitive.

The decrease in the PRAB caused the production costs of chicken meat to decrease, which stimulated its production by  $1.7\%$  and a  $-9.1\%$  drop in the price of chicken meat. Finally, the increase in CA caused a better use of balanced feed, thus reducing production costs in the chicken meat industry, which stimulated its production by  $104.9\%$ . Such an increase in supply caused a  $-551.9\%$  decrease in the price of chicken meat. These data indicate that the behavior of the variables PPCC, PRAB and CA determined price drop of chicken meat, and that the most determining variable in the behavior of this price was feed conversion. To what was mentioned above, Barbut (2015) added that those improvements in breeding and processing, in combination with innovation in the primary processing sector of chicken industry, and in the agricultural sector have led to an overall decrease in the price consumers pay for a unit of chicken meat.

In the absence of studies that analyze the effect of technological development on the prices of agricultural products and, especially, on the chicken meat market, the results are compared with what is stipulated by economic theory. As Tomek and Kaiser (2014) stated, in a given market, constant technological development causes the supply function to shift to the right, and if the supply of the analyzed good increases faster than demand, then the price of the product will decrease. If this occurs over time, the trend in the prices of a given product will be downward. Salvatore (2009) established that, if a production process presents a technological improvement that reduces production costs, the supply curve will shift downwards; this is, towards an increase in supply and a decrease in the price of the product.

In 2022, the OECD joined with the Food and Agriculture Organization of the United Nations (FAO), indicated that it is expected an increase between  $12$  and  $13\%$  in chicken meat production in Mexico from 2022 to 2031. This increment would be promoted by a rising demand and a favorable meat-forage price ratio compared to other meats, in response to technological development in animal health, feeding practices and genetics. Regarding the consumption of this type of meat in the country, OECD-FAO expect the above mentioned increase, due to the tendency to consume more white meat because of ease in preparation and a perception of being a better food option. In turn, these perceptions are coupled with the fact that the prices of chicken meat are lower than those of other types of meat. Regarding prices, OECD-FAO stated that the world reference price of chicken meat, after experiencing an increase in 2021, shall resume a downward trend, and it will continue so in real terms until 2031.

Regarding technological change, OECD-FAO (OCDE-FAO, 2022) projected an improvement in the forage to meat conversion rate in those countries that have this rate set at  $1.75$  (similar to that of Mexico), where this rate is expected to decrease by  $0.05\%$  per year until 2031. The United States Department of Agriculture (USDA, 2022) projected that global chicken meat consumption will increase by  $16.7\%$  from 2023 to 2031, driven by an increase in the population of developing countries and an increase in population income. This Agency expects Mexico's poultry production to grow during the 2023-2031

period at a slower rate than consumption, which would cause an increase in chicken meat imports in order to meet demand. As for prices, the Agency established that the nominal prices of chicken meat products will show an upward trend until 2031; but, it will depend on inflation if real prices increase or decrease.

Derived from the above, it is proposed that those Mexican policies that stimulate the development and acquisition of chicken breeds with a higher feed conversion rate would be the best instruments to face the challenge of the constant increase in demand for chicken meat.

## CONCLUSIONS

The increase in the supply of chicken meat was greater than the increase in demand during the period 1994 to 2021 because of technological development. The inverse effect of the technological variable caused the decrease in the price of chicken meat to the producer. Due to this decrease in the real price of chicken meat to the producer, the activity remained profitable, because of the observed decrease in the total cost of production. The behavior of the factors that explain the supply of chicken meat in the period analyzed were determinants to price drop.

The decrease in the prices of the competitive good evaluated and the inputs used as feed for broilers, as well as the technological change (an improved feed conversion rate) explained the drop in the price of chicken meat to the producer. Those positive effects of free trade could be nullified in the near future if global economics would determine an increase in the price of inputs used for feeding broilers, or a change in the price of goods that compete with the chicken industry. If that were the case, the price of chicken meat would eventually be increased.

## REFERENCES

- Barbut, Shai. (2015). *The Science of Poultry and Meat Processing*. University of Guelph.
- INEGI (Instituto Nacional de Estadística y Geografía). (2024). Sistema de Cuentas Nacionales de México. Índice Nacional de Precios al Consumidor y sus Componentes. [https://www.inegi.org.mx/app/tabulados/default.aspx?nc=ca55\\_2018](https://www.inegi.org.mx/app/tabulados/default.aspx?nc=ca55_2018)
- Nochebuena-Molina, Alvaro, García-Salazar, J. A., González-Estrada, E., & López-Reyna, M. del C. (2023). Determinantes de la oferta de carne de pollo en México de 1994 a 2021: importancia del desarrollo tecnológico y el precio de los granos forrajeros. *Acta Universitaria*, 33, 1-15. <https://doi.org/10.15174/au.2023.3901>
- OCDE (Organización para la Cooperación y el Desarrollo Económicos). (2018). Exámenes de mercado en México: estudio de caso del mercado de la carne de pollo. <https://web.archive.oecd.org/2018-10-24/497142-ESP-WEB-REPORT-Chicken-MeatMarketMexico2018.pdf>
- OCDE-FAO (Organización para la Cooperación y el Desarrollo Económicos / Organización de las Naciones Unidas para la Alimentación y la Agricultura). (2022). OCDE-FAO Perspectivas Agrícolas 2022-2031. <https://www.oecd-ilibrary.org/docserver/820ef1bb-es.pdf?expires=1685668043&id=id&accname=guest&checksum=50F2C4F6FB8A7EE7A83A4E5E6229F365>
- OECD (Organization for Economic Cooperation and Development). (2016). Market Examinations in Mexico: A manual by the OECD Secretariat. <https://www.oecd.org/daf/competition/Market-Examinations-in-Mexico-Manual-2016.pdf>
- Rigolin, P. (2014). ¿Conversión alimenticia 1:1c para 2025?: un vistazo al futuro de la avicultura. <https://www.wattagnet.com/home/article/15508713/conversion-alimenticia-1-1-para-2025-un-vistazo-al-futuro-de-la-avicultura>
- Salvatore, Dominik. (2009). *Microeconomía* (4a ed.). McGraw-Hill Educación.

- SIAP (Servicio de Información Agroalimentaria y Pesquera). (2022). Índice Nacional de Precios al Consumidor. Dirección de Análisis Estratégico del Servicio de Información Agroalimentaria y Pesquera. [https://www.gob.mx/cms/uploads/attachment/file/781538/INPC\\_an\\_lisis\\_1ra\\_quinc\\_nov\\_2022.pdf](https://www.gob.mx/cms/uploads/attachment/file/781538/INPC_an_lisis_1ra_quinc_nov_2022.pdf)
- SIAP (Servicio de Información Agroalimentaria y Pesquera). (2024). Base de datos 2024. <https://www.gob.mx/siap/documentos/siacon-ng-161430>
- Tomek, W. G., & Kaiser, H. M. (2014). *Agricultural product prices* (5a ed.). Cornell University Press.
- UNA (Unión Nacional de Avicultores). (2022). Compendio de indicadores económicos del sector avícola 2022. Unión Nacional de Avicultores.
- USDA (United States Department of Agriculture). (2022). *USDA Agricultural Projections to 2031*. Office of the Chief Economist, World Agricultural Outlook Board, U.S. Department of Agriculture. Prepared by the Interagency Agricultural Projections Committee. Long-Term Projections Report OCE-2022-1, 106 pp. <https://www.usda.gov/sites/default/files/documents/USDA-Agricultural-Projections-to-2031.pdf>





# *Cryptosporidium* spp. detection in water tanks and ponds of dairy farms

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## ABSTRACT

**Objective:** To identify *Cryptosporidium* spp. in water tanks and ponds of dairy farms from the Comarca Lagunera.

**Design/Methodology/Approach:** The experiment was carried out in dairy farms from the Comarca Lagunera, a region that extends on both sides of the border between the states of Coahuila and Durango, Mexico. Water samples from 36 open-air ponds (with or without polyethylene covers) and four stainless-steel tanks were analyzed using a modified version of the conventional Ziehl-Neelsen method. In addition, n=28 feces samples were taken from 10 dairy farms.

**Results:** The modified Ziehl-Neelsen method was used to identify *Cryptosporidium* spp. in five water samples (12.5%) out of the 33 samples taken from open-air ponds without a polyethylene cover. *Cryptosporidium* spp. was not detected in the 28 remaining water samples (84.9%). In addition, the parasite was not detected either in the three water samples from open-air ponds with a polyethylene cover or in the four samples from the stainless-steel tanks. Meanwhile, *Cryptosporidium* spp. was found in 57% of the 28 feces samples.

**Limitations/Implications:** Molecular studies should be carried out to identify the *Cryptosporidium* species found.

**Findings/Conclusions:** The parasite in question was detected in some open-air ponds of the dairy farms under study using the conventional diagnosis method. Future research should include an analysis to determine if the species found are zoonotic, in order to prevent potential diseases among humans and animals.

**Keywords:** Zoonoses, Protozoan, Cattle, Mexico.

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## INTRODUCTION

Cattle production has a worldwide impact: millions of families work in dairy production. In addition, it provides food security to countries and households and it is a major source of income (FAO, 2023). The domestication of cattle took place about 10,000 years ago, providing humankind with a survival and development alternative. Furthermore, the fast development of technology has transformed dairy production into one of the main food industries (Silanikove *et al.*, 2015).

The five countries with the highest dairy production are India, USA, China, Pakistan, and Brazil (FAO, 2023). For its part, Mexico holds the eighth place among worldwide producers. Meanwhile, the Mexican states of Jalisco, Coahuila, Durango, and Chihuahua

account for 50% of the total domestic production (SIAP, 2023). In northern Mexico, parts of Coahuila and Durango make up an area called Comarca Lagunera. This region is one of the main producers in the country. The arid climate and scarce precipitation of the dairy basin result in a high production. In addition, the intensive production systems of the area are highly technified—from automatic milking systems to milking handling preserving cold chain conditions—, enabling their growth and development (Gallegos-Daniel *et al.*, 2023).

From the epidemiological point of view, zoonotic diseases have a major impact on domestic animals. These diseases can be transmitted to humans directly or through fomites and they can be transmitted or propagated through water (Thompson *et al.*, 2016). Bacteria, viruses, and protozoa are three etiological agents that cause waterborne diseases. Protozoa are the less regulated agent, because conventional water treatments do not tackle their cystic form. *Cryptosporidium* spp. is included in this group. This parasite causes cryptosporidiosis, an emergent disease identified by the American authorities in 1993, after an outbreak that took hundreds of human lives in Milwaukee, Wisconsin (Doménech, 2013).

Studies about water in the Comarca Lagunera region are scarce and, consequently, no information about water pollution related to *Cryptosporidium* spp. is available. Therefore, this study proposed that water ponds and tanks that supply water to calves have *Cryptosporidium* spp. oocysts. Consequently, identifying the cryptosporidia in water is fundamental to determine if it is a source of transmission in dairy herds.

## MATERIALS AND METHODS

The study was carried out in September 2021 and May 2023 in the Comarca Lagunera. This region is located in both sides of the border between the states of Coahuila and Durango (25° 33' 00" N and 10° 26' 00" W).

Water samples from open-air ponds of 40 regional dairy farms were analyzed. The samples were taken from September to November 2021. Each 4 L sample was taken from the opposite side of the water inlet. A layer of organic matter was identified at the pond's edge. It was carefully removed to take a water sample from the area. Previously disinfected plastic containers were used for the sampling. These containers were placed at  $\approx 4$  °C in a cooler and taken to the lab. The water sample information included if they were taken from a pond covered with oilcloth or polyethylene covers or if the tank had a concrete bottom. Water samples from farms without a water pond were collected from stainless-steel tanks.

### Water sample analysis

The samples were allowed to settle for 24 h at room temperature in the Unidad de Diagnóstico Veterinario lab of the Universidad Autónoma Agraria Antonio Narro - Unidad Laguna. Afterwards, a pump was used to suck the supernatant and then it was sieved with a .0017 inches (#325) test sieve. Approximately 80 ml of sediment were finally recovered. Subsequently, the recovered sediment was centrifuged at 2,500 xg for 10 minutes, in 10 ml tubes with screw tops. The supernatant was sucked and the sediment

was suspended in a 2.5% potassium dichromate solution (5:1 ratio). Afterwards, the water samples were centrifuged again at 2,500 xg for 10 minutes. A 2 ml aliquot was taken from each sample and was placed in 2.5 ml microcentrifuge tubes for their analysis. The solution rested for 1 h. Subsequently, 50  $\mu\text{L}$  were taken from the bottom of the tubes and were placed in a microscope slide. The samples were air dried and stained with the modified Ziehl-Neelsen method (mZN) (García *et al.*, 1983). A Coplin staining jar was used to filter carbol fuchsin, before the slides were treated for 30 minutes. Afterwards, they were washed with running water and immersed in acid-alcohol-resistant for 10 seconds. Subsequently, they were washed with running water and immersed in methylene blue for five minutes. Finally, they were again washed with running water and air-dried. Once they were dried, the slides were treated with xylol and placed in coverslips. Light microscopy with a 40x magnifying glass was used to visualize the samples, comparing the shape, size, and redness of oocysts of a positive control previously identified in a cow feces sample.

### **Collection and analysis of feces samples**

In addition to the water samples collected in the area, feces samples were taken from 28 calves (1-20 days old). The handling of the calves used in this complied with the technical specifications for the production, care, and use of animals in the lab (SAGARPA, 2001). A bottle labelled with the name of the farm, earing cattle number, and date of birth of the calves was used to collect the feces sample. The samples were kept in a cooler (2-8 °C).

Two grams of the feces from each sample were placed on a microscope slide. The material was used to carry out an extension. Subsequently, the samples were air-dried and stained with the modified Ziehl-Neelsen method (mZN) (García *et al.*, 1983). A Coplin staining jar was used to filter carbol fuchsin, before the slides were treated for 30 minutes. Afterwards, they were washed with running water and immersed in acid-alcohol-resistant for 10 seconds. Subsequently, they were washed with running water and immersed in methylene blue for five minutes. Finally, they were again washed with running water and air-dried. Once they were dried, the slides were treated with xylol and placed in coverslips. Light microscopy with a 40x magnifying glass was used to visualize the samples, comparing the shape, size, and redness of oocysts of a positive control previously identified in a cow feces sample.

### **Data analysis**

Descriptive statistics were used to analyze the positive and negative values of samples obtained from water ponds, water tanks, and feces that recorded a positive result with the modified Ziehl-Neelsen method. Inferential statistics were used to establish the relationship between water storage conditions (open or closed water tank or pond, with or without a polyethylene cover, or with a concrete bottom) and the positive and negative results of the feces samples subjected to a water analysis. The Chi-Square test ( $\chi^2$ ) was used to calculate the ratio between the categorical variables, using the InfoStat-Statistical Software (2020). The significance level was  $P < 0.05$ .

## RESULTS AND DISCUSSION

*Cryptosporidium* spp. was found in five samples (12%) in tanks without covers. These samples were part of the 36 samples taken from water ponds with and without polyethylene covers (Table 1). Meanwhile, no oocysts were found in four samples taken from water tanks.

A total of 28 feces samples were taken from 10 dairy farms. *Cryptosporidium* spp. was found in 16 samples (57%) from nine dairy farms: seven samples (25%) from five dairy farms were positive for *Cryptosporidium* spp. in water; and nine samples (32%) from four dairy farms, were negative in water. In addition, the remaining 12 samples tested negative for *Cryptosporidium* spp. (Table 2).

### Number of samples examined (n=28) Number of positive samples

Using the staining method of the mZN, this study found *Cryptosporidium* spp. in the open-air ponds of five dairy farms (12.5%). No oocysts were found in dairy farms with closed water storage systems, such as stainless-steel tanks. These closed systems are less likely to be polluted by *Cryptosporidium* spp. oocysts from the environment, because they are protected from winds, wildlife (such as waterfowl and landbirds), and insects that could carry oocysts to dairy farm water sources (Åberg *et al.*, 2020). According to Wu *et al.* (2020), *Cryptosporidium* spp. is a single-cell protozoan parasite that causes gastroenteritis to humans and animals. For their part, Zhou *et al.* (2003) pointed out that water is a reservoir for *Cryptosporidium* spp. and other microorganisms.

The 36 water samples subjected to the mZN were divided into two groups: samples from water ponds with polyethylene covers and samples from water tanks with a concrete bottom and without polyethylene covers. The plastic infrastructure of the tanks of three

**Table 1.** *Cryptosporidium* spp. found in water samples. Five out of 40 samples recorded a positive diagnosis using the modified Ziehl-Neelsen method. They accounted for 12.5% of the total. Significance:  $P < 0.05$ .

| Water              | Samples examined (n=40) | Positive samples | p-value |
|--------------------|-------------------------|------------------|---------|
| Tank               | 4                       | 0                |         |
| Pond               | 36                      | 5 (12.5%)        | 0.4396  |
| Pond with cover    | 3                       | 0                | 0.4824  |
| Pond without cover | 33                      | 5 (15.1%)        |         |

**Table 2.** *Cryptosporidium* spp. found in feces samples. Sixteen out of 28 samples recorded a positive diagnosis using the modified Ziehl-Neelsen method. They accounted for 57% of the total. Significance:  $P < 0.05$ .

| Feces   | Samples examined (n=28) | samples positive | p-value |
|---|-------------------------|------------------|---------|
| Five stables were positive for <i>Cryptosporidium</i> spp. in the water | 14                      | 7 (25%)          | 0.4450  |
| Five stables were negative for <i>Cryptosporidium</i> spp. in the water | 14                      | 9 (32%)          |         |

dairy farms recorded negative results. Eighty-six percent of the negative samples were from dairy farms with tanks without coating. These results are the consequence of the periodical preventive management of the pond, the biosecurity measures followed to prevent diseases in the farms, and the disease treatment protocols applied to the animals (Cleere *et al.*, 2017).

Meanwhile, the mZN was used for a presumptive cryptosporidiosis diagnosis of neonatal animals. The results indicated a total prevalence of 57%. Out of this total, 32% of the feces samples from dairy farms tested positive to *Cryptosporidium* spp., although, according to the mZN, the protozoa were not found in water. In the case of these dairy farms where the parasite was found in the feces but not in their water sources, the animals could have been infected by direct fecal-oral transmission, bad husbandry practices, or housing animals of different ages in the same stables (Agrawal *et al.*, 2023). Nevertheless, 25% of the positive feces samples came from dairy farms where, according to the mZN, *Cryptosporidium* spp. was present in their water sources. Therefore, the animals were probably infected by water from polluted ponds; however, water is not the only source of transmission of oocysts and the subsequent infection (Ikiroma and Pollock, 2021).

*Cryptosporidium* spp. are commonly found in calves at an early age. This study was carried out in ten different dairy farms, with  $\pm 20$  days old animals (Diaz *et al.*, 2004). Although the samples were not taken in the same day, this study confirmed the presence of the causative agent of cryptosporidiosis (Qi *et al.*, 2020).

## CONCLUSIONS

*Cryptosporidium* spp. has a worldwide distribution and impacts a large number of species. Using a modified version of the Ziehl-Neelsen method, this study detected its presence in water samples from ponds and tanks where calves drink. Future research should identify the *Cryptosporidium* species found in the Comarca Lagunera to determine if they are zoonotic or not. This protozoan causes major economic losses and pollutes groundwater, consequently infecting the human population. In addition, dairy farms should implement a plan to prevent this infection.

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## REFERENCES

- Silanikove, N., Leitner, G., & Merin, U. (2015). The interrelationships between lactose intolerance and the modern dairy industry: Global perspectives in evolutionary and historical backgrounds. *Nutrients*, 7(9), 7312-7331. <https://doi.org/10.3390/nu7095340>
- FAO (2023) Food and Agriculture Organization of the United Nations 2023. Consulta: 07 Noviembre 2023. Disponible en: <https://www.fao.org/dairy-production-products/production/es/>
- SIAP-Sader (2023). Escenario mensual de productos agroalimentarios. Leche de bovino 2023. Dirección de análisis estratégico. Consulta: 07 Noviembre 2023. Disponible en: [https://www.gob.mx/cms/uploads/attachment/file/839191/Leche\\_de\\_Bovino\\_Junio.pdf](https://www.gob.mx/cms/uploads/attachment/file/839191/Leche_de_Bovino_Junio.pdf)
- Gallegos-Daniel, C., Taddei-Bringas, C., & González-Córdova, A. F. (2023). Panorama de la industria láctea en México. In Estudios Sociales. *Revista de Alimentación Contemporánea y Desarrollo Regional* (Issue 46). <https://doi.org/10.24836/es.v33i61.1251>

- Thompson, R. C. A., Koh, W. H., & Clode, P. L. (2016). *Cryptosporidium* — What is it? In Food and Waterborne Parasitology (Vol. 4, pp. 54-61). Elsevier Inc. <https://doi.org/10.1016/j.fawpar.2016.08.004>
- Doménech, J. (2013). *Cryptosporidium* y Giardia, problemas emergentes en el agua de consumo humano. *Offarm*, 22(11), 112-116. <https://www.elsevier.es/es-revista-offarm-4-articulo-cryptosporidium-giardia-problemas-emergentes-el-13055926%0A>
- García, L. S., Bruckner, D. A., Brewer, T. C., & Shimizu, R. Y. (1983). Techniques for the recovery and identification of cryptosporidium oocysts from stool specimens. *Journal of Clinical Microbiology*, 18(1), 185-190. <https://doi.org/10.1128/jcm.18.1.185-190.1983>
- Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, 2001. NORMA oficial Mexicana NOM-062-ZOO-1999, Especificaciones técnicas para la producción, cuidado y uso de los animales de laboratorio. Diario Oficial de Federación, 22 de Agosto 2001.
- Åberg, M., Emanuelson, U., Troell, K., & Björkman, C. (2020). A single-cohort study of *Cryptosporidium bovis* and *Cryptosporidium ryanae* in dairy cattle from birth to calving. *Veterinary Parasitology: Regional Studies and Reports*, 20. <https://doi.org/10.1016/j.vprsr.2020.100400>
- Wu, Y., Zhang, K., Zhang, Y., Jing, B., Chen, Y., Xu, C., Wang, T., Qi, M., & Zhang, L. (2020). Genetic diversity of *cryptosporidium parvum* in neonatal dairy calves in Xinjiang, China. *Pathogens*, 9(9), 1-9. <https://doi.org/10.3390/pathogens9090692>
- Zhou, L., Singh, A., Jiang, J., & Xiao, L. (2003). Molecular Surveillance of *Cryptosporidium* spp. in Raw Wastewater in Milwaukee: Implications for Understanding Outbreak Occurrence and Transmission Dynamics. *Journal of Clinical Microbiology*, 41(11), 5254-5257. <https://doi.org/10.1128/JCM.41.11.5254-5257.2003>
- Cleere, J., Gill, R., & Dement, A. (2017). Bioseguridad en las instaciones de ganado bovino para carne.
- Murillo, Brenda Janet Collazo López, Eva Melissa Mosqueda Gómez, Juan Luis Álvarez Canales, A. J., & Aguirre Trigueros, J. (2019). Tinción de Kinyoun para el diagnóstico de *Cryptosporidium* spp Kinyoun stain for the diagnosis of *Cryptosporidium* spp. *Scielo*, 17(2), 1-2. [www.medigraphic.com/actamedicawww.medigraphic.com/actamedica](http://www.medigraphic.com/actamedicawww.medigraphic.com/actamedica)
- Agrawal, R., Shukla, P. C., Pande, N., & Shreen. (2023). Dairy Farm Management Practices as Risk Factors Linked to *Cryptosporidium* spp. Infection in Dairy Calves. *Asian Journal of Dairy and Food Research*, 42(2), 144-149. <https://doi.org/10.18805/ajdfr.DR-1874>
- Ikiroma, I. A., & Pollock, K. G. (2021). Influence of weather and climate on cryptosporidiosis —A review. *Zoonoses and Public Health*, 68(4), 285-298. <https://doi.org/10.1111/zph.12785>
- García, C. C., Cruz-Vázquez, C., Revilla, R. L., Garza, M. S., Cruz, R. R., Mendoza, I. V., & Esparza, L. M. (2009). Frecuencia e identificación molecular de *Cryptosporidium* spp en becerros lactantes mantenidas en confinamiento en Aguascalientes, México. *Técnica Pecuaria En Mexico*, 47(4), 425-434.
- Díaz de Ramírez, Adelina, Ramírez-Iglesia, Lilido N, Hernández Salas, Olga, & Montilla, Noraima. (2004). *Cryptosporidium* sp. en becerros neonatos de ganadería lechera y de doble propósito del estado Trujillo, Venezuela. *Zootecnia Tropical*, 22(2), 125-132. Recuperado en 25 de noviembre de 2023, de [http://ve.scielo.org/scielo.php?script=sci\\_arttext&pid=S0798-72692004000200002&lng=es&tlng=es](http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0798-72692004000200002&lng=es&tlng=es).
- Qi, M., Zhang, K., Huang, M., Wang, S., Xu, C., Wang, T., Jing, B., & Li, J. (2020). Longitudinal detection of *Cryptosporidium* spp. in 1-10-week-old dairy calves on a farm in Xinjiang, China. *Parasitology Research*, 119(11), 3839-3844. <https://doi.org/10.1007/s00436-020-06904-z>

# European and Mexican regulations on animal welfare in experimental and cultured aquatic animals

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## ABSTRACT

**Objective:** To analyze the differences between the regulatory frameworks of the European Union and Mexico in terms of aquatic animal protection and welfare, in order to propose improvements in Mexican legislation.

