Colegio de Postgraduados

Prospects in Vanilla (*Vanilla planifolia* Andrews) production in Mexico in relation to temperature fluctuations

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ABSTRACT

Objective: To establish a time series model correlating vanilla production with temperature variation to forecast vanilla production in Mexico.

Design/methodology/approach: Data on vanilla production in Mexico (Tons) and the annual average temperature were obtained for the period 1985-2020. An ARIMA model was constructed; Granger causality test was conducted to determine the effect of temperature on vanilla production, in addition to evaluating the orthogonal response of the model. A forecast for vanilla production was made for the period 2020-2040.

Results: ARIMA (1,1,1) model was found, and the influence of temperature on vanilla production was determined. Both thermal variation and the production of the last three years determine current production. A reduction in the quantity of tons of vanilla produced in the coming years is expected. It is considered that this cultivation is highly sensitive to sudden increases or decreases in temperature.

Limitations on study/implications: Vanilla cultivation is sensitive to temperature variation; therefore, in the face of climate change, it is considered necessary to take a series of actions in the present. These actions encompass a genetic perspective, new cultivation methods and locations, as well as technological investment.

Findings/conclusions: Vanilla production is influenced by temperature variation and is sensitive to sudden increases or declines. If actions are not taken in the present, a reduction in the national production of vanilla in Mexico is expected due to climate change.

Keywords: ARIMA model, Climate change, Crops, Orchidaceae, Time series.

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INTRODUCTION

The threat of climate change has caused concern in recent years, as essential climatic factors for crop growth such as precipitation and temperature will be severely affected, and thus they will impact agricultural production (Armenta-Montero *et al.*, 2022; Hatfield and Prueger, 2015). Although the effects of climate change on crop production may vary from one region to another, it is expected that the predicted changes will have far-reaching impacts, especially in countries with tropical zones (Heino *et al.*, 2019). In the face of this possible future scenario, the consequences can be profound for subsistence farmers located in fragile environments, where significant changes in productivity are expected (Raza *et al.*, 2019).

One of the crops that will be affected by climate change is vanilla (Barreda-Castillo *et al.*, 2023a). Vanilla (*Vanilla planifolia* Andrews) is an orchid of economic interest because its fruits are highly valued in the food and aromatic industry (Hernández-Hernández, 2018a), in addition to medicinal properties (Teoh, 2019). Despite its economic importance, this species is classified as "subject to special protection" (SEMARNAT, 2010), and it is also protected worldwide by the Convention on International Trade in Endangered Species of Wild Flora and Fauna, and the International Union for Conservation of Nature Red List (Armenta-Montero *et al.*, 2022; IUCN, 2022). Due to the plants have been propagated asexually, genetic erosion has occurred, and the cultivation has become vulnerable to several scenarios, including climate change (Hernández-Hernández, 2018b).

The cultivation of vanilla in Mexico has experienced fluctuations throughout its history. In recent times, there was a maximum production of 637 tons in 2007, and a minimum production of 10 tons in 1979 (Figure 1). However, México used to be the world's leading vanilla producer in the period between 1870 and 1910, which is also called "the era of mass production of vanilla", where Mexico exported large tons of this fruit to the world (Kouri, 2000; Lubinsky *et al.*, 2018), to become nowadays a minor producer, surpassed by other countries such as Madagascar and Indonesia, for example (Grisoni and Nany, 2021). There is a relationship between the increase in temperature during flowering season and a subsequent loss of fruit-forming capacity, causing significant economic losses (Hernández-Hernández and Lubinsky, 2011). Furthermore, it should be considered that the traditional way of cultivating it in areas where temperatures have risen will not be able to meet the future needs of this crop (Armenta-Montero *et al.*, 2022; Barreda-Castillo *et al.*, 2023a).