**Design/methodology/approach:** Comparative study of legislative frameworks, the European Union regulatory framework on animal welfare, the current situation of Mexican regulations and the identification of gaps and areas of opportunity.

**Results:** The European Union has a comprehensive legislative framework that includes the regulation of animal husbandry, animal experimentation and transport, as well as aquatic organisms. Mexico has significant deficiencies, *i.e.*, the absence of a General Animal Welfare Law and a clear lack of specific regulation for aquatic animals.

**Limitations on study/implications:** There is no general animal welfare law for Mexico; therefore, improvements are proposed in consideration of the European Union's regulatory framework.

**Keywords:** Aquatic animals, legislation, bioethics, Mexico, European Union.

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## INTRODUCTION

Animal abuse in Mexico is not a sporadic or uncommon phenomenon. According to Giles Navarro (2023), the problem of animal abuse is much bigger than what can be seen through the cases documented in social networks. Mexico ranks first in Latin America in animal abuse and third worldwide (Berlanga, 2021). Also according to Berlanga (2021) between 2019 and 2020, 2,490 complaints were received for animal mistreatment, however, only 101 aggressors were linked to process and 18 sentences were issued for this crime, while only fourteen aggressors had as a penalty the deprivation of their freedom in the whole country so it is estimated that the punishment rate for animal mistreatment

in Mexico is less than 0.01%. The above figures are practically originated by situations in which the welfare of companion and wild animals is compromised, without considering experimental animals or animals used in livestock production and aquaculture. If these were taken into account, the figures would surely increase to much higher levels.

The concept of “animal welfare”, defined by the World Organization for Animal Health as “the physical and mental state of an animal in relation to the conditions in which it lives and dies”, has been included in numerous national and international regulations; thus, Article 13 of the Treaty on the Functioning of the European Union states that animals are sentient beings “when formulating and implementing the Union’s policies on agriculture, fisheries, transport, internal market, research and technological development and space...”.

In relation to animal experimentation, according to Serra Palao (2021), mentioning Kolar (2006 and 2015) and Leyton (2010), this practice is carried out under five main areas: basic research, research for biomedical and pharmaceutical purposes, for industrial and commercial purposes, for educational purposes and finally, in the military field. In the case of research aimed at developing or improving production capacities within the agricultural field (in which aquaculture production could be included), this can be included within the “commercial” field. Serra Palao mentions that in the European Union alone, in 2020, nine million animals were used for experimentation. In the Report from the Commission to the European Parliament and the Council (Report 2019 on statistics on the use of animals for scientific purposes in the Member States of the European Union in 2015-2017; Comisión Europea, 2020) and which is cited by the same author, the number of animals subjected to experimentation is counted. In the case of aquatic organisms, it is established that for zebrafish, *Danio rerio*, and “other fish” (without defining species) a total of 3,799,499 individuals subjected to experimentation is accumulated. This figure is the highest of all reported species and is only below the corresponding number for mice, which is 17,408,496. Another aquatic species reported are cephalopods with individuals subjected to experimentation totaling 25,260. In this same report, the term “animal welfare” is mentioned in relation to the protection of the natural environment in the interest of the health or welfare of humans or animals and the preservation of species. Furthermore, in relation to the reuse of the total number of animals used in experimental procedures, based on the principle of the three Rs, mentioning that it is only allowed considering the actual level of severity experienced by the animal and its health and welfare.

In the case of Mexico, Frías-Álvarez and Ortiz-Millán (2024) focused on calculating the total number of animals used for these purposes from January 2015 to October 2021, based on data requested from the National Institute for Transparency, Access to Information and Protection of Personal Data (INAI). Authorized laboratory animal facilities reportedly used 5,437,263 animals in this period. However, the authors caution that these data should be taken with caution due to the absence of an official registry that includes all Mexican institutions that use animals for these purposes. The research revealed the use of a wide range of species from different taxonomic groups, including mammals, birds, reptiles, amphibians, fish and invertebrates. The main purposes of use of these animals included technological development, innovation, laboratory testing, biological production, quality control, diagnostic purposes, basic and applied research, and education. Specific

mention is made of the use of invertebrates in aquaculture research. A total of 185,903,422 invertebrates were reported to have been used for this purpose in the six-year period analyzed. Institutions reporting the use of invertebrate animals for aquaculture research purposes included universities, research centers and specialized aquaculture institutes. The document indicates that fish are the second most used group of animals for scientific purposes in Mexico, with a notable increase in their use compared to other species or animal groups. This increase can be attributed to the expansion of aquaculture research and the development of the home aquarium industry. In particular, zebrafish have been widely used as a model in aquatic ecotoxicology studies.

For aquatic animals subjected to experimentation and aquaculture production, the interest in minimizing conditions of mistreatment that can lead to stress and suffering is practically null in many countries, including Mexico. This may be due to the popular belief that aquatic animals (crustaceans, fish, mollusks) do not perceive pain as mammals do. Aréchiga-Palomera *et al.* (2023) mention that the debate on whether fish can experience pain has been the subject of discussion in the scientific community for the last two decades. Some scientists argue that fish cannot feel pain due to the lack of a cerebral cortex, which they claim is necessary to experience pain. They claim that pain is a subjective experience that requires a conceptual psychological subject, which is not the case for fish. However, other scientists argue that fish can experience pain. They rely on the presence of nociceptive pathways in the nervous systems of fish, which are similar to those of mammals. These pathways are related to the detection of noxious stimuli and trigger behavioral and physiological responses in fish. In addition, the structure and function of the nervous system are broadly similar to those of terrestrial vertebrates, with a central nervous system, consisting of a brain and spinal cord, connected to the sensory organs and muscles by a peripheral nervous system. In general, the sensory organs of fish are remarkably similar in structure and function to those of terrestrial vertebrates, as is the endocrine system, including hormones involved in stress responses (Huntingford and Kadri, 2014). The debate about pain in fish (and other aquatic animals) has implications for the aquaculture and fisheries industry as it relates to animal welfare and ethical issues. This debate can even have epistemological-ethical implications, as can be seen in the work of Henríquez and Pradenas (2022), which discusses the “sentient” capacity of fish and how the acceptance, or not, of this quality could grant a moral status to these animals or, on the contrary, maintain a position in which they are beings without the capacity to experience pain and therefore alien or removed from any legal proposal to guarantee their welfare. Some scientific journals require authorization from animal welfare committees for research involving animals. Although anesthetics are being used to minimize pain in aquatic animal research and handling practices, the debate on whether they can experience pain continues, despite the fact that there is already scientific evidence to prove it.

Celaya-Tentori and Almaraz-Alvarado (2018) mention that the regulatory dynamics, in relation to aquaculture in Mexico, have not kept pace with global demands, and intermittent progress is observed in aquaculture policy instruments, as well as a limited vision in terms of the aquaculture-biotechnology binomial, qualifying this as diffuse and lacking long-term strategies for subregions and species. The authors address the evolution

of aquaculture regulations, highlighting their importance in the global context and pointing out the specific challenges faced by Mexico in this area. In this study it is worth noting that, although the regulations are approached from a historical viewpoint, terms that could allude to animal welfare or protocols that minimize suffering in the handling or slaughter of cultured organisms are not included. The focus is only on regulations, highlighting their importance in the global context and pointing out the challenges faced by Mexico in this area. This is contradictory to say the least, since this country is a member of the World Organization for Animal Health (OIE) organization that among its main concerns and actions are to ensure animal welfare and that has specifically created international standards for farmed fish that, in our experience, are not applied in Mexico. In contrast, Spain, also a signatory to the OIE conventions, apparently does have a regulatory framework that should be applied in the management of farmed fish and other species, through the legislation adopted by the European Union (EU) as a whole. Title 7 of the OIE Aquatic Animal Health Code specifically addresses the welfare of farmed fish and includes aspects of transport, stunning and slaughter. However, it does not address protocols to prevent suffering during the different phases of culture, so welfare is limited to the aspects outlined above. The following regulations stand out: Law 32/2007, of November 7, for the care of animals, in their exploitation, transport, experimentation and slaughter and Royal Decree 1614/2008, of October 3, regarding animal health requirements for aquaculture animals and products, as well as the prevention and control of certain aquatic animal diseases.

Based on the above scenario, the objective of this study is to establish the existing legal universe in Mexico, in relation to the animal welfare of aquatic animals subjected to experimentation and aquaculture production, in comparison with that existing in the EU, with the intention of establishing the weaknesses, possible coincidences and opportunities to improve the former based on the experience of the latter.

## **MATERIALS AND METHODS**

An exhaustive database search was conducted to identify relevant documents on animal protection and welfare in the European Union (EU) and Mexico. In the case of the EU, documents were selected from a broad legislative framework aimed at promoting and protecting animal welfare in areas such as animal husbandry, experimentation, transport and companion animal husbandry. The European regulations reviewed included Directive 2010/63/EU, Regulation (EC) No. 1099/2009, Directive 2006/88/EC, Decision 2008/392/EC and Directive 2013/35/EU, all obtained from the Official Journal of the European Union. In addition, Law 7/2023, consulted in the Spanish Official Gazette, was included.

For the context in Mexico, the regulations available in the Official Journal of the Federation were reviewed, given that there is currently no General Animal Welfare Law (despite being proposed and approved, it remains pending enactment). The documents analyzed in the Mexican framework were the General Law of Ecological Equilibrium and Environmental Protection (LGEEPA), the Mexican Official Norm NOM-062-ZOO-1999 and the General Law of Sustainable Fisheries and Aquaculture. A comparative analysis between the European Union (EU) and Mexico was carried out to identify gaps and key areas in Mexico's regulatory framework with respect to animal welfare and protection.

## RESULTS AND DISCUSSION

### European Union

The European Union (EU) has specific regulations on aquatic animal experimentation in the context of scientific research. The main regulation addressing this issue is Directive 2010/63/EU of the European Parliament and of the Council, which establishes rules for the protection of animals used for scientific purposes. Although this Directive focuses primarily on terrestrial animal experimentation, it also includes specific provisions for the protection of aquatic animals used in research (Table 1). The key aspects related to aquatic animal testing in Directive 2010/63/EU are summarized below:

1. Definition of aquatic animals: The Directive defines “aquatic animals” as vertebrates and cephalopods, such as fish and octopuses, involved in research.
2. Authorization and ethical evaluation: Experiments with aquatic animals must be authorized and evaluated by ethical committees, which guarantee ethical practices and minimization of suffering.
3. The “3R” principle: The Directive encourages the reduction, refinement and replacement of animals in experimentation, to reduce their use and suffering, and to promote alternatives.
4. Animal welfare standards: Establishes appropriate housing, care, feeding and humane euthanasia conditions for experimental animals.
5. Annual reporting and transparency: Member states must submit annual reports on the use of animals in research to promote transparency.

It is clear that Directive 2010/63/EU seeks to balance scientific research with the welfare of experimental animals, terrestrial or aquatic. In addition, Regulation (EC) No. 1099/2009, on the protection of animals at the time of killing, includes fish as part of the vertebrate animals that should be subject to separate rules in relation to the rest, terrestrial, without further elaborating on the possible protocols that could be used. Obviously, there is no mention of aquatic animals when used for experimental purposes and euthanasia or slaughter procedures.

More specifically, Council Directive 2006/88/EC, which deals with animal health requirements for animals and the prevention and control of certain diseases in aquatic animals, focuses on animal health and safety issues in aquaculture. Although its main objective is to protect the health of aquatic animals and to prevent and control diseases, the directive does not directly address animal welfare. However, per se, “protecting health” is already an element that is directly related to animal welfare. While animal welfare is an issue related to the way aquatic animals are reared, handled and transported, Directive 2006/88/EC does not focus on specific aspects of welfare, such as the space available for the animals, their living conditions, their handling or their slaughter.

### Mexico

There is no animal welfare law in Mexico. In 2016, the first attempt was made to present a legislative initiative in the Chamber of Deputies to approve a General Animal Welfare

**Table 1.** Animal Protection and Welfare Regulations in the European Union: approach and role.

| Name of Standard   | Approach  | Role   |
|--|---|--|
| Directive 2010/63/EU on the protection of animals used for scientific purposes                 | Regulation of the use of animals in scientific research | Protect animals used in scientific research and promote alternative methods to reduce their use.   |
| Regulation (EC) No. 1099/2009 on the protection of animals at slaughter                        | Animal welfare standards during slaughter               | Ensure animal welfare during slaughter through humane practices and adequate training of personnel.  |
| Directive 2006/88/EC on animal health requirements for aquaculture animals                     | Aquaculture sanitary control and disease prevention     | To protect the health of aquatic animals and prevent the spread of diseases in aquaculture.  |
| Decision 2008/392/EC on arrangements for Internet-based information on aquaculture enterprises | Transparency in the aquaculture industry                | Provide transparency and accessibility to information on aquaculture production companies and control of authorized processing establishments.                         |
| Directive 2013/35/EU on the protection of animals in scientific procedures.                    | Animal welfare in scientific research                   | To ensure a high level of protection and welfare for animals in scientific procedures, also promoting innovation.  |
| Law 7/2023 on the protection of the rights and welfare of animals.                             | Recognition of animal dignity in society                | Recognize the dignity of animals as living beings and regulate behavior towards them in coexistence, without considering them merely as elements of economic activity. |

Law in Mexico. Apparently, pressures from bullfighting and fighting cocks businessmen, as well as livestock producers, for perceiving damage to their interests, did not favor its approval. This prevents the homologation of state laws, which are very different. Recently, the Mexican Senate approved a reform aimed at guaranteeing the protection, proper treatment, conservation and care of animals. The initiative has already been approved at the federal level and is now under review by state congresses for analysis and eventual ratification, with the aim of granting it constitutional status. The proposal contemplates amendments to several articles of the Constitution and establishes that the Congress will have the power to issue the General Law on Animal Welfare, Care and Protection. The proposed reforms to the constitutional articles are so that study plans and programs must include the care and protection of animals (article 3), prohibit animal mistreatment and guarantee their protection by the State (article 4) and empower the Congress to issue a general law for the protection of animals (article 73). With the required ratification by a majority of state congresses completed, the reform is now on track to attain constitutional status upon its official promulgation. Subsequently, it will be necessary to develop secondary laws to complement these regulations and ensure the comprehensive implementation of animal welfare. However, laws require a regulatory framework that allows their application, and in this sense, aquatic animals for experimentation and cultivation should be included as subjects to be considered for their protection. This would mean modifying the perception of these animals as non-sentient and of little interest to the general population.

At present, the regulations that address animal welfare issues in Mexico are included, in an almost diluted manner, in various Official Standards and laws, which mention the

subject but do not cover all the required aspects, much less all the animal species that could be subject to habitual mistreatment.

The General Law of Ecological Balance and Environmental Protection (LGEEPA) in Mexico has an important component related to animal welfare. In 2019, this law was amended to include specific provisions related to animal protection and welfare. The reforms to the LGEEPA in 2019 created a stronger legal framework for the protection of animals in the country. The LGEEPA includes key points on animal welfare, such as the prohibition of mistreatment and cruelty, the regulation of animal experimentation practices, and the imposition of sanctions for those who fail to comply with these provisions (Table 2).

These reforms to the LGEEPA also recognize the importance of animal welfare in relation to ecological balance and environmental protection, since cruelty to animals can have a negative impact on ecosystems and the quality of life of animals. This inclusion in the LGEEPA apparently reflects Mexico's commitment to the promotion of animal welfare and protection within the framework of its environmental and ecological policy. However, in the absence of a General Animal Welfare Law, its scope is limited and does not cover the entire scenario that should be addressed. The fundamental principles established in this law include providing animals with water, food, an adequate environment for their rest and movement, preventive medical care and treatment when necessary, as well as allowing them to express their natural behavior and ensuring species-appropriate care conditions.

The following paragraphs of this law state that the Federal Government of Mexico is responsible for establishing official standards that define the basic principles of dignified and respectful treatment of animals, addressing aspects such as their capture, captivity, commercialization, quarantine, training, exhibition, exploitation, transport and slaughter. It also has the task of supervising compliance with these standards. However, it does not

**Table 2.** Animal Protection and Welfare Regulations in Mexico: approach and role.

| Name of Standard  | Approach  | Role  |
|---|---|---|
| General Animal Welfare Law (proposed)                                       | Animal protection and welfare in Mexico.                        | Establish federal and homogeneous coverage for the protection of animals, prohibit mistreatment and guarantee the inclusion of animal welfare in educational plans and programs.    |
| General Law of Ecological Equilibrium and Environmental Protection (LGEEPA) | Protection of animals and the ecological environment.           | Prohibit animal abuse, regulate experimentation and establish sanctions for non-compliance. Promotes the relationship between animal welfare and ecological balance.                |
| Mexican Official Standard NOM-062-ZOO-1999                                  | Laboratory animal welfare.                                      | Establish standards for housing, care, ethical handling and humane euthanasia of laboratory animals. Requires training of personnel and ethics committees.                          |
| General Law for Sustainable Fisheries and Aquaculture                       | Sustainability and animal welfare in aquaculture and fisheries. | Promotes sustainable aquaculture development, regulates practices for the health of aquatic organisms and encourages ethical practices in captivity. Includes habitat conservation. |

report on the mechanisms or protocols that should be implemented to guarantee the above, nor the government agencies that should be involved to achieve such objectives.

The Federal Attorney's Office for Environmental Protection (PROFEPA) is the government institution in charge of supervising and enforcing laws and regulations related to the environment and the protection of fauna in Mexico and plays a fundamental role in the supervision and promotion of animal welfare (Table 2). However, its primary work is oriented towards wild animals in captivity, zoos, breeders, animal entertainment centers, among others. Therefore, its incidence in the scenario of aquatic animals in experimentation or production is practically null.

Regarding the handling of laboratory animals for experimentation, Mexican Official Standard NOM-062-ZOO-1999 establishes the technical requirements and specifications for the production, care and use of laboratory animals in Mexico (Table 2). This standard regulates facilities and housing conditions for laboratory animals, ensuring adequate standards of ventilation, lighting, temperature and humidity. It also establishes guidelines for care and maintenance, such as feeding, hygiene, disease prevention and requirements for personnel in charge. In terms of welfare, it dictates ethical guidelines for handling animals, reducing their stress and pain, and regulates humane euthanasia when necessary. In addition, it requires detailed documentation of all activities and specifies personnel training, as well as the creation of ethics committees for the evaluation of research protocols.

The main objective of NOM-062-ZOO-1999 is to guarantee the welfare of laboratory animals used in scientific research in Mexico and establishes standards for their care and ethical management (Table 2). This standard seeks to balance the need for research with the protection and welfare of the animals involved. However, it does not include aquatic animals in any of its chapters, so it is only a general document that should be referred to when addressing animal welfare aspects in experimentation and adapting it to the particular requirements of aquaculture research or production.

More related to the issue of aquatic animals for aquaculture production, the General Law on Sustainable Fisheries and Aquaculture is a law in Mexico that regulates fishing and aquaculture activities with a focus on sustainability and conservation of marine and aquatic resources (Table 2). The law establishes principles for the sustainable exploitation of fishery and aquaculture resources, preserving marine biodiversity and species regeneration. It defines access rights, regulating concessions and authorizations, and provides for measures to prevent overexploitation, such as minimum sizes, closed seasons and fishing quotas. It promotes sustainable aquaculture as a complement to fishing production and encourages management through refuge areas and exclusion zones. It also establishes a monitoring system with sanctions, recognizes the importance of conserving marine ecosystems by preventing pollution and waste, and encourages the participation of local and indigenous communities in regulating the sector.

Although this law focuses on conservation and regulation of fishing and aquaculture activities, it also includes provisions related to animal welfare, although not necessarily in detail. It is worth mentioning that, although the law focuses on aquaculture production, the development of this activity requires a great effort of previous research for the development of culture technologies, in this sense the diverse aquatic organisms that are cultivated are,

in the same way, experimental organisms that had to be submitted to bioassays of all kinds. The General Law on Sustainable Fisheries and Aquaculture contributes to animal welfare by maintaining the health and quality of aquatic organisms in aquaculture facilities, regulating management, feeding and disease prevention practices. Although it does not focus specifically on animal welfare, it promotes ethical treatment in captivity, avoiding unnecessary suffering in production systems. It also promotes the conservation of marine and aquatic habitats, benefiting both wild species and captive-bred organisms.

## **Comparison**

### **European Union**

The EU has a comprehensive regulatory framework to regulate animal welfare in areas such as animal husbandry, experimentation, transport and companion animal husbandry, with specific rules for each. With Directive 2010/63/EU, animals used in scientific research are regulated, including aquatic animals. In addition, the “3R” principle (reduction, refinement and replacement) is promoted to minimize their suffering. Furthermore, the EU encourages transparency through annual reports on the use of animals in research, allowing public oversight and promoting accountability in the handling of laboratory animals.

### **Mexico**

Lack of a General Animal Welfare Law: Mexico does not have a general animal welfare law covering a wide range of issues. The initiative to establish a General Animal Welfare Law in 2016 faced resistance from various interest groups. Related regulations are scattered in various laws that make their cohesion and implementation complicated. The constitutional reforms presented by the Executive to Congress this year could remedy this lack of a law that would federally protect animals.

Mexico’s General Law of Ecological Balance and Environmental Protection (LGEEPA) establishes that the Federal Government must create standards for the dignified and respectful treatment of animals in activities that include capture, captivity, commercialization, quarantine, training, exhibition, exploitation, transport and slaughter. Despite this, the law does not specify clear protocols to guarantee animal welfare nor does it designate entities responsible for compliance. NOM-062-ZOO-1999 regulates the use of laboratory animals, but focuses on terrestrial animals, without including aquatic animals. The General Law on Sustainable Fisheries and Aquaculture regulates fishing and aquaculture activities with a focus on the conservation and health of marine resources, which indirectly contributes to animal welfare, but does not specifically address animal handling or slaughter.