Regarding the uncertainty of climate change, prospective studies become necessary, as it has been done in crops such as beans (Medina-García *et al.*, 2016), as well as in banana (Hamjah, 2014), corn (Verma *et al.*, 2012), cotton (Debnath *et al.*, 2013), sugarcane (Suresh and Priya, 2011), wheat (Iqbal *et al.*, 2005), among others. An alternative is the use of the

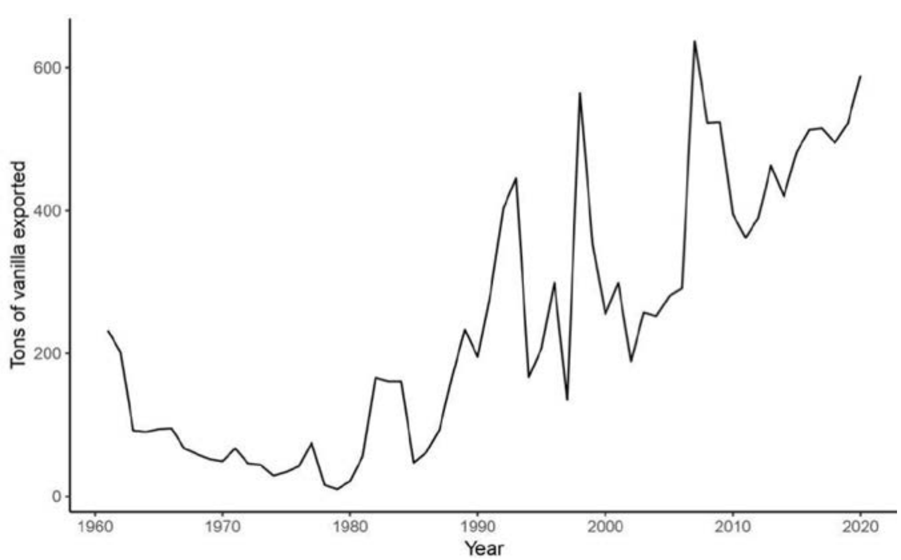

Figure 1. Historical vanilla production in Mexico, during the period 1960-2020. Figure constructed from data reported by UNdata (2023).

ARIMA model (Auto Regressive Integrated Moving Average), which is useful in time series exhibiting seasonality (Fattah *et al.*, 2018; Wang *et al.*, 2020), as is the case with vanilla, as the majority of the production is obtained only in certain months of the year (Hernández-Hernández, 2018a). Even though there is a first approach to predicting the behavior of vanilla production in Mexico (Luis-Rojas *et al.*, 2020), that model did not consider external factors such as thermal oscillation, which can cause stochastic events in this fragile crop. Therefore, the objective of this study was to establish a time series model relating the national vanilla export and the variation in Mexico's annual average temperature to forecast future production values, in order to propose actions in the present.

MATERIALS AND METHODS

Data on the average annual temperature (°C) of Mexico was obtained for the period between 1985 and 2020 from information provided by the National Water Commission, available through CONAGUA (2023). To ascertain the historical vanilla production in Mexico, export records (tons) published by the Food and Agriculture Organization of the United Nations were consulted, avaliable from UNdata (2023). Official records were considered from the year 1985 to 2020.

To determine if the vanilla production data correspond to a stationary series, Dickey-Fuller Test ($p=0.05$) was carried out. Possible values of MA (q) and AR (p) were determined using the autocorrelation function (ACF) and partial ACF, respectively. To determine the effect that temperature will have on the future production of vanilla in Mexico in the period 2020-2040, a multivariate time series analysis using an autoregressive integrated moving average (ARIMA) model was employed (Tsay, 2014).

Ljung-Box test was performed ($p=0.05$) to corroborate that the residuals were white noise (Hassani and Yeganegi, 2020). Additionally, a Granger causality test (Granger, 1969) was conducted to verify the effect of temperature on vanilla production. The orthogonal response of the model was evaluated, in search of sensitivity to stochastic events.

The statistical analysis was performed using R 3.6 software (R core team, 2017), with astsa (Stoffer and Poison, 2023), forecast (Hyndman and Khandakar, 2008), seasonal (Sax and Eddelbuettel, 2018), TSA (Chan and Ripley, 2022), tseries (Trappletti and Hornik, 2023), urca (Pfaff, 2008), and vars (Pfaff, 2008) packages.

RESULTS AND DISCUSSION

It was determined that vanilla production data in Mexico correspond to a stationary series, with a lag order of 3 (Dickey-fuller$=-3.8238$, $p<0.05$). Thus, vanilla production is dependent on temperature variations and agricultural management over the three previous years. This could be related to the three years of waiting that producers make before obtaining flowering, and therefore it may determine future vanilla production (Iftikhar *et al.*, 2023).