In general, the European Union has implemented a broader and more specific regulatory framework for animal welfare, including aquatic animals used in research. In contrast, Mexico lacks a general animal welfare law and focuses on specific regulations for laboratory animals and conservation issues in aquaculture. The lack of specific regulations for aquatic animals may be an important gap in the protection of their welfare in Mexico.

### **Improving Mexican regulations based on European standards**

To improve animal welfare conditions for aquatic animals in experimentation and culture in Mexico, taking the European Union regulations as a model, the following measures could be considered:

- i) Develop a Comprehensive Animal Welfare Law covering specific aspects for aquatic animals in research and aquaculture production, already existing in European directives.
- ii) Establish specific regulations for aquatic animal experimentation, promoting the “3R” principles and guaranteeing ethical and animal welfare standards.
- iii) A modification to NOM-062-ZOO-1999 to include specific provisions for aquatic animals in experimentation, ensuring a level of protection similar to that of terrestrial animals.
- iv) Implement transparency and annual reporting on the use of aquatic animals in research and production, following the EU model.
- v) Promote public education and awareness of aquatic animal welfare.
- vi) Include the participation of experts and local communities in decision-making related to aquaculture production and research.
- vii) Encourage research into alternative methods that reduce the need to use animals in experimentation.
- viii) Improve the General Law on Sustainable Fisheries and Aquaculture with specific provisions to guarantee the welfare of aquatic animals in aquaculture facilities, regulating aspects such as space, living conditions and ethical management.
- ix) Consider implementing specific regulations for the slaughter or euthanasia of aquatic animals, ensuring humane methods and training of personnel.

Taken together, these improvements could contribute significantly to strengthening animal welfare conditions for aquatic animals in Mexico, bringing them in line with the standards and practices adopted in the European Union. By adopting measures inspired by EU regulations and customizing them to the Mexican context, animal welfare conditions for aquatic animals in experimentation and culture could be significantly improved. This would contribute to balancing the need for research and production with the protection and welfare of these animals.

### **CONCLUSIONS**

The EU has a comprehensive and specific regulatory framework for animal welfare, addressing various areas such as animal husbandry, experimentation, transport and companion animal husbandry. Directive 2010/63/EU stands out for establishing clear rules for the protection of animals used in scientific research, including aquatic animals, and promoting the “3R” principles (reduction, refinement and replacement). In addition, transparency and accountability are emphasized through annual reporting on the use of animals in research, and aquatic animal experimentation is specifically regulated.

Mexico lacks a general animal welfare law, and related regulations are scattered in different laws, making their cohesion and implementation difficult. Although the LGEEPA includes provisions related to animal welfare, it does not specify the mechanisms or protocols to guarantee it, and supervision falls to the Federal Attorney General's Office for Environmental Protection (PROFEPA), whose incidence on aquatic animals in experimentation is limited. The Mexican Official Standard for Laboratory Animals (NOM-062-ZOO-1999) does not include specific provisions for aquatic animals, and the General Law on Sustainable Fisheries and Aquaculture focuses more on sustainability and conservation than on animal welfare.

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During the evaluation of this manuscript, the Executive Branch of Mexico presented to the Chamber of Deputies the initiative for the General Animal Welfare Law, which was approved in December 2024. Although this law has not yet come into effect, Congress has complied with the constitutional mandate by presenting the initiative for its creation. However, uncertainty remains as to whether the secondary laws will include farmed aquatic animals under their scope of protection.

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### REFERENCES

- Aréchiga Palomera, M. A., Vega-Villasante, F., Vargas Ceballos, M. A., Chong-Carrillo, O., Nieves Rodríguez, K. N., & Nolasco-Soria, H. (2023). La insoportable levedad del pescador: el dolor en peces. *Revista LUCIDUM CIENCIA*, 2(3): 21-28.
- Berlanga, A. (2021). Resultado sobre el maltrato animal en México. AnimaNaturalis. Recuperado de <https://www.animanaturalis.org/n/14574/Resultados-sobre-el-maltrato-animal-enMexico>
- Celaya Tentori, M., & Almaraz Alvarado, A. (2018). Recuento histórico de la normatividad pesquera en México: un largo proceso de auge y crisis. *Entreciencias: Diálogos en la sociedad del conocimiento*, 6(16): 33-48.
- Comisión Europea. (2020). Informe de 2019 sobre las estadísticas relativas al uso de animales con fines científicos en los Estados miembros de la Unión Europea en 2015-2017. COM/2020/16 final. Disponible en [[https://eur-lex.europa.eu/legal-content/ES/TXT/HTML/?uri=CELEX%3A52020DC0016#:~=El%20n%C3%BAmero%20de%20animales%20utilizados%20por%20primera%20vez%20\(en%20su,%20C39%20millones%20\(2017\)\)](https://eur-lex.europa.eu/legal-content/ES/TXT/HTML/?uri=CELEX%3A52020DC0016#:~=El%20n%C3%BAmero%20de%20animales%20utilizados%20por%20primera%20vez%20(en%20su,%20C39%20millones%20(2017)))]
- Gaceta Parlamentaria. (2024). Iniciativa del Ejecutivo federal Con proyecto de decreto, por el que se reforman los artículos 3o., 4o. y 73 de la Constitución Política de los Estados Unidos Mexicanos, en materia de protección y cuidado animales. Anexo 2. Cámara de Diputados, LXV Legislatura, 5 de febrero de 2024, Número 6457-2.
- Frías-Álvarez P, Ortiz-Millán G. (2024). The Numbers of Animals Used in Mexico for Scientific and Educational Purposes. *Alternatives to Laboratory Animals*, 52(1): 28-41. doi:10.1177/02611929231217033
- Giles Navarro, C. A. (2023). El maltrato animal y sus sanciones en México. Instituto Belisario Domínguez Senado De La República. *Notas estratégicas*, 189.
- Henríquez, A., & Pradenas, A. (2022). El estatus moral y jurídico de los peces: problemas y propuestas para su protección en la industria acuícola. En I. González Marino (Ed.), *Derecho Animal. Derechos de los animales y la superación del antropocentrismo* (pp. 141-157). Santiago: EJS.
- Huntingford, F. A., & Kadri, S. (2014). Defining, assessing and promoting the welfare of farmed fish. *Rev Sci Tech*, 33(1): 233-244. doi: 10.20506/rst.33.1.2286.
- Kolar, R. (2006). Animal Experimentation. *Science and Engineering Ethics*, 12(1): 111-122.
- Kolar, R. (2015). How Long Must They Suffer? Success and Failure of our Efforts to End the Animal Tragedy in Laboratories. *Alternatives to Laboratory Animals*, 43(2): 129-143.

- Leyton, F. (2010). Problemas bioéticos de la experimentación con animales no-humanos. *DA. Derecho Animal. Forum of Animal Law Studies*, 1(3): 1-15. Recuperado de <https://raco.cat/index.php/da/article/view/349694>
- Serra Palao, P. (2021). Empatía para una ciencia sin sufrimiento animal: un enfoque desde Lori Gruen. *Revista de Bioética y Derecho*, 51: 141-156.



# Morphological and agronomic characterization of pigmented corn races

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## ABSTRACT

**Objective:** to morphologically characterize accessions of pigmented maize belonging to 25 races for use in genetic improvement programs.

**Design/Methodology/Approach:** the means of morphological, agronomic and biochemical variables of 275 accessions from 25 maize races were determined. Then, analyses of variance, comparisons of means, and cluster analyses were performed.

**Results:** there was non-significant variation in plant height, height to the first ear, and number of leaves. The variability was significant in stem diameter, weight of one-thousand grains, grain width, and anthocyanin content. In terms of hardness, 18 of the 25 races fitted the recommended value of flotation index. Four large groups were defined at a Euclidean distance of 5.

**Limitations/ Implications of the study:** this research was limited exclusively to the study of pigmented accessions, excluding those that lacked this characteristic. This delimitation is justified by the particular objectives of the study. Nevertheless, it is pertinent to consider that the incorporation of non-pigmented accessions in future breeding research could allow the combination of desirable attributes from both (pigmented and non-pigmented) groups. However, genetic variability beyond pigmentation trait is anticipated to be restricted among these groups.

**Findings/Conclusions:** it was possible to identify the races that comply, in terms of hardness and grain width, with the Mexican standard NMXFF-034/1-SCFI-2020. In addition, the median anthocyanin content was identified, as well as the maximum and minimum value. It was possible to group the races into four groups based on their similarity. The diversity found can be used in genetic improvement programs, as well as in production programs.

**Keywords:** *Zea mays*, genetic diversity, pigmented maize, native varieties.

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## INTRODUCTION

Mexico is considered the center of origin, domestication, and diversification of maize, since there is a great genetic diversity throughout the national territory, as evidenced by



the 68 native races identified (Kato *et al.*, 2009; Caballero-García *et al.*, 2019; López-Morales *et al.*, 2020). This genetic diversity is composed of complexes of multiple local variants or landraces, which meet the cultural needs of the producers and adapt to the agroecological conditions of each region (Pressoir y Berthaud, 2004). Maize landraces are produced in all agroecological regions of Mexico (Hernandez-Trejo *et al.*, 2023), so those play an important role in the domestic strategies of farmers, because are resistant and predictable options in terms of agronomic behavior, issuing confidence for production (Hellin *et al.*, 2013; Bellon *et al.*, 2011).

Pigmented maize is highly valued by consumers, due to the nice appearance it adds to products that are part of the human diet and economically sustain small producers in rural areas (Hernández *et al.*, 2017). These natural water-soluble pigments of the flavonoid group —anthocyanidin glycosides— which are present in the vacuoles of plant cells, giving red, purple or blue color are known as anthocyanins (Guillén-Sánchez *et al.*, 2014). The content and type of anthocyanins in the maize kernel varies according to the color of the grain and the concentration of the pigment in the different structures (Salinas *et al.*, 2013). The objective of this research was to morphologically characterize accessions of pigmented maize belonging to 25 races for their use in genetic improvement programs.

## **MATERIALS AND METHODS**

### **Genetic material**

A total of 275 pigmented maize accessions corresponding to 25 maize races were evaluated; these were provided by the gene bank of the International Maize and Wheat Improvement Center (CIMMYT, Mexico). These accessions come from tropical and subtropical regions of the Mexican Republic. The races are (English transliterated) Ancho, Arrocillo, Arrocillo Amarillo, Azul, Bofo, Bolita, Cacahuacintle, Celaya, Chalqueno, Conico, Conico Norteno, Cristalino de Chihuahua, Elotes Conicos, Elotes de Sinaloa, Elotes Occidentales, Maiz Dulce, Mushito, Nal-Tel, Olotillo, Oloton, Pepitilla, Reventador, Tabloncillo, Tepecintle and Tuxpeno.

### **Experimental site**

The evaluation of the genetic materials was done in the experimental lands of the Universidad Autónoma Agraria Antonio Narro in Saltillo, Coahuila, Mexico, at coordinates 25° 20' 37" N and 101° 01' 53" W and 1820 m altitude; With an average annual rainfall of 400 mm and an average annual temperature of 20 °C.

### **Crop management**

The sowing was made in June 2019, manually with a population density of 62 500 plants per hectare, in rows separated 0.80 m, and 0.20 m between plants. The experimental units located in 4 m long furrows per accession. The technical management of the crop was based on the recommendations of (SAGARPA, 2015). In the soil, the fertilization dose of 300 kg ha<sup>-1</sup> of nitrogen in the form of urea, and 100 kg ha<sup>-1</sup> of phosphorus was applied. Weeds were controlled manually and mechanically at pre-planting and 30 days after planting.

### Variables evaluated

**Plant height.** The measurement of this variable was done in the reproductive stage of the crop (R1, or presence of '*jilote*', the tassel), excluding the size of tassel and silks. Four plants under full competition were taken as the experimental unit by accession, reporting the plant height value in meters (m).

**Height to the first ear.** Sampling was done in the reproductive stage of the crop (R5, or physiological maturity by milky kernels line), measuring from the base of the stem to the beginning of the first ear. Four plants under full competition by accession were taken as the experimental unit.

**Stem diameter.** This variable was measured at a height of 10 cm from the base of the stem. The sample was evaluated at the end of the vegetative stage of the crop (VT, or presence of tassel), taking as the experimental unit a total of 4 plants under full competition by accession.

**Number of leaves per plant.** This variable was measured at the end of the vegetative stage of the crop (VT), taking as an experimental unit a total of 4 plants under full competition by accession.

**Weight of one-thousand grains.** For each accession, the average weight of 100 grains was recorded in triplicate, then that value was extrapolated, according to ISTA (2018) procedure.

**Grain width.** The average width of 10 grains per accession was determined, according to the methodology described by SNICS (2014), with the use of a digital Vernier (Truper, Model 14388, Mexico).

**Total anthocyanin content.** Twenty grains of each accession were ground and anthocyanin extraction was performed by weighing 20 mg of flour inside 1.5 mL Eppendorf tubes and adding 1.3 mL of trifluoroacetic acid (TFA). The absorbance of the samples was read at 520 nm in a Quant BioTek microplate reader (Palacios, 2018). The results were recorded in micrograms per gram ( $\mu\text{g g}^{-1}$ ).

**Grain hardness.** To determine this variable, the flotation index was obtained by performing the procedure as described in the NMXFF-034/1-SCFI-2020 standard (Secretaría de Economía-México, 2020). This consists of placing 100 grains in a sodium nitrate solution at a  $1.25\text{ g mL}^{-1}$  density ( $\pm 0.001\text{ g mL}^{-1}$ ), at a temperature of 22 °C to 23 °C; then quantifying the number of grains risen to the surface. Very hard grains are considered when the number of grains rising to the surface goes from 0 to 12; hard grains account from 13 to 37 rising to the surface; in grains with intermediate hardness 38 to 62 rise to the surface; soft grains if the number of grains rising to the surface ranges from 63 to 87; and very soft grains if rising grains are accounted from 88 to 100 grains (the total of grains in the sample).

### Statistical analyses

To compare the agronomic, morphological, and biochemical variables of 25 pigmented maize races, an analysis of variance and a comparison of means using Tukey's test ( $p \leq 0.05$ ) were performed. The coefficient of variation of the flotation index for each race was obtained through the accessions. Based on the variables, total

anthocyanin content, flotation index, weight of one-thousand grains, grain width, plant height, stem diameter, height to the first ear, and number of leaves per plant; a cluster analysis was performed to generate a dendrogram, calculating the Euclidean distance with data standardized to mean zero and variance one. These analyses were performed in the statistical software suite R Studio (v. 4.1.2), using libraries *ggplot2*, *factoextra*, *cluster* and *purrr*.

## RESULTS AND DISCUSSION

The highest values of plant height were found in the ‘Elotes de Sinaloa’ race, the races with the lowest plant height were ‘Arrocillo’ and ‘Nal-Tel’ (Table 1). These results are

**Table 1.** Comparison of means of agronomic, morphological and biochemical variables of 25 pigmented maize races.

| Landrace                | AP<br>(m) | AM<br>(m) | DT<br>(cm) | NH<br>(Adim) | PMG<br>(g) | AG<br>(cm) | CAT<br>( $\mu\text{g g}^{-1}$ ) |
|-------------------------|-----------|-----------|------------|--------------|------------|------------|---------------------------------|
| Ancho                   | 1.74      | 0.68abc   | 1.9b       | 12a          | 352cd      | 0.53a      | 309b                            |
| Arrocillo               | 1.53      | 0.50bc    | 1.8b       | 9a           | 333cde     | 0.67a      | 391ab                           |
| Arrocillo Amarillo      | 1.63      | 0.37c     | 2.2ab      | 11a          | 331cdef    | 0.51a      | 385ab                           |
| Azul                    | 1.78      | 0.74abc   | 2.5a       | 13a          | 314def     | 0.57a      | 315b                            |
| Bofo                    | 1.73      | 0.67abc   | 2.1ab      | 11a          | 352c       | 0.55a      | 325b                            |
| Bolita                  | 1.75      | 0.75abc   | 2.1ab      | 13a          | 308efg     | 0.5a       | 273b                            |
| Cacahuacintle           | 1.8       | 0.82a     | 2.4ab      | 14a          | 394bc      | 0.48a      | 348b                            |
| Celaya                  | 1.6       | 0.60abc   | 2.4ab      | 12a          | 405bc      | 0.6a       | 243b                            |
| Chalqueño               | 1.74      | 0.69abc   | 2.1ab      | 11a          | 363c       | 0.57a      | 367b                            |
| Cónico                  | 1.71      | 0.64abc   | 2.1ab      | 11a          | 365c       | 0.53a      | 301b                            |
| Cónico Norteño          | 1.86      | 0.68abc   | 2.0b       | 11a          | 326cdef    | 0.57a      | 313b                            |
| Cristalino de Chihuahua | 1.8       | 0.75abc   | 2.2ab      | 13a          | 311defg    | 0.6a       | 343b                            |
| Elotes Cónicos          | 1.69      | 0.62abc   | 2.0b       | 11a          | 358c       | 0.57a      | 324b                            |
| Elotes de Sinaloa       | 1.9       | 0.80ab    | 2.4ab      | 14a          | 446ab      | 0.53a      | 347b                            |
| Elotes Occidentales     | 1.82      | 0.73abc   | 2.0b       | 12a          | 439b       | 0.52a      | 330b                            |
| Maíz Dulce              | 1.8       | 0.75abc   | 1.6c       | 12a          | 283fg      | 0.47a      | 595a                            |
| Mushito                 | 1.87      | 0.77ab    | 2.1ab      | 13a          | 323cdef    | 0.44a      | 305b                            |
| Nal-Tel                 | 1.53      | 0.53abc   | 1.9b       | 9a           | 244g       | 0.64a      | 292b                            |
| Olotillo                | 1.73      | 0.65abc   | 2.2ab      | 12a          | 401bc      | 0.59a      | 272b                            |
| Oloton                  | 1.69      | 0.65abc   | 2.1ab      | 12a          | 471a       | 0.57a      | 368b                            |
| Pepitilla               | 1.8       | 0.75abc   | 2.1ab      | 12a          | 403bc      | 0.66a      | 349b                            |
| Reventador              | 1.73      | 0.66abc   | 2.0b       | 11a          | 298efg     | 0.48a      | 261b                            |
| Tabloncillo             | 1.7       | 0.65abc   | 2.0b       | 12a          | 325cdef    | 0.51a      | 267b                            |
| Tepecintle              | 1.74      | 0.62abc   | 1.9b       | 11a          | 386c       | 0.5a       | 280b                            |
| Tuxpeño                 | 1.68      | 0.61abc   | 2.0b       | 11a          | 285fg      | 0.56a      | 357b                            |

AP: plant height (non-significant difference); AM: height to the first ear; DT: stem diameter; NH: number of leaves per plant; Adim: dimensionless; PMG: weight of one-thousand grains; AG: grain width; CAT: total anthocyanin content. Means with different letters indicate statistical difference ( $p \leq 0.05$ ).

similar to those presented by Arellano-Vázquez *et al.* (2003) in native varieties of blue-grain maize of poor adaptability in five localities of the highlands of Central Mexico, with plant height values between 1.36 m and 1.51 m; non-significant difference was found in the variable height to the first ear.

The highest stem diameter was found in the 'Azul' race with 2.6 cm and the smallest was obtained by the 'Maíz Dulce' race with 1.6 cm, these values are similar to those obtained by Verde-Aquino and Santolalla-Ruiz (2021) in a research on the adaptation of 30 double-cross hybrids of maize for forage with an overall average of 1.88 cm. The number of leaves ranged from 9 to 14, with a mode of 11 and an average of 11.7; these values are similar to those obtained by Cutiño-Mendoza *et al.* (2022) in the agronomic evaluation of three varieties of maize where they recorded 12 leaves per plant of native maize.

The weight of one-thousand grains presented a significant difference in the 25 races of maize. The Oloton race obtained the highest value (471 g) and the Nal-Tel race obtained the lowest (244 g). Ramírez *et al.* (2020) reported a maximum value for weight of one-thousand grains of 335.78 g in a purple native maize variety. The grain width ranged from 0.44 to 0.67 cm, only the races Mushito and Maíz Dulce had a grain width less than 0.476 cm, which is the minimum acceptable reference for maize grain that is intended for the production of tortillas and nixtamal-manufactured products, as established in the Mexican standard NMXFF-034/1-SCFI-2020 (Secretaría de Economía, 2020). The minimum and maximum anthocyanin content were 243 and 595  $\mu\text{g g}^{-1}$ , for the Celaya and Maíz Dulce races, with a median of 324 (Table 1).

The flotation index showed values between 18% and 75% (Table 2) for Elotes de Sinaloa and Tabloncillo, which corresponds to grains ranging from hard to soft. Nine races presented hard grains, 14 with intermediate hardness and 2 showed soft grains. Seven races exceeded the recommended flotation index value, whereas the remaining 18 races meet the recommended hardness by showing from 10% to 50% floating grains (NMXFF-034/1-SCFI-2020; Secretaría de Economía, 2020).

In the dendrogram generated based on the agronomic and morphological variables of the 25 maize races analyzed (Figure 1), four large groups are shown on the base of a Euclidean distance of 5. The first group has two subgroups; the first subgroup is composed of the races Celaya, Olotillo, Pepitilla, Elotes occidentales and Oloton, whereas the second subgroup is composed of the races Cacahuacintle, Elotes de Sinaloa, Bolita, Mushito, Azul, and Cristalino de Chihuahua.

The second group included the Maíz Dulce race alone. The third group is composed of the races Arrocillo and Nal-Tel. The fourth group is formed of the races Arrocillo Amarillo, Reventador, Tepecintle, Ancho, Tabloncillo, Tuxpeno, Elotes conicos, Bofo, Conicos, Chalqueno and Conico norteno (English transliterated).

## CONCLUSIONS

We characterized 275 accessions of pigmented maize from 25 native races, that were compared through morphological, agronomic and biochemical variables. This made it possible to identify those races that comply with the Mexican standard NMXFF-034/1-

**Table 2.** Flotation index and grain hardness of 25 maize races.

| Landrace                | Flotation index | CV   | Grain hardness        |
|-------------------------|-----------------|------|-----------------------|
| Ancho                   | 44              | 0.76 | Intermediate hardness |
| Arrocillo               | 37              | 0.34 | Hard                  |
| Arrocillo Amarillo      | 30              | 0.16 | Hard                  |
| Azul                    | 54              | 0.64 | Intermediate hardness |
| Bofo                    | 44              | 0.86 | Intermediate hardness |
| Bolita                  | 44              | 0.67 | Intermediate hardness |
| Cacahuacintle           | 38              | 0.67 | Intermediate hardness |
| Celaya                  | 75              | 0.16 | Soft                  |
| Chalqueño               | 60              | 0.54 | Intermediate hardness |
| Cónico                  | 43              | 0.73 | Intermediate hardness |
| Cónico Norteño          | 46              | 0.69 | Intermediate hardness |
| Cristalino de Chihuahua | 23              | 0.15 | Hard                  |
| Elotes Cónicos          | 49              | 0.66 | Intermediate hardness |
| Elotes de Sinaloa       | 18              | 0.99 | Hard                  |
| Elotes Occidentales     | 54              | 0.67 | Intermediate hardness |
| Maíz Dulce              | 50              | 0.66 | Intermediate hardness |
| Mushito                 | 57              | 0.28 | Intermediate hardness |
| Nal-Tel                 | 48              | 0.33 | Intermediate hardness |
| Olotillo                | 19              | 0.92 | Hard                  |
| Oloton                  | 51              | 0.50 | Intermediate hardness |
| Pepitilla               | 20              | 0.35 | Hard                  |
| Reventador              | 26              | 0.75 | Hard                  |
| Tabloncillo             | 75              | 0.42 | Soft                  |
| Tepecintle              | 33              | 0.95 | Hard                  |
| Tuxpeño                 | 32              | 0.99 | Hard                  |

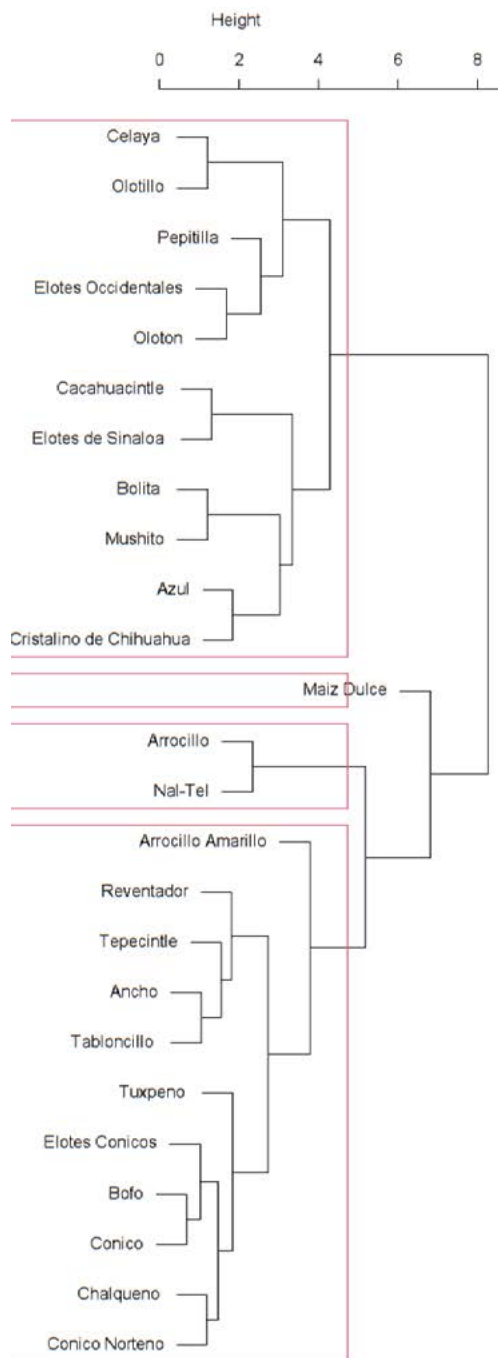
As a reference, the desirable flotation index values go from 10%-50%, according to NMXFF-034/1-SCFI-2020 (Secretaría de Economía, 2020). CV: coefficient of variation.

SCFI-2020, in terms of hardness and grain width. In addition, the median anthocyanin content was identified, as well as the maximum and minimum value.

With the variables evaluated, it was possible to group these races into four groups according to their similarity. The diversity found can be used in genetic improvement programs, as well as in production programs for the better use of these native varieties of Mexican maize.

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**Figure 1.** Dendrogram of 25 maize races, considering the variables total anthocyanin content, flotation index, weight of one-thousand grains, grain width, plant height, stem diameter, height to the first ear, and number of leaves per plant.

## REFERENCES

- Arellano-Vázquez, J. L., Tut-Couoh, C., María-Ramírez, A., Salinas-Moreno, Y., & Taboada-Gaytán, O. R. (2003). Maíz azul de los Valles Altos de México. I. Rendimiento de grano y caracteres agronómicos. *Revista Fitosanitaria Mexicana*, 26(2), 101-101.
- Bellon M. R., & Hodson D., Hellin J. (2011). Assessing the vulnerability of traditional maize seed systems in Mexico to climate change. *Proc. Natl. Acad. Sci. USA*. 108:13432-7. doi:10.1073/pnas.1103373108

- Caballero-García, M. A., Córdova-Téllez, L. & López-Herrera, A. J. (2019) Validación empírica de la teoría multicéntrica del origen y diversidad del maíz en México. *Revista Fitotecnia Mexicana* 42:357-366, <https://doi.org/10.35196/rfm.2019.4.357-366>
- Cutiño-Mendoza, A., Vuelta-Lorenzo, D. R., Molina-Lores, L. B., Vargas-Batis, B., Fernández-Hechavarría, M., & Mustelie-Ocle, M. C. (2022). Evaluación agronómica de 3 variedades de maíz (*Zea mays* L.) en las condiciones edafoclimáticas de la finca “El Porvenir” del consejo popular “La Coronú”, Contra maestre. *Revista Transdisciplinaria de Estudios Sociales y Tecnológicos*, 2(3), 49-58. <https://doi.org/10.58594/rtest.v2i3.55>
- Guillén-Sánchez, J., Mori-Arismendi, S., & Paucar-Menacho, L. (2014). Características y propiedades funcionales del maíz morado (*Zea mays* L.) var. subnigrivioláceo. *Scientia Agropecuaria* 5: 211-217.
- Hellin, J., Keleman, A., López, D., Donnet, L., & Flores, D. (2013). La importancia de los nichos de mercado: Un estudio de caso del maíz azul y del maíz para pozole en México. *Revista fitotecnia mexicana*, 36, 315-328.
- Hernández, Q. J. D. D., Rosales, N. A., Molina, M. A., Miranda, P. A., Willcox, M., Hernández, C. J. M., & Palacios, R. N. (2017). Cuantificación de antocianinas mediante espectroscopia de infrarrojo cercano y cromatografía líquida en maíces pigmentados. *Rev. Fitotec. Mex.* 40(2):219-225.
- Hernandez-Trejo, A., López-Santillán, J. A., Estrada-Drouaillet, B., Reséndiz-Ramírez, Z., Coronado-Blanco, J. M., & Malvar, R. A. (2023). Aptitud combinatoria y efectos recíprocos de la precocidad en poblaciones nativas de maíz de Tamaulipas. *Revista mexicana de ciencias agrícolas*, 14(2), 171-183. Epub 19 de junio de 2023. <https://doi.org/10.29312/remexca.v14i2.2990>
- ISTA (International Seed Testing Association). (2018). International rules for seed testing. International Seed Testing Association: Bassersdorf, CH-Switzerland.
- Kato Y. T. A., Mapes S., C., Mera O., L. M., Serratos H., J. A., & Bye B., R. A. (2009). Origen y Diversificación del Maíz: Una Revisión Analítica. Universidad Nacional Autónoma de México, Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. México, D. F. 116 p.
- López-Morales, F., García-Zavala, J. J., Corona-Torres, T., Cruz-Izquierdo, S., López-Romero, G., Reyes-López, D., Vásquez-Carrillo, M. G., & Molina-Galán, J. D. (2020). Comparación del rendimiento y cambios morfológicos en maíz Tuxpeño V-520C adaptado a valles altos en México. *Revista Fitotecnia Mexicana*. <https://doi.org/10.35196/rfm.2020.2.133>
- Palacios, R. N. (2018). Calidad nutricional e industrial de maíz: laboratorio de calidad nutricional de maíz “Evangelina Villegas” CDMX, México: CIMMYT.
- Pressoir G., & Berthaud, J. (2004). Population structure and strong divergent selection shape phenotypic diversification in maize landraces. *Heredity* 92:95-101, <https://doi.org/10.1038/sj.hdy.6800388>
- Ramírez Reynoso, O., Escobar Álvarez, J. L., Maldonado Peralta, M. D. L. Á., Rojas García, A. R., Hernández Castro, E., & Valenzuela-Lagarda, J. L. (2020). Calidad de mazorca y grano en maíces criollos de la Costa Chica, Guerrero. *Revista mexicana de ciencias agrícolas*, 11(SPE24), 239-246.
- SAGARPA (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación) (2015). Maíz punta de riego. Agenda Técnica Agrícola Guanajuato. Segunda edición. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias– INIFAP-. Servicio Nacional de Sanidad, Inocuidad y Calidad Alimentaria– SENASICA. México. pp: 225-232.
- Salinas Moreno, Y., García Salinas, C., Coutiño Estrada, B., & Vidal Martínez, V. A. (2013). Variabilidad en contenido y tipos de antocianinas en granos de color azul/morado de poblaciones mexicanas de maíz. *Revista fitotecnia mexicana*, 36(Supl. 3-a), 285-294. [http://www.scielo.org.mx/scielo.php?script=sci\\_arttext&pid=S0187-73802013000500005&lng=es&tlng=es](http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0187-73802013000500005&lng=es&tlng=es)
- Secretaría de Economía (2020). Productos alimenticios para uso humano no industrializados– cereales– maíz (*Zea mays* L.); especificaciones y métodos de prueba NMXFF-034/1-SCFI-2020 (cancela a la NMX-FF-034-2002). Secretaría de Economía, Gobierno de México. <https://sidof.segob.gob.mx/notas/docFuente/5650699>
- SNICS (Sistema Nacional de Inspección y Certificación de semillas). (2014). Guía técnica para la descripción varietal de maíz (*Zea mays* L.).
- Verde-Aquino, J., & Santolalla-Ruiz, S. H. (2021). Adaptación de 30 híbridos dobles de maíz forrajero (*Zea mays* L.) en el rendimiento de biomasa y de grano seco. *Revista Investigación Agraria*, 3(1), 52-62.

# Foliar application of amino acids improves growth and productivity of radish (*Raphanus sativus* L.)

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## ABSTRACT

**Objective:** Foliar application of amino acids can be an ecological alternative to increase the productivity of horticultural plants. Therefore, the objective of this study was to evaluate the effect of foliar application of the amino acid-based growth promoter VIUSID agro<sup>®</sup> (VA) on the radish growth and productivity variety 'Red Hazera'.

**Design/methodology/approach:** An experiment was carried out in a randomized block design with three treatments and five replicates. A control (VA0) and two concentrations of the growth promoter at 1.2- and 1.5- mL L<sup>-1</sup> were applied in improving leaf area, chlorophyll content, dry and fresh biomass of leaves and tubers, growth rates, and agricultural yield.

**Results:** The results showed that the foliar application of growth promoter influenced positively on radish growth and productivity, especially the concentrations of 1.5 mL L<sup>-1</sup> showed higher TCC, TAN, FTB, polar diameter and increased agricultural yield by 21% compared to the control treatments. Nonetheless, foliar application of growth promoter at concentration of 1.2 mL L<sup>-1</sup> improves TDB, CC, LFB, LA and the agricultural yield was 10% high than the control treatment.

**Findings/conclusions:** Taken together, the results of this study indicated that foliar application of growth promoter is an alternative strategy for increasing radish productivity under garden conditions.

**Keywords:** amino acids, vegetables, urban agriculture, yield, VIUSID agro<sup>®</sup>.

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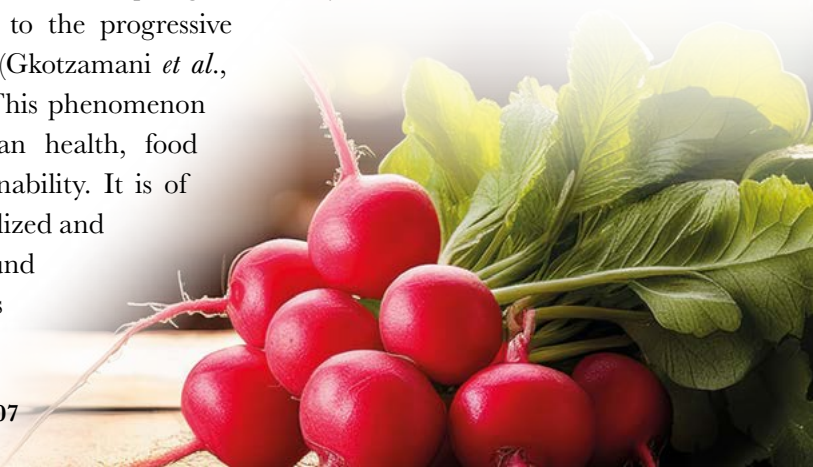
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## INTRODUCTION

Climate change causing direct and indirect effects, which limiting plant productivity such as drought, uneven rainfall distribution, soil salinization and elevated temperatures, are largely caused by inadequate anthropological activity and the need for intensive agriculture due to the progressive increase in world population (Gkotzamani *et al.*, 2024; Makuya *et al.*, 2024). This phenomenon represents a threat to human health, food security and ecological sustainability. It is of particular concern in marginalized and vulnerable communities around the world, where action is urgently needed to reduce



adverse climate impacts and support the sustainable development goals, especially as they relate to food (Amoak *et al.*, 2022).

In this context, it is crucial to increase food production with strategies that promote environmental conservation. In this sense, the foliar application of beneficial elements, including bioproducts and amino acids, becomes an important option to consider (Peña Calzada *et al.*, 2022). On the other hand, it has been documented that amino acid-based growth promoters can stimulate growth and production in agricultural crops without causing negative impacts on the environment (Matysiak *et al.*, 2020). In addition, recent research has shown that these products can improve the quality of agricultural products when are applied via foliarly (Hu *et al.*, 2023). Moreover, spraying amino acids such as alanine (Ala), arginine (Arg), glutamine (Glu), glycine (Gly), methionine (Met) and proline (Pro) has been shown to be effective in mitigating the effects of abiotic stress in vegetables and grains (Abdelkader *et al.*, 2023; Repke *et al.*, 2022) and can benefit vegetative growth, fruit set, yield, and fruit quality (Almutairi *et al.*, 2022).

Another element to take into account is nitrogen (N), which is among the main elements affecting plant development, physiology and metabolism (Olivera-Viciedo *et al.*, 2024). N assimilation is related to key physiological or metabolic processes in plants, such as photosynthesis, photorespiration, respiration, amino acid synthesis, and the tricarboxylic acid (TCA) cycle (Li *et al.*, 2024). In addition, organic N also favors the ability of plants to cope with biotic and abiotic stresses (Wang *et al.*, 2022), so combined with foliar application of organic N with amino acids can be beneficial.

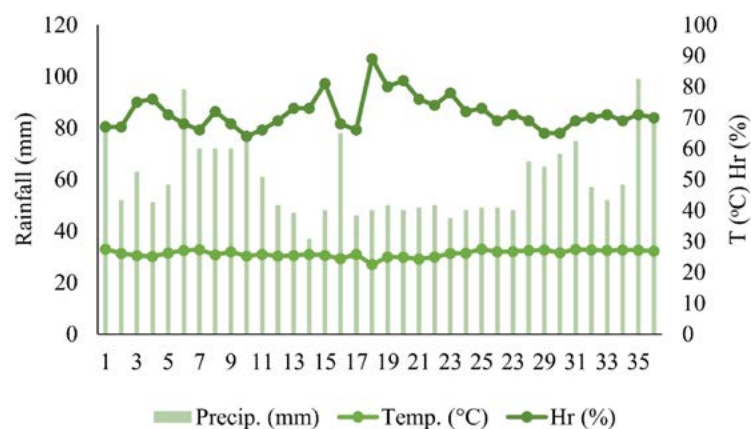
VIUSID agro is a growth promoter that contains important amino acids such as glycine, tryptophan, alanine, arginine and organic nitrogen in its composition. The effect of the product has been demonstrated in several important crops like that soybean (*Glycine max* L.) (Peña-Calzada *et al.*, 2022), corn (*Zea mays* L.) (Absy *et al.*, 2018; Peña *et al.*, 2021) and multiple species, where vegetables stand out (Peña *et al.*, 2017). In radish, the effect of the product has not been sufficiently studied and this is the first result obtained in the variety 'Red Hazera'.

Therefore, the following hypotheses were presented i) the foliar application of the growth promoter benefits dry mass accumulation, growth rates, as well as total chlorophyll content and yield. ii) the capacity to increase the evaluated variables will be greater as the doses increase. To verify this, the objective of the research was to evaluate the effect of foliar application of the amino acid-based growth promoter (VIUSID agro<sup>®</sup>) on radish growth and productivity variety 'Red Hazera'.

## MATERIALS AND METHODS

### Research overview

The research was carried out in the experimental area of the University of Sancti Spíritus José Martí Pérez, located at the coordinates (21° 93' 27.95" N 79° 43' 40.90" W). The variety used was 'Red Hazera', obtained from the seed company with 96% germination. Irrigation was by sprinkling, twice a day. The temperature, humidity and rainfall were recorded by the Provincial Station of Sancti Spíritus, Figure 1. The planting date was March 13, 2023 and was harvested on April 18 of the same year. For substrate preparation,



**Figure 1.** Mean climatic variables, Rainfall (mm), Temperatures (Tem) (°C) and relative humidity (Hr) (%).

irrigation, agro-technology and pest and disease control, the norms established in the technical manual for garden production, intensive orchards and semi-protected garden were followed (Rodríguez *et al.*, 2007).

### Experimental design

The experimental design was randomized blocks with three treatments and five replicates. The plots size was 5 m<sup>2</sup>. The sowing frame was 0.10×0.05 m. Five plants per plot were randomly marked for a total of 25 plants evaluated per treatment, 75 in the trial and the calculation area was 2.40 m<sup>2</sup>.

### Treatments and composition of growth promoter

Treatments consisted in a Control (VA0) and the foliar application of the amino acid-based growth promoter VIUSID agro<sup>®</sup> at concentrations of 1.2 mL L<sup>-1</sup> (VA1) and 1.5 mL L<sup>-1</sup> (VA2). The declared composition of the growth promoter VA is: amino acids, Aspartic acid 1.6 %, Arginine 2.5 %, Glycine 2.4 % and Tryptophan 0.5 %, Organic nitrogen 1.8 %, pH 6.80, density 1.14 and net mass 1.14 kg (Peña-Calzada *et al.*, 2022).

### VIUSID Agro<sup>®</sup> application

Applications were made in the morning at 8:30 to 9:30 hours once the dew had evaporated and wind drift was avoided. A total of four application and in an interval of seven days during the crop cycle. A manual back sprayer with a capacity of 8 L was used.

### Measurement and determination of variables

Studied variables were evaluated at two moments inside of crop cycle at 23 and 36 days after sowing (DAS), at the same time, last evaluation coincided with the radish harvest.

The number of leaves per plant was counted and recorded. The length and width of the leaves were determined with a 1500×30 mm stainless steel ruler (Format 7647511500). For the dry mass (DM), the stove (MJW WS 100) was used at 60 °C until constant mass and then the DM was determined in a Sartorius digital balance, with a precision of ±0.01 g.

Stem equatorial and polar diameter was measured and recorded with a digital calibrator Digite® model ACC115-006-11 and ±0.03 mm of accuracy.

The fresh mass of all plant organs was determined in a Sartorius digital balance (model BS 124S) with an accuracy of ±0.01 g in each moment evaluated. To calculate the power of the source and the power of the demand (Santos *et al.*, 2010) described below: Source power=Source size (AF)\* Source activity (TAN), Demand power=Demand size (ms)\* Demand activity (TCR of the tuber). To determine the chlorophyll content, a (TYS-B Chlorophyll Meter) was used, the readings were taken on a clear day without clouds (12-1:00 pm) on the third leaf from apex to base, always in the same orientation and at three points in a triangular form (Peña Calzada *et al.*, 2022).

For harvesting, it was taken into account that all treatments were within the established range, equatorial stem diameter greater than 2.4 cm. For the calculation of yield, the indirect method was used, which consists of determining the production of a plant and then calculating the production per area, taking into account the production per plant and the number of plants per area. The following procedure was used for the growth rates (Table 1).

### Statistical analysis

The AgroEstat statistical package (Brabosa & Maldonado, 2015) was used for results analysis. Normality and homogeneity of variance were performed by Kolmogorov-Smirnov Levene tests, respectively. When normality and homogeneity existed, we using a simple analysis of variance (ANOVA) and the Tukey multiple range test (p<0.05) for mean comparison.

**Table 1.** Plant growth index (Santos *et al.*, 2010).

| Growth rate           | Symbol | Formula                                     | Units                                    |
|-----------------------|--------|---|--|
| Absolute growth rate  | TCA    | $TCA = (W2 - W1) / (T2 - T1)$               | (g·day <sup>-1</sup> )                   |
| Leaf area             | LA     | $LA = (l \times a) f$                       | (cm <sup>2</sup> )                       |
| Net assimilation rate | TAN    | $TAN^* = 2(W2 - W1) / (AF2 + AF1)(t2 - t1)$ | (g·cm <sup>-2</sup> ·day <sup>-1</sup> ) |
| Relative growth rate  | TCR    | $TCR = 2(W2 - W1) / (W2 + W1)(t2 - t1)$     | (g·g <sup>-1</sup> ·day <sup>-1</sup> )  |
| Leaf area ratio       | RAF    | $RAF = \frac{1}{2}(AF1 / W1 + AF2 / W2)$    | (cm <sup>2</sup> ·g <sup>-1</sup> )      |
| Crop growth rate      | TCC    | $1 / AS * (W2 - W1) / (t2 - t1)$            | (g·cm <sup>-2</sup> ·day <sup>-1</sup> ) |
| Leaf area duration    | DAF    | $((IAF1 + IAF2)(T2 - T1)) / 2$              | (day <sup>-1</sup> )                     |
| Leaf area index       | IAF    | $(AF2 - AF1) / As$                          |  |
| Leaf efficiency index | IEF    | Commercial dry mass<br>Leaf area            |  |
| Harvest index         | IK     | Commercial dry mass<br>Total dry mass       |  |

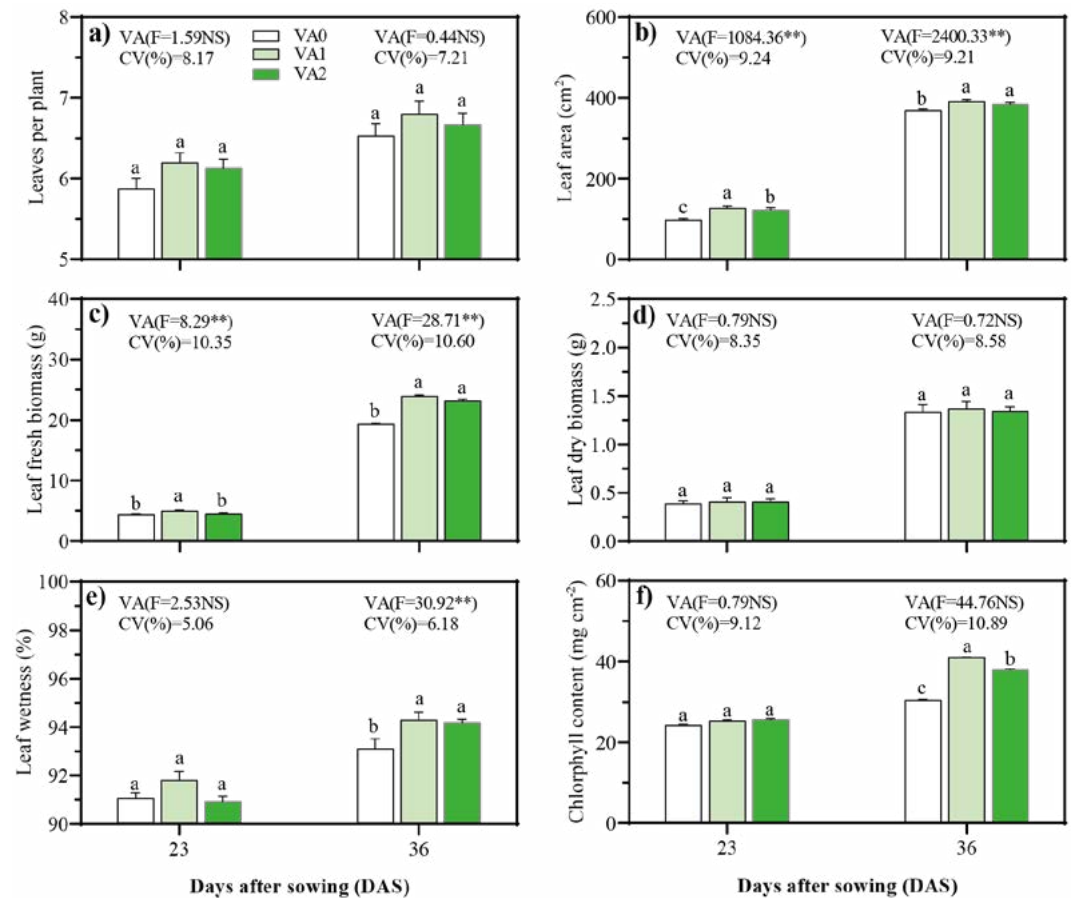
AF=leaf area, T=time, W=dry mass, TAN\*: The formula was used because (α) ranged from 1.5 to 2.5.