Partial ACF analysis exhibited possible AR (p) values of 0 and 1 (Figure 2), whereas ACF analysis exhibited possible MA (q) values of between 1 and 12 (Figure 2). In order to select the best model that described the behavior of the data, the auto.arima function was used (Hyndman and Khandakar, 2008), obtaining the model ARIMA (1,1,1) ($\sigma^2=8884$, log

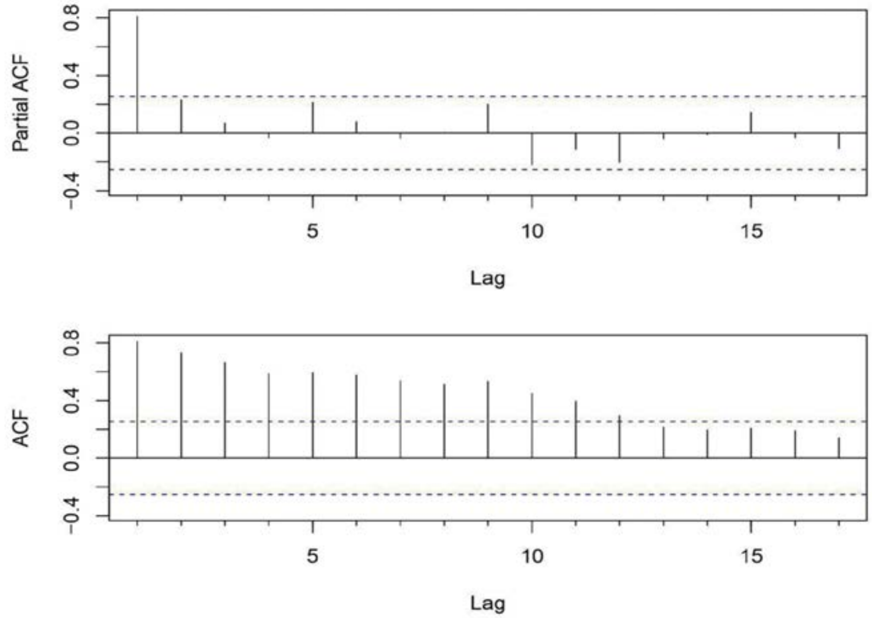

Figure 2. Partial autocorrelation function (ACF) and ACF estimated for ARIMA (1,1,1) model.

likelihood=−350.7, AIC=709.4, BIC=717.71). It was confirmed that the model residuals were white noise (D. F.=20, χ^2=25.777, p=0.17).

The model we found was similar to the one reported by Luis-Rojas *et al.* (2020), however, they did not consider external factors such as temperature, as we did. In contrast, we found the influence of temperature on vanilla production through Granger causality test (D.F.=32, F=13.245, p<0.01). It was confirmed that the model only operated in one direction, this means, no influence of vanilla production on temperature fluctuations was found (D.F.=32, F=13.245, p=0.74).

The equation defining the model is expressed in the following formula:

$$X_t = 101.91331X_{1t-1} + 0.03847X_{2t-1} + 30.99266X_{1t-2} + 0.01684X_{2t-2} \\ + 58.45541X_{1t-3} - 0.017137X_{2t-3} - 3665.309 + a_{1t}$$

Where X_t refers to the predicted value of vanilla produced, 1_{t-n} to the value dependent on the quantity of vanilla tons, the coefficient 2_{t-n} to temperature variations, and a_{1t} to the model error (D.F.=26, F=5.832, p<0.05). The proposed model was compared against the predicted values for 2020-2022 with respect to the values reported by Gobierno de México (2023). In 2020, a difference of 11.72 tons was observed, in 2021 of 2.41 tons, and in 2022 of 4.74 tons (Figure 3).

Based on the aforementioned equation, the production value of vanilla tons in Mexico was estimated, along with its minimum and maximum values. Contrary to the model proposed by Luis-Rojas *et al.* (2020), our model allowed us to predict vanilla production for the period 2020-2040. The predicted values are expressed in Table 1.