## RESULTS AND DISCUSSION

### Effect of treatments on leaf characteristics at 23 and 36 (DAS)

ANOVA showed no significant effect among VA treatments on leaves number per plant in both moments evaluated (Figure 2a). However, leaf area (LA) showed significant differences among VA treatments. At 23 DAS, VA1 revealed higher LA compared with the others VA treatments and significantly increased LA by 30% compared to the VA0 treatments; but VA2 also exhibited increases in LA by 25% than that VA0 doses. Additionally, at 36 DAS, VA1 and VA2 treatments showed similar effects in LA and increasing by 6% in comparison with the VA0 treatment (Figure 2b).

Leaf fresh biomass (LFB) was significantly higher in the VA1 treatment at 23 DAS as compared to the rest treatments. In addition, at 36 DAS, VA1 and VA2 application showed equal effects and increasing LFB by 22% in comparison with the VA treatment (Figure 2c). However, the dry biomass revealed no significant differences in both evaluations (Figure 2d). Similarly, the percentage of leaf moisture (LM) at 23 DAS, no significant differences were found among treatments; while, at 36 DAS, VA1 and VA2 treatments exhibited



**Figure 2.** Leaves per plant a), leaf area b), leaf fresh biomass c), leaf dry biomass d), leaf wetness e) and chlorophyll content f) in radish plants at 23 and 36 days after planting (DAS) in function of the three treatments VA0, VA1, and VA2. Unequal letters indicate significant differences within each independent time (23 and 36 DAS), according to Tukey's multiple range test ( $p < 0.05$ ).

similar effects and significantly increased LM compared to the VA0 treatment (Figure 2e). Furthermore, leaf chlorophyll content (LCC), no differences were found among treatments at 23 DAS. However, at 36 DAS, LCC was higher in the VA1 application in comparison with the Control and VA2 treatments and increased LCC by 35% compared to the control; nevertheless, at the same time VA2 application increased LCC by 25% respect to the control treatment (Figure 2f).

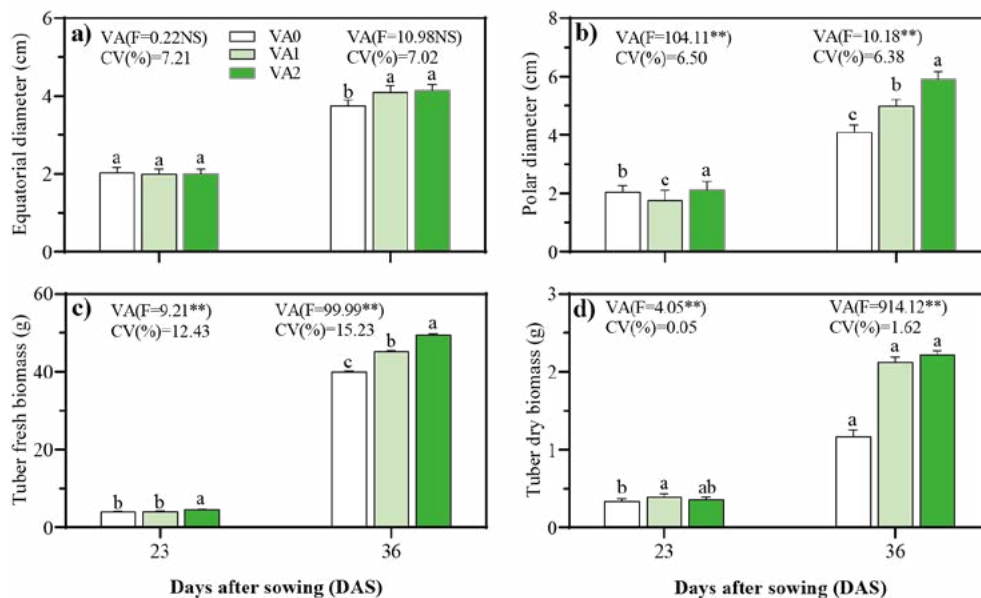
Foliar application of VIUSID agro<sup>®</sup> positively influenced in radish growth, probably by the kinds of amino acids containing and lower amount of organic nitrogen. These facts have been linked to antioxidant and growth-stimulating effects, both under normal conditions and under abiotic stresses (Sabagh *et al.*, 2019). In addition, organic nitrogen applied foliar in small doses leads to stimulate plant growth, which resulting in higher dry mass accumulation and yield (Ferrari *et al.*, 2021). Similar findings in radish variety Scarle Globe was previously reports with low doses of VIUSID agro<sup>®</sup> (Peña-Calzada *et al.*, 2018), which subsequent increases on plant growth and productivity. Furthermore, the foliar application of VA in promoting plant growth and development were observed earlier in plant species such as bean (Peña Calzada *et al.*, 2017), lettuce and beet (Peña Calzada *et al.*, 2024; Pérez-Fernández *et al.*, 2022), soybean (Peña Calzada *et al.*, 2022).

### **Effect of treatments on tuber characteristics at 23 and 36 DAS**

Equatorial diameter of bulb (EDB) not showed significant differences between treatments in the first evaluation; nevertheless, at 36 DAS, the EDB was similar in VA1 and VA2 treatments and revealed significant increases (10 %) in comparison with the VA0 treatment (Figure 3a). In addition, polar diameter (PD) at 23 DAS the best response was achieved by VA2 treatments with significant differences than that VA0 and VA1 treatments; however, VA0 treatments showed higher PD respect to the plants treated with VA1 doses. Similarly, at 36 DAS, the higher PD was in the VA2 treatment, with increasing PD by 45% and 22% in relation to the VA0 and VA1 treatments, respectively; but at the same time, foliar application with VA1 treatment exhibited higher PD compared to the control treatment (Figure 3b).

Tuber fresh and dry biomass were influenced by the treatments in the two evaluations performed (Figure 3c, d). At 23 DAS the tuber fresh biomass (TFM) was significantly higher in the VA2 treatment respect to the others treatments. However, at 36 DAS the TFM was higher in the VA2 treatment, with increases by 24% and 10% compared to the VA0 and VA1 treatments, respectively; nevertheless, plants treated with VA1 concentration showed higher (13%) TFM in relation to the control plants (Figure 3c). Additionally, tuber dry biomass (TDB) at 25 DAS not exhibited significant differences among treatments; but, in the last assessment foliar application of VA1 and VA2 treatments showed similar effects and increases TDB by 81% relative to VA0 treatment (Figure 3d).

These results are related to the application of the growth promoter since Glycine when applied independently or combined with tryptophan, plays a fundamental role in the formation of total chlorophylls and vegetative growth (Repke *et al.*, 2022). In addition, amino acids in foliar application improve crop yield and quality and increase root volume, which



**Figure 3.** Equatorial diameter a), polar diameter b), tuber fresh biomass c), and tuber dry biomass d) in radish plants at 23 and 36 days after planting (DAS) in function of the three studies treatments VA0, VA1, and VA2. Unequal letters indicate significant differences within each independent time (23 and 36 DAS), according to Tukey's multiple range test ( $p < 0.05$ ).

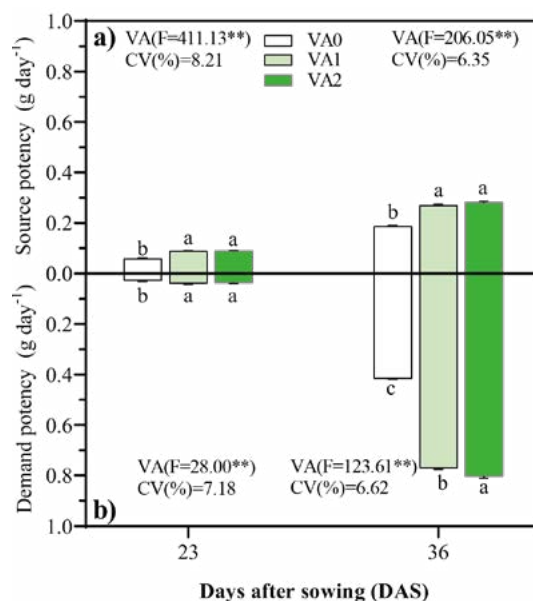
is related to better nutrient uptake, resulting in improved growth and productivity (Mosa *et al.*, 2021; Souri & Hatamian, 2019). Furthermore, foliar application of organic nitrogen improves general crop conditions and favors important processes such as photosynthesis and the bio-assimilates transfer (Dou *et al.*, 2024).

### Effect of treatments on source power and demand at 23 and 36 DAS

Source potency (leaves, LSP) and demand potency (tuber, TDP) at 23 and 36 DAS were influenced by the treatments. In the first evaluation, the LSP and TDP showed equal effects between VA1 and VA2 treatments and were significantly higher by 51% and 36%, respectively, compared to the control treatment (Figure 4a). Nevertheless, at 36 DAS the response was inverse and in turn influenced by treatments and crop cycle. LSP and TDP was higher in the VA1 and VA2 treatments (without difference between them) and showed increases by 48% and 84%, respectively, relative to the VA0 treatment, (Figure 4b).

### Effect of treatments on crop growth rates

The treatments influenced the active growth rates of the crop as TAN, the higher TAN was achieved in the VA1 and VA2 treatments without differences between them and an increased TAN by 52% and 58% as compared to the control treatment, respectively (Table 2). In addition, the net assimilation rate (TAN) showed high values in the treatment VA2 and with significant differences relative to the rest of the treatments and a 48% increase compared to the control (Table 2). Additionally, the relative growth rate (TCR) revealed similar response between VA1 and VA2 treatments and increases in TCR by 23% compared to the control treatment (Table 2).



**Figure 4.** Source potency at 23 and 36 DAS a) and demand potency at 23 and 36 DAS b) in radish plants in function of the three studies treatments VA0, VA1, and VA2. Unequal letters indicate significant differences within each variable, according to Tukey’s multiple range test ( $p < 0.05$ ).

The TCC was significantly higher in plants that received the VA1 and VA2 treatments compared to VA0, and the increases were 57% than the control. Similarly, leaf area ratio (RAF) was higher in the control treatment and showed significant difference with the other treatments, which indicate that VA1 and VA2 treatments required 6% less area to produce the same biomass amount. Likewise, leaf area duration (DAF) was significantly higher in

**Table 2.** Effect of treatments on active growth rate, net assimilation rate, relative growth rate, crop growth rate, leaf area ratio, and leaf area duration.

| Treatments | TAC<br>(g · day <sup>-1</sup> )                    | TAN<br>(g · cm <sup>-2</sup> · day <sup>-1</sup> ) | TCR<br>(g · g <sup>-1</sup> · day <sup>-1</sup> ) |
|------------|--|--|---|
| VA0        | 0.1176 b   | 0.00049 c  | 0.0815 b  |
| VA1        | 0.1791 a   | 0.00069 b  | 0.0980 a  |
| VA2        | 0.1860 a   | 0.00073 a  | 0.1018 a  |
| VA (F)     | 262.30**   | 178.34**   | 92.88   |
| HSD (5%)   | 0.0080   | 0.0071   | 0.0039  |
| Treatments | TCC<br>(g · cm <sup>-2</sup> · day <sup>-1</sup> ) | RAF<br>(cm <sup>2</sup> g <sup>-1</sup> )          | DAF<br>(day <sup>-1</sup> )                       |
| VA0        | 0.0008 c   | 142.99 a   | 13.6262 a   |
| VA1        | 0.0012 b   | 136.13 b   | 13.3501 a   |
| VA2        | 0.0013 a   | 133.88 b   | 12.5441 b   |
| VA (F)     | 262.30**   | 10.23**  | 45.30**   |
| HSD (5%)   | 0.0001   | 5.1085   | 0.2875  |

Unequal letters in the same column indicate significant differences within each variable, according to Tukey’s multiple range test ( $p < 0.05$ ).

the VA0 and VA1 treatments with similar effects between them and showed increases DAF by 8% in comparison with the VA2 treatment (Table 2).

The leaf efficiency indexes showed higher values in the VA1 and VA2 treatments (similar effects between them) compared to the VA0 treatment, and showed increases of 44% in IEF, 8% in IAF and 31% in IK compared to the control, respectively (Table 3).

The results in growth rates are related to the use of the growth promoter, since it is demonstrated that it increases the dry mass in a time interval and also the distribution of dry mass since similar results were found in Chinese cabbage (Peña-Calzada *et al.*, 2019), tobacco (Peña *et al.*, 2018), and the radish variety Scarle Globe (Peña-Calzada *et al.*, 2018).

### Effect of treatments on crop yields

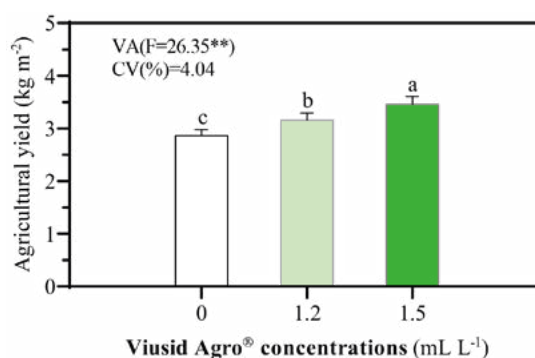
The agricultural yield (AY) was significantly higher with the foliar application of growth promoter as compared to control, in particular VA2 treatment increase AY by 21% and 10% respect to the control and VA1 treatment, respectively; but at the same, this last treatment increasing AY by 10% compared to the control treatment (Figure 5).

These results are associated with the use of the growth promoter based on amino acids and organic nitrogen, as numerous investigations reported benefits of the product on crop growth and yields (Bustamante González *et al.*, 2023; Peña Calzada *et al.*, 2017; Peña *et al.*, 2021). Authors attribute this effect on the productivity of the product to its composition (Romero *et al.*, 2023).

**Table 3.** Effect of treatments on leaf efficiency index, leaf area index, harvest index, and yield index.

| Treatments | IEF      | IAF      | IK       |
|------------|----------|----------|----------|
| VA0        | 0.0039 b | 1.6726 b | 0.4687 b |
| VA1        | 0.0054 a | 1.8168 a | 0.6058 a |
| VA2        | 0.0058 a | 1.7800 a | 0.6238 a |
| VA (F)     | 166.19** | 45.30**  | 87.08**  |
| HSD (5%)   | 0.0004   | 0.0383   | 0.0313   |

Unequal letters in the same column indicate significant differences within each variable, according to Tukey's multiple range test ( $p < 0.05$ ).



**Figure 5.** Agricultural yield in radish plants in function of the three studies treatments VA0, VA1, and VA2. Unequal letters indicate significant differences within each variable, according to Tukey's multiple range test ( $p < 0.05$ ).

## CONCLUSIONS

The foliar application of the amino acid-based growth promoter (VIUSID agro<sup>®</sup>) influenced positive and directly in radish growth and productivity, resulting in higher leaf area, total chlorophyll content, fresh and dry mass accumulation, growth index and agricultural. Additionally, the spraying of the concentration of 1.5 mL L<sup>-1</sup> of VA favored the TCC, TAN, FTB, polar diameter and increased agricultural yield by 21% compared to the control treatments Whereas, foliar application of growth promoter at concentration of 1.2 mL L<sup>-1</sup> enhanced the TDB, CC, LFB, LA and the agricultural yield was higher (10%) than the control treatment. Taken together, the results of this study indicated that foliar application of growth promoter is an alternative ecological to crops management grown under garden conditions.

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## REFERENCES

- Abdelkader, M., Voronina, L., Baratova, L., Shelepova, O., Zargar, M., Puchkov, M., Loktionova, E., Amantayev, B., Kipshakbaeva, A., & Arinov, B. (2023). Biostimulants-Based Amino Acids Augment Physio-Biochemical Responses and Promote Salinity Tolerance of Lettuce Plants (*Lactuca sativa* L.). *Horticulturae*, *9*(7). <https://doi.org/10.3390/horticulturae9070807>
- Absy, R., Abdel-Latif, H., & Atta, M. (2018). Effect of Growth Promoter Supplement on Yield and Grain Quality of Maize (*Zea mays* L.). *Egyptian Journal of Agronomy*, *40*(2):165-180. <https://doi.org/10.21608/agro.2018.3790.1104>
- Almutairi, K. F., Saleh, A. A., Ali, M. M., Sas-Paszt, L., Abada, H. S., & Mosa, W. F. A. (2022). Growth Performance of Guava Trees after the Exogenous Application of Amino Acids Glutamic Acid, Arginine, and Glycine. *Horticulturae*, *8*(12):1-13. <https://doi.org/10.3390/horticulturae8121110>
- Amoak, D., Luginaah, I., & McBean, G. (2022). Climate Change, Food Security, and Health: Harnessing Agroecology to Build Climate-Resilient Communities. *Sustainability (Switzerland)*, *14*(21). <https://doi.org/10.3390/su142113954>
- Barbosa, J. C. & Maldonado, W. J. (2015). Experimentação agrônômica y agroestat – sistema para análises estatísticas de ensaios agrônômicos. Jaboticabal, FCAV/UNESP. 396p. [http://www.ipni.net/publication/ia-brasil.nsf/0/F76C84589C9A03A283257F85006BAE66/\\$FILE/Page20-153.pdf](http://www.ipni.net/publication/ia-brasil.nsf/0/F76C84589C9A03A283257F85006BAE66/$FILE/Page20-153.pdf)
- Bustamante González, C. A., Yudmila Vázquez Osorio, & Ferras, Y. (2023). Effects of different VIUSID Agro<sup>®</sup> concentrations on the growth of *Coffea arabica* L. seedlings. *Agro Productividad*, *16*(7):79-87. <https://doi.org/10.32854/agrop.v16i7.2522>
- Dou, Z., Zhou, Y., Zhang, Y., Guo, W., Xu, Q., & Gao, H. (2024). Influence of Nitrogen Applications during Grain-Filling Stage on Rice (*Oryza sativa* L.) Yield and Grain Quality under High Temperature. *Agronomy*, *14*(1). <https://doi.org/10.3390/agronomy14010216>
- Ferrari, M., Dal Cortivo, C., Panozzo, A., Barion, G., Visioli, G., Giannelli, G., & Vamerali, T. (2021). Comparing Soil vs. Foliar Nitrogen Supply of the Whole Fertilizer Dose in Common Wheat. *Agronomy*, *11*(11):2138. <https://doi.org/10.3390/agronomy11112138>
- Gkotzamani, A., Ipsilantis, I., Menexes, G., Katsiotis, A., Mattas, K., & Koukounaras, A. (2024). The Impact of Salinity in the Irrigation of a Wild Underutilized Leafy Vegetable, *Sonchus oleraceus* L. *Plants*, *13*(11):1-13. <https://doi.org/10.3390/plants13111552>
- Hu, S., Li, K., Zhang, X., Yang, C., Zhang, R., & Guo, H. (2023). The Impact of the Foliar Application of Amino Acid Aqueous Fertilizer on the Flavor of Potato Tubers. *Foods*, *12*(21):1-15. <https://doi.org/10.3390/foods12213951>

- Li, Z., Khan, K., Yang, L., Pan, Y., & Zhou, X. (2024). Continuous Straw Returning Combined with Nitrogen Application Improve Soil Properties and Yield of Double Cropping Maize in Subtropical Regions. *Sustainability*, *16*(12):5265. <https://doi.org/10.3390/su16125265>
- Makuya, V., Tesfahuney, W., Moeletsi, M. E., & Bello, Z. (2024). Assessing the Impact of Agricultural Drought on Yield over Maize Growing Areas, Free State Province, South Africa, Using the SPI and SPEI. *Sustainability (Switzerland)*, *16*(11):1-24. <https://doi.org/10.3390/su16114703>
- Matysiak, K., Kierzek, R., Siatkowski, I., Kowalska, J., Krawczyk, R., & Miziniak, W. (2020). Effect of Exogenous Application of Amino Acids L-Arginine and Glycine on Maize under Temperature Stress. *Agronomy*, *10*(6):769. <https://doi.org/10.3390/agronomy10060769>
- Mosa, W. F. A., Ali, H. M., & Abdelsalam, N. R. (2021). The utilization of tryptophan and glycine amino acids as safe alternatives to chemical fertilizers in apple orchards. *Environmental Science and Pollution Research*, *28*(2):1983-1991. <https://doi.org/10.1007/s11356-020-10658-7>
- Olivera-Viciedo, D., Salas Aguilar, D., de Mello Prado, R., Peña Calzada, K., Calero Hurtado, A., de Cássia Piccolo, M., Bomfim Soares, M., Lizcano Toledo, R., Alves, G. R., Ferreira, D., Rodrigues, R., & de Moura Zanine, A. (2024). Silicon-Mediated Adjustments in C:N:P Ratios for Improved Beetroot Yield under Ammonium-Induced Stress. *Agronomy*, *14*(6):1104. <https://doi.org/10.3390/agronomy14061104>
- Peña-Calzada, K., Olivera-Viciedo, D., Calero-hurtado, A., Rodríguez Fernández, J. C., Kukurtcu, B., Placencia Álvarez, Y. M., & Castro Salas, A. (2019). Productive Response of *Brassica rapa* L. subsp. chinensis to Application of VIUSID Agro. *Journal of Agricultural Science and Technology B*, *9*(2):103-109. <https://doi.org/10.17265/2161-6264/2019.02.003>
- Peña-Calzada, K., Rodríguez, J. C., Viciedo, D. O., Hurtado, A. C., Meléndrez, J. F., & Valdez, R. G. (2018). Efecto de dosis de VIUSID Agro® en el comportamiento morfo-fisiológico y productivo del rábano (*Raphanus sativus* L.). *Revista de La Facultad de Agronomía*, *35*:293-317. <https://produccioncientificaluz.org/index.php/agronomia/article/view/27278/27919>
- Peña Calzada, K., Calero Hurtado, A., Peistrup, V., Mühlmann, I., Rodríguez Miranda, D., Rodríguez Coca, L. I., Rodríguez González, M., & Rodríguez Fernández, J. C. (2024). Respuestas fisiológicas y productivas de plantas de remolacha tratadas con una solución de aminoácidos. *Temas Agrarios*, *29*(1):113-125. <https://doi.org/10.21897/pkxmyw03>
- Peña Calzada, K., Olivera Viciedo, D., Habermann, E., Calero Hurtado, A., Lupino Gratão, P., De Mello Prado, R., Lata-Tenesaca, L. F., Martínez, C. A., Ajila Celi, G. E., & Rodríguez, J. C. (2022). Exogenous Application of Amino Acids Mitigates the Deleterious Effects of Salt Stress on Soybean Plants. *Agronomy*, *12*(9). <https://doi.org/10.3390/agronomy12092014>
- Peña Calzada, K., Rodríguez Fernández, J. C., Santana Sotolongo, M., Viciedo, D. O., Valle Expósito, C. D., & Hernández, R. D. (2017). Effects of a growth promoter on bean (*Phaseolus vulgaris* L.) crops in Sancti Spiritus province, Cuba. *Acta Agronomica*, *66*(3):360-366. <https://doi.org/10.15446/acag.v66n3.53820>
- Peña, K., Calero-hurtado, A., Olivera-Olivera, D., Rodríguez, J. C., Fernandes, T., & Ajila, G. (2021). Technical note / Nota Técnica Respuesta agroproductiva de. *Rev. Fac. Agron. (LUZ)*, *38*(3):573-584.
- Peña, K., Rodríguez Fernández, J. C., Olivera-Viciedo, D., Calero-hurtado, A., Dorta, R., Meléndrez, J., Fernando Veloso, Y., & Kukurtcu, B. (2018). Effect of the Growth Promoter VIUSID Agro on the Morphophysiological and Productive Performance of Tobacco Growth (*Nicotiana tabacum* L.). *Journal of Agricultural Science and Technology B*, *8*(3):157-167. <https://doi.org/10.17265/2161-6264/2018.03.002>
- Peña, K., Rodríguez, J. C., Olivera, D., Meléndrez, J., Rodríguez, L., García, R., & Rodríguez, L. (2017). Development Research. *International Journal of Development Research*, *7*(2):11737-11743. <https://www.journalijdr.com/sites/default/files/issue-pdf/7818.pdf>
- Pérez-Fernández, N., Gutiérrez-Gevara, O., & Fonseca-Pérez, M. (2022). Efecto de VIUSID® Agro en el cultivo de lechuga (*Lactuca sativa* L.) en condiciones de organoponía. *Cultivos Tropicales*, *43*(4):1-7. <https://ediciones.inca.edu.cu/index.php/ediciones/article/view/1704/3370>
- Repke, R. A., Silva, D. M. R., dos Santos, J. C. C., & de Almeida Silva, M. (2022). Alleviation of Drought Stress in Soybean by Applying a Biostimulant Based on Amino Acids and Macro- and Micronutrients. *Agronomy*, *12*(10). <https://doi.org/10.3390/agronomy12102244>
- Rodríguez, A., Companioni, N. E., Peña, P., Fresneda, J., Estrada, J. & Rey, R. (2007). Manual técnico para organopónico, huertos intensivos y organoponía semiprottegida. Sexta edición. La Habana. 184 p.
- Romero, L. M., Estrada, N. M., Gálvez, J. R., Concepción, O. M., & Kukurtcu, B. (2023). Effect of Viused Agro® on the Growth of Banana (*Musa Spp.*) Seedlings Under Nursery Conditions. *International Journal on Agriculture Research and Environmental Sciences*, *4*(2):0-4. <https://doi.org/10.51626/ijares.2023.04.00036>
- Sabagh, A. E. L., Hossain, A., Islam, M. S., Barutçular, C., Ratnasekera, D., Kumar, N., Meena, R. S., Gharib, H. S., Saneoka, H., & da Silva, J. A. T. (2019). Sustainable soybean production and abiotic stress

- management in saline environments: A critical review. *Australian Journal of Crop Science*, 13(2):228-236. <https://doi.org/10.21475/ajcs.19.13.02.p1285>
- Santos, M., Segura, M., & Nústez, C. E. (2010). Análisis de Crecimiento y Relación Fuente-Demanda de Cuatro Variedades de Papa (*Solanum tuberosum* L.) en el Municipio de Zipaquirá (Cundinamarca, Colombia). *Revista Facultad Nacional de Agronomía Medellín*, 63(1):5253-5266.
- Souri, M. K., & Hatamian, M. (2019). Aminochelates in plant nutrition: a review. *Journal of Plant Nutrition*, 42(1):67-78. <https://doi.org/10.1080/01904167.2018.1549671>
- Wang, W., Wang, X., Liao, H., Feng, Y., Guo, Y., Shu, Y., & Wang, J. (2022). Effects of Nitrogen Supply on Induced Defense in Maize (*Zea mays*) against Fall Armyworm (*Spodoptera frugiperda*). *International Journal of Molecular Sciences*, 23(18). <https://doi.org/10.3390/ijms231810457>



# The multidimensionality of Ecophysiology in forests

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## ABSTRACT

**Objective:** This study describes the multidimensionality and significance of ecophysiology in forests within the context of climate change.

**Design/methodology/approach:** A comprehensive review and classification of scientific articles indexed in the Google and Google Scholar repository was conducted. The focus was on articles related to the importance, functions, and history of ecophysiology, as well as its relationship with forests.

**Results:** Ecophysiological studies are fundamental for understanding how plants have evolved in response to environmental changes through centuries. Research in this discipline has increased significantly over the last decade, particularly concerning aspects of climate change.

**Limitations on study/implications:** This review relied exclusively on publications available in Google and Google Scholar.

**Findings/conclusions:** Knowledge of forest ecophysiology is fundamental to predicting how plants undergo adaptations to future environmental changes, including the effects of climate change.

**Keywords:** ecophysiology, adaptation, organisms, climate.

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## INTRODUCTION

The study of plants has historically served as a cornerstone in the development of scientific inquiry, extending back to the origins of humanity (Balick & Cox, 2020). This emphasis underscores the essential role that plants play in sustaining human life and supporting terrestrial ecosystems (Harris, 2020). In this context, plant ecophysiology occupies a critical position in the intersection of ecology and physiology, two disciplines that have been enriched over time by the contributions of numerous researchers. Given the pivotal developments in ecophysiology, advancements in related fields also

directly benefit this discipline by providing a comprehensive conceptual framework to understand the complex interactions between plants and their environment (Cavieres *et al.*, 2016; Wilkening *et al.*, 2024). By integrating principles from both ecology and physiology, ecophysiology plays a crucial role in studying and understanding how environmental factors influence the physiological processes of plants and how they adapt to their surroundings (Ainsworth *et al.*, 2016). Plant ecophysiology and ecology are interconnected fields that focus on different aspects of plant life and their interactions with the environment (Ainsworth *et al.*, 2016). Ecophysiology specifically investigates how the physiological processes of plants respond to environmental factors such as light, water, and nutrients. It emphasizes the underlying mechanisms of these responses and their implications for plant growth and survival. By integrating knowledge from both physiology and ecology, ecophysiology provides insights into how plants adapt to varying conditions in their natural habitats (Lambers *et al.*, 2019).

In contrast, ecology is a broader discipline that studies the relationships between organisms, including plants, and their environment. It encompasses various interactions within ecosystems, such as competition, predation, and symbiosis, as well as the distribution and abundance of species. While ecology can provide context for understanding plant behavior within ecosystems (Begon & Townsend, 2020), ecophysiology explores deeper into the physiological mechanisms that underpin these ecological interactions (Ainsworth *et al.*, 2016).

Interactions among plants, soils, and soil biota have been studied for centuries, initially from agricultural or forestry perspectives but more recently from a fundamental and theoretical ecological approach. This evolution in focus highlights the multidimensionality of ecophysiology, which considers multiple factors affecting plants simultaneously, such as water, soil, light, and climatic conditions. In forests, where these interactions are particularly complex, this multidimensionality is essential for understanding how plant species adapt to their environment and respond to environmental changes.

In 1866, Ernst Haeckel coined the term “ecology” and defined it as the science that focuses on the relationships between organisms and their environment, thereby establishing a foundation for studying interactions between organisms and their environmental conditions. Building on this foundation, Pickett *et al.* (1994) suggested that ecology emerged from the need for emphasizing, by Schimper, to integrate physiology and biogeography (Lüttge & Scarano, 2004). This interdisciplinary perspective allows for a comprehensive understanding of how organisms adapt to their environments. In the context of climate change, this multidimensionality becomes even more critical.

Forests face unprecedented challenges due to rapid changes in temperature, precipitation patterns, and extreme weather events. Ecophysiology provides tools to better understand how these factors affect plants from an integrative perspective. A fundamental aspect is the inherent multidimensionality of forest ecophysiology, which considers the complex interactions among plant physiology, soil dynamics, climatic conditions, and biological interactions between species. By addressing these multiple dimensions, a more comprehensive understanding is achieved for regarding how trees interact with their environment and respond to environmental factors such as light, water, and nutrients.

Thus, the objective of this review is to describe the multidimensionality and significance of ecophysiology in forests within the context of climate change.

## **MATERIALS AND METHODS**

The methodology employed in this review is based on a qualitative and exploratory approach designed to identify and analyze key concepts and significant advancements in the field of forest ecophysiology within the context of climate change. A comprehensive bibliographic search was conducted using keywords such as “forest ecophysiology” and “climate change” in the Google and Google Scholar database. This platform was selected for its accessibility and extensive coverage of scientific literature, facilitating the collection of relevant information across various disciplines and formats (Biblioteca Complutense, 2025).

A total of 35 references were selected, including research articles, books, and book chapters. The inclusion criteria were: i) publications addressing the ecophysiology of plants or forests; ii) studies analyzing the responses of forest ecosystems to climate change; and iii) works relevant to understanding physiological and ecological mechanisms in forest environments. The references include a broad time range from 1974 to 2024, allowing for the incorporation of both historical studies and recent advancements. Furthermore, the analyzed documents are available in both English and Spanish, ensuring a bilingual and multicultural perspective in data interpretation.

A bibliometric analysis was not conducted, as the primary objective was to synthesize key information and construct a coherent conceptual framework that allows for a profound understanding of forest ecophysiology in the context of climate change. A prior qualitative focus was carried out due to the dynamic and complex nature of the field, where interactions among biological, ecological, and environmental factors are fundamental. Additionally, bibliometric analysis can be limited by its reliance on quantitative metrics that do not always adequately reflect conceptual relevance or study quality. By concentrating on the depth and relevance of content, we aim to provide a more integrated perspective that can guide future research in this area.

## **RESULTS AND DISCUSSION**

### **Plant ecophysiology, its origins**

Ernst Stahl (1848-1919) is acknowledged as a foundational figure in ecophysiology, having introduced experimental techniques that significantly advanced plant physiology by exploring the functions of stomata in transpiration and photosynthesis, thus establishing key principles for understanding plant-environment interactions (Lüttge, 2007; Lüttge & Scarano, 2004). In the 20<sup>th</sup> century, researchers like Otto Stocker and Bruno Huber expanded upon Stahl's work by creating innovative instruments that allowed for precise measurements of plant behavior in natural settings, focusing on essential physiological processes (Valladares & Rodríguez-López, 2010). The technological advancements of the 1970s and 1980s further propelled the field, enabling *in situ* assessments of critical environmental variables. A significant study by Kathleen Green and Robert Wright (1977) illustrated that increased atmospheric CO<sub>2</sub> levels could linearly enhance the net

photosynthesis of *Pinus ponderosa* (Green & Wright, 1977). Subsequent investigations revealed that water stress markedly limits gas exchange and photosynthetic efficiency in *Pinus radiata*, underscoring the vital role of water availability for forest productivity and the necessity for effective water management strategies (Benecke, 1980). As the 21<sup>st</sup> century outspread, ecophysiology regained prominence in high-impact scientific literature, integrating mechanisms at the individual level to analyze ecological and evolutionary phenomena (Valladares & Rodríguez-López, 2010). Collectively, the contributions of early ecophysiologicalists like Stahl have been instrumental in enhancing our comprehension of how plants adapt to ever-changing environmental conditions.

Gilbert Aussenac (2000) explored the influence of forest stands on microclimatic conditions and their implications for plant ecophysiology, emphasizing the role of local climatic characteristics in shaping microclimates that affect temperature, light, and water availability. This understanding is vital for optimizing silvicultural practices to enhance forest health and productivity. Additionally, research indicates that conifers in the Sierra Nevada ecotone utilize soil moisture more efficiently than shrubs, underscoring the importance of water availability for their survival in montane environments (Royce & Barbour, 2001). Recent advancements, such as using thermal cameras to monitor tree transpiration, further highlight the necessity of effective water management and ecophysiological knowledge for sustaining forest ecosystems amid climate change (Javadian *et al.*, 2024).

In 2024, Joshi *et al.* examined seasonal variations in the ecophysiological traits of leaves from coexisting perennial and deciduous tree species in a white oak forest (*Quercus leucotrichophora*) in the central Himalayas, focusing on traits such as net photosynthetic capacity and stomatal conductance. Their findings highlighted distinct strategies employed by these trees in response to seasonal changes, which are essential for their growth and survival. This research contributes to our understanding of species coexistence and their ecological roles in temperate forest ecosystems, providing insights for forest management programs and conservation efforts in the Himalayan region (Joshi *et al.*, 2024). Furthermore, it emphasizes the necessity for long-term physiological monitoring to address climate change impacts on forest health and productivity, as current funding often prioritizes innovative but less effective projects over critical in situ studies (Ruhil *et al.*, 2024). Recent studies have indicated that the vulnerability of species such as *Liquidambar styraciflua* is linked to factors like stomatal conductance and leaf water potential, with water being a key determinant for their development. These investigations not only aid at assessing species resilience to climate change but are also vital for developing management and conservation strategies that benefit both ecosystems and local communities (Esperón-Rodríguez & Barradas, 2015).

### **Approaches to ecophysiology in forest ecosystems**

Plant ecophysiology is a crucial discipline that investigates the physiological mechanisms behind ecological interactions, focusing on how plants acclimate, adapt, and grow in response to environmental factors. By examining these processes at molecular, biochemical, and physiological levels, ecophysiology bridges botany, plant physiology, and

ecology, enhancing our understanding of plant responses to critical factors such as water availability, light, and nutrients (Huante *et al.*, 2002; Lambers *et al.*, 2019).

This field plays a vital role in addressing climate change and resource scarcity by providing insights into how physiological processes influence plant adaptation to changing conditions (Ainsworth *et al.*, 2016; Hasanuzzaman, 2020a, 2020b). Through the analysis of plants at both molecular and whole-plant levels, researchers gain valuable knowledge about species thriving in diverse environments and their responses to environmental stressors (Bhatla & Lal, 2023; Felisberto *et al.*, 2024; Mendes *et al.*, 2023). This understanding is essential for managing community dynamics and ecosystem functioning in the face of environmental changes (Halofsky *et al.*, 2020; Wallis *et al.*, 2021).

Ecophysiological studies provide a foundation for understanding processes from tissues to ecosystems (Ainsworth *et al.*, 2016). By exploring the relationships between physiological traits and environmental conditions, researchers can assess ecosystem efficiency and resilience to fluctuations in climate and resources. This knowledge elucidates how specific traits enable survival and competition among species, influencing their distribution and trait expression along ecological gradients (Buzhdygan *et al.*, 2020; Medina, 1977; Smith *et al.*, 2023; Maciel-Mata *et al.*, 2015; Visakorpi *et al.*, 2023).

### **Current importance of plant ecophysiology**

Plant ecophysiology deepens our understanding of plant evolution, productivity, and nutrient use efficiency by examining their adaptation to ecosystems over time. This knowledge is essential for developing strategies to harness plants and forests in mitigating global climate change. In particular, the ecophysiological analysis of forests provides a detailed link between tree phenology, physiology, and climatic influences, offering critical insights into the complex interactions and feedback mechanisms that shape tree-environment dynamics in the face of the ongoing climate crisis (Stagakis *et al.*, 2022).

Plant productivity is closely linked to their ability to efficiently utilize available soil nutrients. Ecophysiology investigates the mechanisms that enable plants to absorb and utilize essential nutrients, including nitrogen, phosphorus, and potassium, which are critical for growth in natural environments. This study also considers the interactions among all biotic and abiotic factors within ecosystems (Ainsworth *et al.*, 2016; Becklin *et al.*, 2016; Reichardt *et al.*, 2020).

### **CONCLUSIONS**

Through time, plant ecophysiology has established itself as a fundamental discipline focused on understanding the physiological processes that regulate plant responses to environmental factors. This field not only contributes to our understanding of plant evolution but also enables the interpretation of their productivity past, present, and future as well as their nutrient use efficiency. Additionally, plant ecophysiology provides new insights into the adaptation of plants to specific ecosystems. By analyzing these interactions throughout different temporal scales, it becomes possible to develop strategies for the sustainable management of plants and forests. This may be crucial for maintaining

vegetation cover with carbon repositories and contributing to the mitigation of global climate change.

## REFERENCES

- Ainsworth, E. A., Bernacchi, C. J., & Dohleman, F. G. (2016). Focus on ecophysiology. *Plant physiology*, 172(2), 619-621
- Aussenac, G. (2000). Interactions between forest stands and microclimate: ecophysiological aspects and consequences for silviculture. *Annals of forest science*, 57(3), 287-301. DOI: 10.1051/forest:2000119
- Balick, M. J., & Cox, P. A. (2020). Plants, people, and culture: the science of ethnobotany. Garland Science
- Becklin, K. M., Anderson, J. T., Gerhart, L. M., Wadgymar, S. M., Wessinger, C. A., & Ward, J. K. (2016). Examining plant physiological responses to climate change through an evolutionary lens. *Plant physiology*, 172(2), 635-649. <https://doi.org/10.1104/pp.16.00793>
- Begon, M., & Townsend, C. R. (2020). Ecology: from individuals to ecosystems. John Wiley & Sons.
- Benecke, U. (1980). Photosynthesis and transpiration of *Pinus radiata* D. Don under natural conditions in a forest stand. *Oecologia*, 44, 192-198. <https://doi.org/10.1007/BF00572679>
- Bhatla, S. C., & Lal, M. A. (2023). Plant physiology, development and metabolism. Springer Nature.
- Biblioteca Complutense. (2025). Google Académico: guía básica . Universidad Complutense de Madrid. Recuperado el 23 de enero de 2025 de <https://biblioguias.ucm.es/google-academico>
- Buzhdygan, O. Y., Meyer, S. T., Weisser, W. W., Eisenhauer, N., Ebeling, A., Borrett, S. R., ... & Petermann, J. S. (2020). Biodiversity increases multitrophic energy use efficiency, flow and storage in grasslands. *Nature Ecology & Evolution*, 4(3), 393-405. <https://doi.org/10.1038/s41559-020-1123-8>
- Cavieres, L. A., Sáez, P., Sanhueza, C., Sierra-Almeida, A., Rabert, C., Corcuera, L. J., ... & Bravo, L. A. (2016). Ecophysiological traits of Antarctic vascular plants: their importance in the responses to climate change. *Plant Ecology*, 217, 343-358. <https://doi.org/10.1007/s11258-016-0585-x>
- Esperón-Rodríguez, M., & Barradas, V. L. (2015). Comparing environmental vulnerability in the montane cloud forest of eastern Mexico: A vulnerability index. *Ecological Indicators*, 52, 300-310. <https://doi.org/10.1016/j.ecolind.2014.12.019>
- Felisberto, J. S., Machado, D. B., Assunção, J. A., Massau, S. A., Queiroz, G. A. D., Guimarães, E. F., ... & Moreira, D. D. L. (2024). Spatio-Temporal Variations of Volatile Metabolites as an Eco-Physiological Response of a Native Species in the Tropical Forest. *Plants*, 13(18), 2599.
- Green, K., & Wright, R. (1977). Field Response of Photosynthesis to CO<sub>2</sub> Enhancement in Ponderosa Pine. *Ecology*, 58(3), 687-692. <https://doi.org/10.2307/1939020>
- Halofsky, J. E., Peterson, D. L., & Harvey, B. J. (2020). Changing wildfire, changing forests: the effects of climate change on fire regimes and vegetation in the Pacific Northwest, USA. *Fire Ecology*, 16(1), 1-26. <https://doi.org/10.1186/s42408-019-0062-8>
- Harris, D. R. (2020). An evolutionary continuum of people–plant interaction. In *The Emergence of Agriculture* (pp. 26-44). Routledge
- Hasanuzzaman, M. (Ed.). (2020a). Plant ecophysiology and adaptation under climate change: mechanisms and perspectives I: general consequences and plant responses. Springer Nature.
- Hasanuzzaman, M. (Ed.). (2020b). Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives II: Mechanisms of Adaptation and Stress Amelioration. Springer Nature.
- Huante, P., Barradas, V. L., & Rincón, E. (2002). Ecofisiología vegetal. *Historia Natural de Chamela*, Universidad Nacional Autónoma de México, 473-489.
- Javadian, M., Aubrecht, D. M., Fisher, J. B., Scott, R. L., Burns, S. P., Diehl, J. L., ... & Richardson, A. D. (2024). Scaling individual tree transpiration with thermal cameras reveals interspecies differences to drought vulnerability. *Geophysical Research Letters*, 51(20), e2024GL111479. <https://doi.org/10.1029/2024GL111479>
- Joshi, R. K., Gupta, R., Mishra, A., & Garkoti, S. C. (2024). Seasonal variations of leaf ecophysiological traits and strategies of co-occurring evergreen and deciduous trees in white oak forest in the central Himalaya. *Environmental Monitoring and Assessment*, 196(7), 634. <https://doi.org/10.1007/s10661-024-12771-3>
- Lambers, H., Oliveira, R. S., Lambers, H., & Oliveira, R. S. (2019). Introduction: history, assumptions, and approaches. *Plant physiological ecology*, 1-10. [https://doi.org/10.1007/978-3-030-29639-1\\_1](https://doi.org/10.1007/978-3-030-29639-1_1)
- Lüttge, U. (2007). Physiological ecology of tropical plants. Springer Science & Business Media.
- Lüttge, U., & Scarano, F. R. (2004). Ecophysiology. *Brazilian Journal of Botany*, 27, 1-10.
- Maciel-Mata, C. A., Manríquez-Morán, N., Octavio-Aguilar, P., & Sánchez-Rojas, G. (2015). El área de distribución de las especies: revisión del concepto. *Acta universitaria*, 25(2), 03-19. <https://doi.org/10.15174/au.2015.690>

- Medina, E. (1977). Introducción a la ecofisiología vegetal. Programa Regional de Desarrollo Científico y Tecnológico, Departamento de Asuntos Científicos, Secretaría General de la Organización de los Estados Americanos.
- Mendes, G. C., Müller, C., & Almeida, A. M. (2023). Physiological, biochemical and molecular approaches in response to abiotic stresses in plants. *Frontiers in Plant Science*, 14, 1194937. doi: 10.3389/fpls.2023.1194937
- Reichardt, K., Timm, L.C. (2020). How Plants Absorb Nutrients from the Soil. In: Soil, Plant and Atmosphere. Springer, Cham. [https://doi.org/10.1007/978-3-030-19322-5\\_16](https://doi.org/10.1007/978-3-030-19322-5_16)
- Royce, E. B., & Barbour, M. G. (2001). Mediterranean climate effects. I. Conifer water use across a Sierra Nevada ecotone. *American Journal of Botany*, 88(5), 911-918. <https://doi.org/10.2307/2657044>
- Ruhil, T., Singh, H., & Barthwal, S. (2024). Long-Term Physiological Monitoring for Detecting Climate Change Impacts on Forest Ecosystems. In H. Singh (Ed.), *Forests and Climate Change: Biological Perspectives on Impact, Adaptation, and Mitigation Strategies* (pp. 817-834). Springer Nature Singapore. [https://doi.org/10.1007/978-981-97-3905-9\\_39](https://doi.org/10.1007/978-981-97-3905-9_39)
- Smith, D. D., Adams, M. A., Salvi, A. M., Krieg, C. P., Ané, C., McCulloh, K. A., & Givnish, T. J. (2023). Ecophysiological adaptations shape distributions of closely related trees along a climatic moisture gradient. *Nature Communications*, 14(1), 7173. <https://doi.org/10.1038/s41467-023-42352-w>
- Stagakis, S., Markos, N., Vanikiotis, T., Levizou, E., & Kyparissis, A. (2022). Multi-Year Monitoring of Deciduous Forests Ecophysiology and the Role of Temperature and Precipitation as Controlling Factors. *Plants*, 11(17), 2257. <https://doi.org/10.3390/plants11172257>
- Valladares, F., & Rodríguez-López, N. F. (2010). Ecofisiología, una aproximación mecanicista a los procesos ecológicos. *Ecosistemas*, 19(1).
- Visakorpi, K., Block, S., Pellissier, L., Levine, J. M., & Alexander, J. (2023). Eco-physiological and morphological traits explain alpine plant species' response to warming. *Functional Ecology*, 37(2), 287-301. <https://doi.org/10.3929/ethz-b-000587865>
- Wallis, C. I., Tiede, Y. C., Beck, E., Böhning-Gaese, K., Brandl, R., Donoso, D. A., ... & Bendix, J. (2021). Biodiversity and ecosystem functions depend on environmental conditions and resources rather than the geodiversity of a tropical biodiversity hotspot. *Scientific Reports*, 11(1), 24530. <https://doi.org/10.1038/s41598-021-03488-1>
- Wilkening, J. V., Feng, X., Dawson, T. E., & Thompson, S. E. (2024). Different roads, same destination: The shared future of plant ecophysiology and ecohydrology. *Plant, Cell & Environment*, 47(9), 3447-3465.



# Artisanal refermentation of *Agave cupreata* bagasse with *Saccharomyces cerevisiae* MG5 as a valorization alternative

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## ABSTRACT

**Objective:** to evaluate the economic feasibility of subjecting broad-leaf agave bagasse to secondary artisanal fermentation, with the use of a native yeast to improve ethanol yields and reduce production costs.

**Design/Methodology/Approach:** the physicochemical characteristics of the bagasse, the amount of sugars according to °Brix, the yields in batches with and without *Saccharomyces cerevisiae* MG5 and the production costs of using the methods described were determined.

**Results:** the bagasse of *Agave cupreata* contains °6 Brix of total sugar, 4.89 pH, 56.76% organic carbon and total fiber of 16.36%. As for the ethanol yields, those were 15 L Mg<sup>-1</sup> and 12 L Mg<sup>-1</sup> with and without added yeasts, respectively.

**Limitations/ Implications of the study:** a secondary artisanal fermentation process is very expensive and not economically feasible.

**Findings/Conclusions:** it is important to standardize the processes of use of agave sugars by small producers in order to improve the processes, to increase yields, and to reduce economic losses. For valorization of the bagasse, it is convenient to search for other alternatives.

**Keywords:** bagasse, broad-leaf agave, fermentation, yields, costs.

## INTRODUCTION

Agave, with its high sugar content, is one of the main resources to be used in the distilled beverages industry; approximately 1.5 million tons (Megagrams, Mg) are used. With this activity, solid waste is generated such as the remaining plant bagasse from the

production, approximately 360 thousand Mg per year. Also liquids such as vinasses that end up dumped directly in the lands owned by the producers; these are byproducts with acidic pH and a high content of dissolved organic matter that impacts the environment (Pérez-Zavala *et al.*, 2020; Córdova *et al.*, 2021; Álvarez-Chávez *et al.*, 2021). Agave bagasse is a lignocellulosic waste whose disposal has increased considerably in recent years. It has become an environmental and public health problem that involves economic losses acting as waste (Pérez-Zavala *et al.*, 2020; Cruz-Moreno *et al.*, 2023).

However, despite its great availability and high content of fermentable sugars, as well as the multiple uses and potential applications, the use of bagasse is limited (Montoya-Rosales *et al.*, 2019). The Agave-mezcal production chain is important for the generation of direct jobs and because of the distillate industry demanding for products. As it is already said, there are sugars lost in bagasse; this loss affects especially small producers who refuse to standardize their processes, but remain guided by their ancestral knowledge inherited from generation to generation (Hoz-Zavala & Nava-Diguero, 2017).

Bagasse is a raw material to make various products such as compost, paper, substrate for mushroom production, bio-based construction, biopolymers, surfactants, and biofuels, among others (Kumar & Chandra, 2020; Márquez Aguilar *et al.*, 2022). Unfortunately, not all *mezcaleros* (*i.e.* the people managing Mezcal production) reevaluate bagasse. It is important to apply strategies for the use and re-use of mezcal bagasse in order to reduce the environmental impact over mezcal producing areas; particularly those with Mezcal Designation of origin (Hoz-Zavala & Nava-Diguero, 2017; Sierra *et al.*, 2021).

The COMERCAM (Mexican Mezcal Quality Regulatory Council) reported for 2023 a national production of 12 239 655 L of mezcal certified with 45% Alc. Vol. This volume increases year after year due to the international high demand for mezcal. In the production of a liter of mezcal, an average of 12 to 15 kg of agave are used, which depends on the species used. So, it is estimated that for the volume (in liters) produced in 2023, an approximate average of 165 235.34 Mg of Agave was used; and the volume of bagasse generated by this industry is unknown. In addition, the production of non-certified mezcal is not accounted for, and the Mexican Mezcal Quality Regulatory Council (COMERCAM) has no record of it. The state of Guerrero (Mexico) ranked sixth as a national producer of mezcal that year (0.68% of the national production). In this Mexican state, two species of agave (*Agave cupreata* and *Agave angustifolia*) are mainly used. There are no records of how much bagasse is generated in the production of this distilled beverage (COMERCAM, 2024).

This study aimed on a strategy of artisanal re-fermentation of agave bagasse with and without yeasts to evaluate viability in yields and costs of the process. The goal is that small producers who still lose sugars in the bagasse disposal can reduce their losses or improve their production processes at the start.

## **MATERIALS AND METHODS**

### **Characteristics of the study area**

The study was implemented in a site called “Mezcalera La Cueva de la Coyota”, in the Mixtec community El Calvario, located 11 km to the south of Chilpancingo, the capital city of the state of Guerrero (Mexico).

### Physicochemical characterization of mezcal bagasse

For the physicochemical characterization of *Agave cupreata* bagasse, 5 kg of fresh bagasse were sent to the Center for Agrifood Innovation and Development of Michoacan (CIDAM). The following parameters were determined in accordance with the corresponding regulations (Table 1).

### Pilot test to obtain artisanal alcohol from the re-fermentation of bagasse with and without yeasts

An artisanal production of ethanol was made using 2 Mg of 6 °Brix bagasse in four fermentation tubs, each with 500 kg of bagasse and 100 L of water at a temperature of 28 °C. In two of the tubs, 80 L of water and 20 L of water with 1% sucrose and 10 g of the yeast *Saccharomyces cerevisiae* GM5 isolated from the agave must were added, and were perfectly mixed in both tubs, in order to start the fermentation process. Added yeast was previously characterized at the molecular level; then all tubs were left to ferment for 7 to 9 days. After the elapsed time, distillation was done in an 800 L stainless steel still, and the volume of ethanol was recovered in 20 L jars, following the recommendations of the CIATEJ manual (2014), in order to minimize economic losses in the process. Finally, the volume and alcohol content of both processes, with and without yeast, were measured; so, the yields per Mg of bagasse were determined (Carrasco-López *et al.*, 2024).

### Determination of alcohol GL degrees

To determine the alcohol degrees, a Gay Lussac hydrometer was used according to the methodology described by Carrasco-López *et al.* (2024).

### Alcohol yield

Alcohol yield is defined as the amount of ethanol produced per amount of feedstock, where RB is the amount of alcohol obtained per gram of biomass, VH (L) is the final volume obtained from each hydrolysate, CR (g L<sup>-1</sup>) is the concentration of ethanol; and 1000 kg refers to the amount of biomass that was available for each sample (Malagón *et al.*, 2017).

$$RB = \frac{VH * CR}{1000 \text{ kg}}$$

**Table 1.** Parameters and methodology used for the physicochemical characterization of *Agave cupreata* bagasse.

| Parameter  | Method                |
|--|-----------------------|
| pH, electrical conductivity  | NMX-F-317-NORMEX-2013 |
| Total solids, volatile solids, dry and wet weight  | NMX-F-428-1982        |
| Total carbohydrates direct calculation with respect to the major components; reducing sugars | NMX-F-312-NORMEX-2016 |
| Total proteins   | NMX-F-068-NORMEX-2011 |
| Organic matter content   | NMX-F-607-NORMEX-2013 |
| Total fiber (dietary and crude)  | NMX-F-613-NORMEX-2017 |

### Cost estimation

Production costs (fixed and variable) were estimated, and a monthly production cycle was assumed. They were compared against the sale prices of ethanol in pharmacies to calculate CRR, the Cycle Rate of Return. In addition, Unit Variable Costs, Unit Fixed Costs and Unit Total Costs were estimated; as well as Profit, for each treatment (Barish & Kaplan, 1978).

## RESULTS AND DISCUSSION

The interest in reducing and reusing the bagasse generated in mezcal production arose by initiative of small producers. Various studies have shown the potential for the revaluation of waste from the mezcal industry (Aguirre Fierro *et al.*, 2020). Some producers are aware they lose sugars in bagasse and have considered the possibility of generating alcohol (ethanol) from the discarded sugars that remain in the bagasse of *Agave cupreata*.

Figure 1 shows the refermentation process of bagasse that still contained 6 °Brix after the use of yeasts or without yeasts (Figure 1 A); likewise, distillation after nine days of fermentation is observed (Figure 1 B).

### Physicochemical characterization of mezcal bagasse

Table 2 shows the results of the physicochemical characteristics of the bagasse of *Agave cupreata*, in which an acidic 4.89 pH is highlighted, that is very similar to that of species such as *Agave potatorum*, *Agave angustifolia*, and *Agave cantala* (Santiago García *et al.*, 2006). Likewise, *A. cupreata* has 1.20 g in 100 g of direct reducing sugars, equal to *A. angustifolia* (1.4 g in 100 g) and below *A. potatorum* (11.7 g in 100 g). Regarding total reducing sugars and insoluble fibers, *A. cupreata* presented only 2.9% and 9.29% in 100 g respectively, well below other agaves such as *A. potatorum*, *A. angustifolia* and *A. cantala* (170.09, 200.76 and 148.28 g in 100 g; or contents of 13.5%, 14% and 16.7%, respectively) (Santiago García *et al.*, 2006).

All these data are relevant to confirm whether it is feasible to use *A. cupreata* bagasse to produce ethanol, as it has been successfully tested with the residues of *A. angustifolia*, *Agave tequilana* and *A. potatorum*, to mention only a few (Rodríguez *et al.*, 2007).



**Figure 1.** Procedures for A: refermentation of the *Agave cupreata* with or without *Saccharomyces cerevisiae*; B: distillation after 9 days of secondary fermentation.

**Table 2.** Physicochemical characterization of *Agave cupreata* bagasse.

| Physicochemical parameters                     | Results |
|--|---------|
| pH   | 4.89    |
| Electrical conductivity (dS cm <sup>-1</sup> ) | 3.75    |
| Total solids (%)                               | 17.45   |
| Volatile solids (%)                            | 13.15   |
| Wet weight (%)                                 | 84.70   |
| Dry weight (%)                                 | 15.30   |
| Total carbohydrates (%)                        | 7.50    |
| Direct reducing sugars (g in 100g)             | 1.20    |
| Total reducing sugars (g in 100 g)             | 2.90    |
| Protein (%)                                    | 5.38    |
| Total Nitrogen (%)                             | 0.86    |
| Organic Matter (%)                             | 97.85   |
| Total organic carbon (%)                       | 56.76   |
| Ether Extract (total fats) (%)                 | 0.28    |
| Dietary fiber (%) Insoluble fraction (%)       | 9.29    |
| Dietary fiber (%) Soluble fraction (%)         | 0.99    |
| Crude fiber (%)                                | 6.08    |
| Total fiber (%)                                | 16.36   |
| Ashes (%)                                      | 2.15    |

### Artisanal ethanol production using refermentation of the bagasse of *Agave cupreata*

A volume of 15.5 L (0.0155 g g<sup>-1</sup>) of ethanol was obtained for each Megagram of bagasse with yeast, and 12.4 L (0.0124 g g<sup>-1</sup>) without yeasts, both adjusted to 45° Alc. Vol. These yields mean a 20% increase when using *S. cerevisiae* MG5. However, these results are very low compared to those obtained when a single fermentation is done. In those processes volumes of 123.5 0.7 L and 156 ± 1.0 L of mezcal were obtained with and without yeasts respectively. Also, fermentation started at 12 °Brix, and 2 °Brix in the distillate. To the resulting bagasse, Brix degrees [°Brix] were not determined (Carrasco-López *et al.*, 2024).

### Estimation of ethanol production costs from bagasse re-fermentation

The costs of artisanal ethanol secondary fermentation were estimated. To calculate these costs, the costs of ethyl alcohol were used as a reference. The following indicators were calculated, Profit (which indicates the effective amount obtained from a sale related to the initial investment), and the Cycle Rate of Return (Percentage of the initial investment that returns at the end of each cycle. A negative rate, as it was the case of this work, indicates losses while a positive CRR indicates profits.

Tables below show the Unit Variable (Table 3), Fixed (Table 4) and Total (Table 5) costs that help the producer to know the minimum costs that must be considered in order not to lose their investment. Or else, to redeem the investment in relation to variable expenses (the

foreseeable investment in each cycle). In this way, each producer is shown in a simplified way the costs generated by this reprocessing proposal, to validate if the profit they receive is real (Blank *et al.*, 2012; Novelo, 2016).

Results showed that the costs for the artisanal production of ethanol using reprocessed or re-fermented bagasse are higher than expected. Therefore, they are not economically

**Table 3.** Determination of variable costs of ethanol production for the re-fermentation of agave bagasse with or without yeasts in the bio-manufacture of mezcal.

| Variable costs       |                                       |                       |          |
|----------------------|---------------------------------------|-----------------------|----------|
| Category             | Concept                               | Unit of measure       | Cost     |
| Mechanical work      | Container filling, weighing y hauling | Working day (15)      | \$5 520  |
|                      | Filling of Alembics                   |                       |          |
|                      | Distillation                          |                       |          |
|                      | firewood cutting                      |                       |          |
| Technical assistance | Assistance                            | Honorarium            | \$1 000  |
| Raw Materials        | Bagasse or vinasse                    | Megagrams             | \$0      |
| Organics             | Yeast                                 | Kilogram              | \$1 600  |
| Energetics           | Firewood                              | Material transfer (2) | \$1 600  |
|                      | Electricity                           | kw consumed           | \$250    |
| Services             | Water                                 | Monthly fee           | \$100    |
| Total \$ MXN         |                                       |                       | \$10 070 |

**Table 4.** Determination of the fixed costs of ethanol production from the artisanal re-fermentation of agave bagasse.

| Costs                            |                 |                 |                     |            |                          |
|----------------------------------|-----------------|-----------------|---------------------|------------|--------------------------|
| Category                         | Concept         | Unit of measure | Useful life (years) | Total cost | Cost per cycle (monthly) |
| Rent                             | Installations   |                 | 20                  | \$250 000  | \$1 041.66               |
| Structures and systems           | Hose            | Meter           | 5                   | \$1 000    | \$16.60                  |
|                                  | Tank or cistern | Piece           | 15                  | \$10 000   | \$55.55                  |
| Machinery and Equipment          | Tanks           | Piece           | 10                  | \$7 178    | \$59.81                  |
|                                  | Alembic         | Piece           | 20                  | \$75 000   | \$312.50                 |
| Tools, Accessories and Materials | Carafes (20)    | Piece           | 2                   | \$1 000    | \$41.66                  |
|                                  | Weigh           | Piece           | 20                  | \$3 500    | \$14.58                  |
|                                  | Refractometer   | Unit            | 5                   | \$10 000   | \$166.66                 |
|                                  | Alcoholmeter    | Unit            | 2                   | \$500      | \$20.83                  |
|                                  | shovels         | Piece           | 1                   | \$1 000    | \$83.30                  |
|                                  | Axe             | Piece           | 1                   | \$1 000    | \$83.30                  |
|                                  | Wheelbarrow     | Piece           | 5                   | \$2 000    | \$33.30                  |
| Total \$ MXN                     |                 |                 |                     | \$362 178  | \$1 929.25               |

\*It was considered that approximately 15 L of ethanol are obtained for each Mg of reprocessed bagasse and if a total of 8 Mg per month (8 tubs, 2 per week) is assumed to be processed, then 120 L of ethanol would be obtained for each cycle. A liter of uncertified mezcal (40% Alc. Vol.) sells for an average of \$ 80 MXN. With this estimate, up to MXN \$ 6400 of net income could be obtained per cycle, which means an income of MXN \$ 76 800 per year.

**Table 5.** Estimation of ethanol production costs in reprocessed bagasse.

|                                   |             |
|-----------------------------------|-------------|
| Production costs (* L)            | \$149.99    |
| *Net Profit=IB-CT=6400-11999.25   | \$5 599.25  |
| Profit margin=(PV-CP)/PV *100     | 87.48%      |
| Rate of return on the cycle=GN/CT | 46.66%      |
| Total unit costs                  | \$11 999.25 |
| Unit variable costs               | \$10 070.00 |
| Unit fixed costs                  | \$1 929.25  |

IB=Net income, CT=Total costs, GN=Profit, PV=Selling price, CP=Production cost (per L); MXN \$: Mexican pesos. \*It was considered that approximately 10 L of high-grade ethanol is obtained for each Mg of reprocessed bagasse and if a total of 8 Mg per month (8 tubs, 2 per week) is assumed to be processed, then 80 L of ethanol would be obtained for each cycle. A liter of uncertified mezcal (40% Alc. Vol.) is sold for an average of MXN \$ 80. With this estimate, up to MXN \$ 6 400 net income could be obtained per cycle, which means an income of MXN \$ 76 800 per year.

viable to develop is option in a biofactory. This is, mezcal producers should look for alternatives to adjust and standardize their sugar consumption processes in the agave must, so as not to generate economic losses and also, to explore other uses of the bagasse obtained in their facilities.

Some alternatives for the use of bagasse is to hold training workshops to make useful by-products; such as compost, briquettes, animal fodder, adobe bricks, ecological pots, mushroom production substrate, among others. This would expand the possibilities of using this waste to generate additional economical resources for producer families, as well as to reduce environmental impact (Paniagua *et al.*, 2021; Acosta *et al.*, 2023; Ordaz *et al.*, 2019).

## CONCLUSIONS

It was shown that it is not feasible to re-ferment bagasse to obtain added value, even if bagasse is discarded with significant amounts of sugars. This is due to re-fermentation costs are high and the extra yields of ethanol are very low. Thus, the recommendation to the producers is to be open to technical training, in order to adjust their mezcal production processes towards consuming all the sugars in the must. Likewise, for the reuse of *Agave cupreata* bagasse, other strategies should be generated and applied to reduce the environmental impact, and to generate additional economic resources for the producer families using broad-leaf agave.

## REFERENCES

- Acosta L., Zamora J., Rodríguez R., González D., Gallardo J. & Salcedo E. 2023. Bagazo y composta de bagazo de agave tequilero en suelos contrastantes: 1. Dinámica de degradación. *Biotechnia*. 25, 2: 90-96.
- Aguirre-Fierro Arely, Héctor A. Ruiz, Miguel A. Cerqueira, Rodolfo Ramos-González, Rosa M. Rodríguez-Jasso, Susana Marques, Rafal M. Lukasik. 2020. Sustainable approach of high-pressure agave bagasse pretreatment for ethanol production. *Renewable Energy*. 155, 1347-1354. <https://doi.org/10.1016/j.renene.2020.04.055>

- Álvarez-Chávez, J., Villamiel, M., Santos-Zea, L. & Ramírez-Jiménez, A. K. 2021. Agave By Products: An Overview of Their Nutraceutical Value, Current Applications, and Processing Methods. *Polysaccharides*, 2, 720–743.
- Barish N. & Kaplan S. 1978. Análisis económico para la toma de decisiones gerenciales y de ingeniería (2ª ed.), McGraw Hill, Nueva York, 791 p.
- Blank, L., Tarquin, A., & Coalla, M. 2012. Ingeniería económica McGraw-Hill. (No. 658, p. 15).
- Carrasco-López, A., Romero-Ramírez, Y., López-Barrera, J. A., Moreno-Terrazas-Casildo, R. D., Ramírez-Peralta, A., Patricio-Hernández, A., & Toribio-Jiménez, J. 2024. The use of native yeasts to improve the organoleptic characteristics and yield of artisanal mezcal. *Agro Productividad*. 17(4), 167-176.
- CIATEJ. 2014. Manual para la estandarización de los procesos de producción del mezcal Guerrerense. Centro de Investigación y Asistencia en Tecnología y Diseño del Estado de Jalisco.
- COMERCAM. 2024. Producción de mezcal. Informe estadístico. Consultado el 30 de mayo de 2024.
- Cordova, D. G., Flores, E. N., García, R. R., & Salvador, J. C. R. 2021. Bagazo de agave: de desecho agroindustrial a materia prima en las biorrefinerías. *Ciencia UNAM*.
- Cruz-Moreno, B. A., Pérez, A. A. F., García-Trejo, J. F., Pérez-García, S. A., & Gutiérrez-Antonio, C. 2023. Identification of secondary metabolites of interest in *Pleurotus djamor* using *Agave tequilana* Bagasse. *Molecules*, 28(2), 557.
- Hoz-Zavala, M. E. E., & Nava-Diguero, P. 2017. Situación del Agave y sus residuos en Tamaulipas. *Revista de Energías Renovables*, 1(1), 19-31.
- Kumar, A. & Chandra, R. 2020. Ligninolytic enzymes and its mechanisms for degradation of lignocellulosic waste in the environment. *Heliyon*, 6(2), e03170.
- Márquez Aguilar, M. A., Castañeda Nolasco, G., & González García, E. 2022. Utilización del bagazo de caña de azúcar (BCA) como estabilizador del bloque hueco de mortero cemento-arena. *Red Universitaria de Urbanismo y Arquitectura*, 14(28), 34-37. <https://doi.org/10.25009/rua.v14i28.165>
- Malagón, M; Paéz, A; Muñoz, A; Santos, J; y Zabala, D. 2017. Producción de bioetanol a partir de diferentes mezclas de los residuos orgánicos generados en una empresa de alimentos. Fundación Universidad de América. *Revista de Investigación* 10(1): 47-59.
- Montoya-Rosales, J. J., Olmos-Hernández, D. K., Palomo-Briones, R., Montiel-Corona, V., Mari, A. G. & Razo-Flores, E. 2019. Improvement of continuous hydrogen production using individual and binary enzymatic hydrolysates of agave bagasse in suspended-culture and biofilm reactors. *Bioresource Technology*, 283, 251-260. <https://doi.org/10.1016/j.biortech.2019.03.072>
- Novelo, J. O. 2016. Análisis de estados financieros. Editorial Digital UNID.
- Ordaz L., Madrid del Palacio M., Rodríguez F., & Bailón A. 2019. Aprovechamiento de los subproductos valiosos de la industria del mezcal en Durango. Colaboraciones de cuerpos académicos en innovación tecnológica.
- Paniagua G., Sarabia Y., y Belmonte Y. 2021. Una segunda vida para los residuos de la industria mezcatera. *Inventio*. 17, 43: 1-7.
- Pérez-Zavala, M. L., Hernández-Arzaba, J. C., Bideshi, D. K., & Barboza-Corona, J. E. 2020. Agave: a natural renewable resource with multiple applications. *Journal of the science of food and agriculture*, 100(15), 5324-5333.
- Rodríguez R., Barrios A., Flores H., Sánchez V., y Ariza R. 2007. Factibilidad económica de la producción de bioetanol con tres especies de *Agave* spp. en regiones productoras de México. *Revista mexicana de ciencias agrícolas*. 7,6: 1439-1453.
- Santiago García, P., Vera Guzmán, A., & Mercedes, L. G. 2006. Evaluación de fructanos en tres especies de agave (*A. angustifolia* Haw., *A. potatorum* Zucc. y *A. cantala* Roxb) del Estado de Oaxaca. Ipn.mx.
- Sierra, E., Alcaraz, J., Valdivia, A., Rosas, A., Hernández, M., Vivaldo, E., & Martínez, A. 2021. Bagazo de agave: de desecho agroindustrial a materia prima en las biorrefinerías. *Materia y Energía*. <https://ciencia.unam.mx/leer/1112/bagazo-de-agave-de-desecho-agroindustrial-a-materia-prima-en-las-biorrefinerias->

# Can equations for Black Belly lambs be used to predict the carcass tissue composition of Dorper lambs?

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## ABSTRACT

**Objective:** This study aimed to evaluate the applicability of equations developed in Black Belly lambs for predicting carcass tissue composition in Dorper lambs.

**Design/methodology/approach:** This study was conducted using twenty 6-month-old ewe lambs ( $30.53 \pm 3.62$  kg). Animals were slaughtered, and the carcass was chilled at 1 °C for 24 hours. The carcass was then split along the dorsal midline, and sections 9-11 were removed from the left half of the carcass. The remainder of the left half of the carcass was dissected into muscle (TCM), fat (TCF), and bone (TCB), and the weight of each was adjusted to the total carcass weight. The equations were assessed for their adequacy. The accuracy and precision of the models were assessed by simple linear regression analysis, graphical analysis, mean square error of prediction (MSEP) and its components, and sources of error.

**Results:** The regression analysis indicated that in equations for TCM and TCF, the slope was not different from unity ( $P > 0.05$ ), but the intercept was different from zero ( $P < 0.05$ ). Nonetheless, all equations showed low to moderate precision ( $0.20 \leq r^2 \leq 0.65$ ), moderate accuracy (bias correction factor  $< 0.65$ ), and low to moderate reproducibility index and agreement with observed data (concordance correlation coefficient of  $0.30 \leq CCC \leq 0.48$ ) for predicting carcass tissues in Dorper lambs. In equations for TCM and TCF, the main component of the MSEP was the means bias ( $> 73.29\%$ ). In the TCB equation, the main component of the MSEP was random error ( $> 69.82\%$ ). This result indicates that further evaluation is required to ensure that there is no lack of fit, *i.e.*, simply random variation that cannot be accounted for by the model in its current form.

**Study limitations/implications:** The study highlights significant limitations in the equations used to estimate the carcass composition of Dorper lambs, showing poor agreement between observed and predicted weights. This highlights the need for more accurate models that consider breed, sex, and local rearing conditions.

**Findings/Conclusions:** Based on these findings, we suggest that the equations tested in this study are not effective in predicting carcass tissue composition in Dorper lambs.

**Keywords:** carcass, hair sheep, mathematical models; prediction, rib section cut.

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## INTRODUCTION

The complete dissection of the sheep carcass allows us to know the tissue composition, but this technique is laborious and expensive. One way of reducing the work involved in dissecting a carcass is to use equations to estimate the carcass tissue composition (Silva *et al.*, 2013). Therefore, several authors present it as an alternative, such as the recording of specific carcass measurements or the use of the tissue composition of primary cuts and the 9-11 rib section to reduce carcass damage (Escalante-Clemente *et al.*, 2022; Rivera-Alegría *et al.*, 2022). Silva *et al.* (2013) state that the evaluation of equations for accurate and precise estimation of carcass composition is a significant advance, as it could help to reduce the cost of experiments. As the evaluation of carcass composition requires the complete dissection of a half carcass, cost is one of the limiting factors for the conduct of some studies in this area. Marcondes *et al.* (2012) also stated that methods that can estimate carcass or body composition without sacrificing the whole carcass are important because they save time, labor and cost. In addition, these methods would have to be of acceptable accuracy to be widely used. Also, due to the wide variety of breeds, management conditions and performance differences between them, it is necessary to look for factors that allow a better integration of the models in different breeds and environmental conditions (Torres *et al.*, 2021).

Due to its low cost, the technique of rib sections 9 to 11 has helped estimate the carcass composition of different animal species (Marcondes *et al.*, 2012; Escalante-Clemente *et al.*, 2021). This technique has recently been used to determine the carcass tissue composition of Black Belly lambs (Escalante-Clemente *et al.*, 2021). Pelibuey and Blackbelly breeds are used in tropical production systems as maternal breeds. Therefore, Katahdin and Dorper breeds have been introduced to increase productivity in these systems. However, there are few reports on carcass traits predicted using these breeds. For example, there have yet to be any reports on using the 9 to 11 rib section to predict carcass traits. According to Tedeschi (2006), the first step in the development of more accurate and reliable models is the identification and acceptance of model inaccuracies. Therefore, assessing the suitability of a mathematical model is an essential step in the modelling process, as it indicates the level of precision and accuracy of the model's predictions for the purpose for which it has been developed. This step is essential to increase confidence in the current model. It also allows the selection of alternative models or suggests model adjustments. The aim of the present study was to evaluate the applicability of an equation developed for Black Belly lambs for predicting carcass muscle weight in Dorper lambs.

## MATERIALS AND METHODS

The study was carried out in the experimental area of the The study was carried out at the Centro de Integración Ovina del Sureste (CIOS), located in R/a Alvarado Santa Irene 2<sup>nd</sup> section, in the municipality of Centro, with a humid tropical climate and temperatures ranging from 15 to 44 °C, with an average of 26 °C, Tabasco, Mexico. Twenty 6-month-old Dorper ewe lambs were used. The animals used in this study were treated following the guidelines and regulations for ethical animal experimentation of the Academic Department of Agricultural Sciences of the Universidad Juárez Autónoma de Tabasco (CIEI: Folio

1173-2022). The average live weight (BW) was  $30.53 \pm 3.62$  kg. Lambs were weaned at 60 days of age and fattened in a cage system with raised slatted floors and group feeding (ten animals per cage) in a feedlot system. When the target BW was reached, animals were selected from the fattening groups for slaughter. The diet consisted of 80% concentrate and 20% forage with an estimated 15% crude protein (CP) and 12 MJ metabolizable energy (AFRC, 1993) and was provided *ad libitum*. The ingredients of the diet included cereal grains (53% ground maize, 14% soya bean meal, 20% star grass hay, 3% molasses, 4% rice flour and a 1% pre-mix of vitamins and minerals).

The animals were slaughtered after a 24-hour fast following the applicable standards (NOM-033-SAG/ZOO-2014 and NOM-088-SAG/ZOO-2014). After slaughter, the carcasses were chilled at 1 °C for 24 h. Ribs 9-11 were taken from the left side of the carcass. The carcass was split medially, and a section through all intercostal spaces between ribs 9-11 (out of a total of 13 pairs of ribs) was taken from the left forequarter, and the segment was removed as described by Escalante-Clemente *et al.* (2022). The left half of the carcass was then weighed and dissected to record the weight of muscle, fat and bone and the weight. The same procedure was followed for rib sections 9-11. The tissues dissected in the left half of the carcass plus those dissected in rib sections 9-11 were adjusted to give the total carcass weight of muscle (TCF), fat (TCF) and bone (TCB).

The equations proposed by Escalante-Clemente *et al.* (2022) were evaluated for predicting total (TCM), fat (TCF), and bone (TCB) of Dorper lambs using the characteristics of the 9-11 rib section (Table 1). The data used to test the equations are shown in Table 2. The equations were assessed for their adequacy. The accuracy and precision of the models were assessed by simple linear regression analysis of the observed values (Y) with the predicted values (X). The carcass tissue compositions estimated by the equations were compared with the values observed using the following regression model:

$$Y = \beta_0 + \beta_1 \times X$$

Where X=predicted value; Y=observed value;  $\beta_0$  and  $\beta_1$ =intercept and slope of the linear equation, under the following statistical hypothesis:  $H_0: \beta_0=0$  and  $H_0: \beta_1=1$  and  $H_a$ : not  $H_0$ . If the null hypotheses were not rejected, the prediction model accurately estimated the carcass tissue composition.

Also, the following procedures were used: graphical analysis, mean square error of prediction (MSEP) and its components, and sources of error (error due to bias, error due to the slope of the regression between observed and predicted values being different from 1, and random error). The coefficient of model determination (CD) was used to assess the variance of the predicted data. The bias correction factor (Cb), a concordance correlation coefficient (CCC) component, was used to indicate deviation from the line of identity. The CCCs were also used as a reproducibility index to consider precision and accuracy. Coefficients  $>0.80$  were considered high precision and accuracy. Moderate precision and accuracy were assumed when the coefficients were  $>0.51$  and  $<0.79$ .

Low precision and accuracy were assumed when the coefficients were  $<0.50$ . Finally, all calculations were performed using the Model Evaluation System (Tedeschi, 2006).

## RESULTS AND DISCUSSION

The mean, minimum, and maximum carcass traits and 9-11 rib sections for Dorper lambs are presented in (Table 1). The total carcass muscle weight (TCM) ranged from 4.32 to 10.25 kg. As for the characteristics of the 9-11 rib section, the weight of ribs 9-11 (WRib) ranged from 0.11 to 0.28 kg. The muscle of sections 9-11 (MRib) ranged from 0.04 to 0.14 kg, while the fat (FRib) ranged from 0.01 to 0.09 kg.

The regression analysis indicated that in equations for TCF the slope was different from 1 ( $P>0.05$ ). However, for TCM and TCB, the slope was not different from unity ( $P>0.05$ ), but the intercept was different from zero ( $P<0.05$ ). This analysis indicated that adjustments were required to estimate the true value, although the model could be used to predict carcass tissues in Dorper lambs. Nonetheless, all equations showed low to moderate precision ( $0.20 \leq r^2 \leq 0.65$ ), moderate accuracy (bias correction factor  $<0.65$ ), and low to moderate reproducibility index and agreement with observed data (concordance correlation coefficient of  $0.30 \leq CCC \leq 0.48$ ) for predicting carcass tissues in Dorper lambs. In equations for TCM and TCF, the main component of the MSEP was the means bias ( $>73.29\%$ ). In the TCB equation, the main component of the MSEP was random error (69.82%). It is good to have a high proportion of MSEP in random, because this helps us to avoid high proportions of MSEP in systematic and mean bias. This is because most of the variation in results is not due to problems in the equation, but rather due to random effects. For TCM and TCF, the result indicates that further evaluation is required to ensure that there is no lack of fit, *i.e.* simply random variation that cannot be accounted for by the model in its current form. The CD value for equations for TCM and TCF also indicated the model overprediction (CD $>1$  indicates underprediction and CD $<1$  indicates overprediction); however, in the equations for TCB, an underprediction was observed by the variation by 63%.

Escalante-Clemente *et al.* (2022) reported that they were able to predict carcass tissue composition in Black Belly lambs using rib dissection 9-11 and found that the use of this technique provided moderate to high accuracy ( $r^2 > 0.59 \leq$  and  $\leq 0.92$ ) and precision ( $>0.96$ ) predictions. The authors conclude that rib dissection 9-11 is a low

**Table 1.** Regression equations used to predict carcass tissue composition in Dorper ewe lambs using the 9<sup>th</sup>-11<sup>th</sup> rib section.

| No. | Equation  | r <sup>2</sup> | MSE  | RMSE | P-Value   |
|-----|---|----------------|------|------|-----------|
| 1   | $TCM(\text{kg}) = 0.89(\pm 0.66^*) + 1.11(\pm 0.10^{***}) \times LHCW + 24.49(\pm 10.16^*) \times FRib$ | 0.90           | 0.12 | 0.34 | $<0.0001$ |
| 2   | $TCF(\text{kg}) = -0.19(\pm 0.41^*) + 0.16(\pm 0.06^*) \times LHCW + 20.37(\pm 6.04^{**}) \times FRib$  | 0.61           | 0.05 | 0.22 | 0.0007    |
| 3   | $TBC(\text{kg}) = 0.58(\pm 0.34^*) + 0.28(\pm 0.05^*) \times LHCW + 9.32(\pm 2.49^{**}) \times BRib$    | 0.80           | 0.02 | 0.14 | $<.0001$  |

TCM: Carcass muscle (kg); TCF: Carcass fat (kg); TCB: carcass bone (kg); MRib: Muscle in the 9<sup>th</sup>-11<sup>th</sup> rib section (kg); FRib: fat in 9-11 rib section (kg); BRib: Bone in the 9<sup>th</sup>-11<sup>th</sup> rib section (kg); LHCW: left half-carcasses weight (kg). Values within parentheses are the SE of the parameter estimates. \*:  $P<0.05$ ; \*\*:  $P<0.01$ ; \*\*\*:  $P<0.001$ .

**Table 2.** Variables used to estimate carcass tissue composition for Dorper lambs.

| Variable | Description  | Mean | SD   | Minimum | Maximum |
|----------|--|------|------|---------|---------|
| LHCW     | left half-carcasses weight (kg).                             | 6.83 | 0.95 | 4.50    | 8.70    |
| WRib     | Weight of 9 <sup>th</sup> -11 <sup>th</sup> rib section (kg) | 0.18 | 0.04 | 0.11    | 0.28    |
| MRib     | Muscle in 9 <sup>th</sup> -11 <sup>th</sup> rib section (kg) | 0.09 | 0.02 | 0.04    | 0.14    |
| BRib     | Bone in 9 <sup>th</sup> -11 <sup>th</sup> rib section (kg)   | 0.04 | 0.01 | 0.03    | 0.06    |
| FRib     | Fat in 9 <sup>th</sup> -11 <sup>th</sup> rib section (kg)    | 0.04 | 0.02 | 0.01    | 0.09    |
| TCM      | Carcass muscle (kg)  | 7.85 | 1.41 | 4.32    | 10.25   |
| TCF      | Carcass fat (kg)   | 3.24 | 0.61 | 2.23    | 4.59    |
| TCB      | Carcass bone (kg)  | 2.51 | 0.50 | 1.64    | 3.68    |

SE: standard deviation.

**Table 3.** Descriptive statistics of the relationships between observed and predicted carcass tissue composition for Dorper lambs.

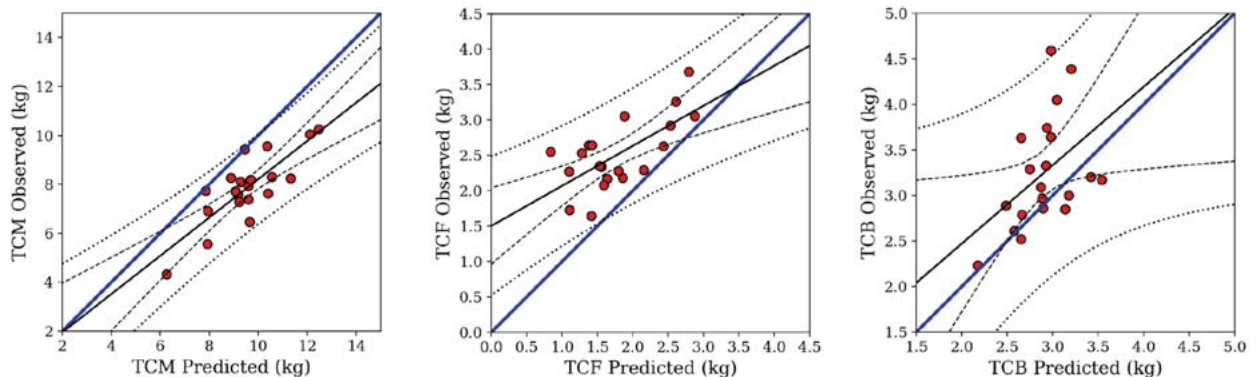
| Variable <sup>1</sup>   | Obs   | TCM   | Obs  | TCF   | Obs  | TCB   |
|-------------------------|-------|-------|------|-------|------|-------|
| Mean                    | 7.84  | 9.53  | 2.51 | 1.78  | 3.24 | 2.89  |
| SD                      | 1.41  | 1.46  | 0.49 | 0.59  | 0.61 | 0.31  |
| Minimum                 | 4.32  | 6.25  | 1.64 | 0.84  | 2.23 | 2.18  |
| Maximum                 | 10.25 | 12.46 | 3.68 | 2.87  | 4.59 | 3.54  |
| r <sup>2</sup>          |       | 0.65  |      | 0.45  |      | 0.20  |
| r                       |       | 0.80  |      | 0.67  |      | 0.44  |
| CCC                     |       | 0.48  |      | 0.35  |      | 0.30  |
| Cb                      |       | 0.59  |      | 0.52  |      | 0.65  |
| MEF                     |       | -0.90 |      | -2.04 |      | -0.14 |
| CD                      |       | 0.38  |      | 0.27  |      | 1.63  |
| Regression analysis     |       |       |      |       |      |       |
| Intercept ( $\beta_0$ ) |       |       |      |       |      |       |
| Estimate                |       | 0.38  |      | 1.50  |      | 0.76  |
| SE                      |       | 1.28  |      | 0.27  |      | 1.17  |
| P-value ( $\beta_0=0$ ) |       | 0.001 |      | 0.001 |      | 0.04  |
| Slope ( $\beta_1$ )     |       |       |      |       |      |       |
| Estimate                |       | 0.78  |      | 0.56  |      | 0.85  |
| SE                      |       | 0.13  |      | 0.14  |      | 0.40  |
| P-value ( $\beta_1=1$ ) |       | 0.12  |      | 0.008 |      | 0.72  |
| MSEP source, % MSEP     |       |       |      |       |      |       |
| Mean bias               |       | 79.25 |      | 73.29 |      | 29.68 |
| Systematic bias         |       | 2.67  |      | 8.77  |      | 0.48  |
| Random error            |       | 18.07 |      | 17.93 |      | 69.82 |
| Root MSEP               |       |       |      |       |      |       |
| Estimate                |       | 1.89  |      | 0.84  |      | 0.63  |
| % of the mean           |       | 19.91 |      | 47.38 |      | 21.99 |

<sup>1</sup> Obs: observed evaluation data set; CCC: concordance correlation coefficient;  $\rho$ =Correlation coefficient estimate (precision). Cb: bias correction factor; MEF: modelling efficiency; CD: coefficient of model determination; MSEP: mean square error of the prediction.

destructive technique that identifies traits in different ruminant species. In Brazilian Somali lamb carcasses, Souza *et al.* (2020) showed that rib dissection 9-11 accurately predicted water, etheral extract (fat), and energy content. They also concluded that breed and sex determine the chemical composition of the carcass and that the etheral extract (fat) content of rib sections 9-11 is the variable that best describes the carcass etheral extract (fat) in hair sheep. In the present study, we evaluated the applicability of an equation developed by Escalante-Clemente *et al.* (2022) for Black Belly lambs to predict carcass muscle weight in Dorper lambs. The equation was developed using rib section characteristics 9-11.

According to Tedeschi (2006), a model's usefulness should be assessed for its sustainability for a particular purpose. Several tests are available to assess model adequacy to ensure impartiality during the decision process of accepting or rejecting the suitability of a mathematical model. For that, the identification and acceptance of a model's wrongness is an essential step towards the development of more reliable and accurate models. Based on the results of the statistical evaluations, the evaluated equations cannot predict the carcass tissue composition of Dorper lambs.

The differences found in the current study may be because we used equations developed for male lambs of non-meat breeds, whose fat deposition occurs later than in female lambs and adult ewes. Because of this difference in tissue deposition between the sexes, some studies have reported that the equations cannot accurately estimate the amount of each tissue in the carcass (Neves *et al.*, 2018). The differences observed in this study regarding Dorper lambs may lead to inaccurate estimates. The model evaluations supported the results of this investigation due to the equations' inability to predict carcass tissue composition in Dorper lambs. Therefore, more data on carcass tissues of hair sheep breeds are needed to develop accurate models for predicting carcass composition. The study highlights significant limitations in the equations used to estimate the carcass composition of Dorper lambs, showing poor agreement between observed and predicted weights. This highlights the need for more accurate models that consider breed, sex, and local rearing conditions.



**Figure 1.** Relationship between the observed and predicted values of carcass tissues in Dorper lambs. The solid line is  $Y=X$ , and the dotted line is the linear regression.

## CONCLUSIONS

The equations used to estimate the carcass tissue composition of Dorper lambs exhibited a poor fit in predicting the relationship between observed and predicted weights, as well as a low level of agreement. Based on these findings, we suggest that the equations tested in this study are not effective in predicting carcass tissue composition in Dorper lambs. This indicates the need to develop models based on breed- and sex-specific data, considering the rearing and management conditions of each area.

## REFERENCES

- AFRC, 1993. Technical Committee on Responses to Nutrients. Energy and protein requirements of ruminants. CAB International, Wallingford, UK.
- Escalante-Clemente S, Vázquez-Jiménez S, López-Durán SK, Arcos-Alvarez DN, Arbez-Abnal TA, Piñeiro-Vazquez AT, Muñoz-Benitez AL, Vargas-Bello-Perez E, Chay-Canul AJ. 2022. Using the 9th–11th rib section to predict carcass tissue composition in Blackbelly sheep. *Italian Journal of Animal Science*, 21(1), 161-167. <https://doi.org/10.1080/1828051X.2021.2002731>
- Marcondes MI, Tedeschi LO, Valadares Filho SC, Chizzotti ML. 2012. Prediction of physical and chemical body compositions of purebred and crossbred Nellore cattle using the composition of a rib section. *Journal of Animal Science*, 90(4), 1280-1290. <https://doi.org/10.2527/jas.2011-3839>
- Neves MLMW, Souza E JO, Vêras RML, Valadares Filho SC, Marcondes MI, Silva GS, Barreto LMG, Ferreira MA, Vêras ASC. 2018. Can the body composition of crossbred dairy cattle be predicted by equations for beef cattle?. *Asian-Australasian Journal of Animal Science*, 31, 10:1604-1610. <https://doi.org/10.5713/ajas.17.0876>
- Rivera-Alegria FM, Ríos-Rincón FG, Macías-Cruz U, Garcia-Herrera RA, Herrera-Camacho J, Benaouda M, Angeles-Hernandez JC, Muñoz-Benitez AL, Vargas-Bello-Perez E, Chay-Canul AJ. 2022. Prediction of carcass characteristics using neck traits from hair-sheep ewes. *Italian Journal of Animal Science*, 21(1), 106-112. <https://doi.org/10.1080/1828051X.2021.2018363>
- Silva LC, Valadares Filho SC, Detmann E, Marcondes MI, Rotta PP, Prados LF, Zanetti D. 2013. Evaluation of equations to predict body composition in Nellore bulls. *Livestock Science*, 151(1), 46-57. <https://doi.org/10.1016/j.livsci.2012.09.014>
- Sousa AR, Campos ACN, Silva LP, Bezerra LR, Furtado RN, Oliveira RL, Pereira ES. 2020. Prediction of the chemical body composition of hair lambs using the composition of a rib section. *Small Ruminant Research*, 191, 106189. <https://doi.org/10.1016/j.smallrumres.2020.106189>
- Tedeschi LO. 2006. Assessment of the adequacy of mathematical models. *Agricultural Systems*. 89, 225-247. <https://doi.org/10.1016/j.agsy.2005.11.004>
- Torres RNS, Costa LBS, Almeida MTC, Ezequiel JMB. 2021. Empirical equations for drinking water intake prediction of growing lambs: Meta-analysis. *Small Ruminant Research* 203(2021) 106487. <https://doi.org/10.1016/j.smallrumres.2021.106487>