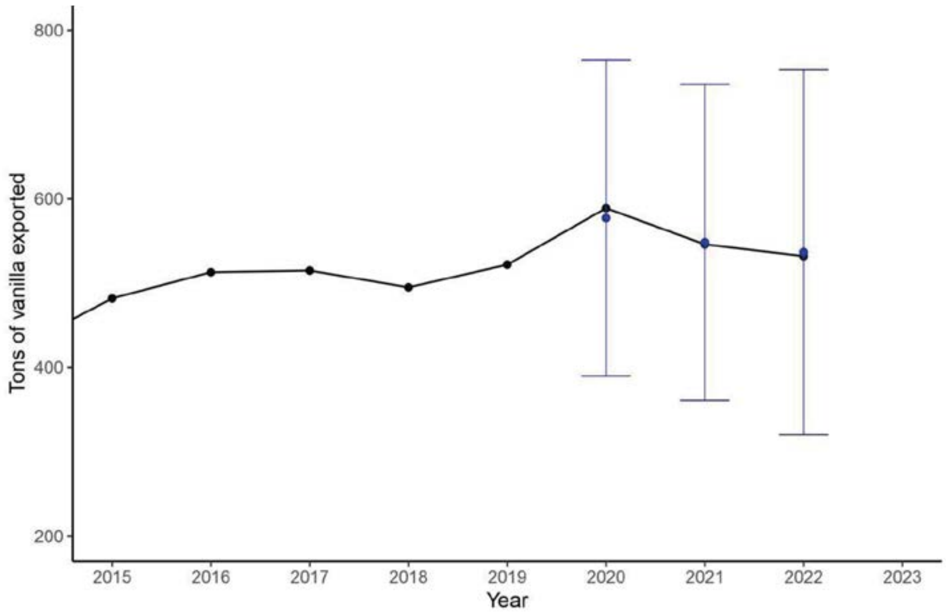

Figure 3. Comparison of the values reported by the ARIMA model (1,1,1) respect to the last three values of vanilla production (tons) in Mexico. Black: tons of vanilla exported in México, according to UNdata (2023) and Gobierno de México (2023). Blue: predicted vanilla tons.

Table 1. Expected vanilla production in Mexico (tons) for the period 2020-2040. (CI=95%).

Year	Forecast	Lower	Upper
2020	577.2763	389.79600	764.7566
2021	548.4151	360.93484	735.8954
2022	536.7486	320.40706	753.0901
2023	533.3949	300.91853	765.8713
2024	532.4309	287.05021	777.8115
2025	532.1537	275.08378	789.2237
2026	532.0741	263.97834	800.1698
2027	532.0512	253.40812	810.6942
2028	532.0446	243.25095	820.8382
2029	532.0427	233.44661	830.6388
2030	532.0422	223.95626	840.128
2031	532.042	214.75025	849.3337
2032	532.042	205.80409	858.2798
2033	532.0419	197.09685	866.987
2034	532.0419	188.61031	875.4736
2035	532.0419	180.32848	883.7554
2036	532.0419	172.23723	891.8466
2037	532.0419	164.32398	899.7599
2038	532.0419	156.57747	907.5064
2039	532.0419	148.98759	915.0963
2040	532.0419	141.5452	922.5387

Similar to Luis-Rojas *et al.* (2020) model, vanilla production will decrease, however, in this forecast study it is considered that the future average annual production of vanilla in Mexico will be around 532 tons. Even the highest values (mean plus confidence interval) predicted are still lower than the current production of the main producing countries (Borbolla-Pérez *et al.*, 2017). It is unlikely that Mexico will once again be one of the main vanilla producing countries in the world, however, mexican vanilla is still considered as the best quality vanilla produced worldwide (Ellestad *et al.*, 2022; Ranadive, 2018), which is why it is suggested to focus efforts on continuing to produce quality vanilla instead of quantity.

Regarding the orthogonal response, the model showed susceptibility to stochastic events (Figure 4), which implies that any abrupt alteration in temperature, national vanilla production would be seriously affected. This is similar to what has been reported in the past, since in 1955 a stochastic event (hurricanes Hilda, Gladys and Janet) almost caused the total loss of vanilla production in Mexico, as well as a second event in 1961 (there was an extremely cold period) in which vanilla cultivation was almost lost nationwide (Suárez-Barrios, 2016; Vera-Cortés, 2007). Due to climate change, global temperatures are expected to increase between 3 to 5 °C (Luo *et al.*, 2020), although some predictions are less conservative and predict an increase of up to 11 °C (Reddy *et al.*, 2017). This increase in temperature will have negative consequences for the vanilla crop, since it has been observed that prolonged exposure to 32 °C (an increase of 7 °C above the optimum) reduces the production of roots and shoots, while exposure to 35 °C (an increase of up to 10 °C) is inhibited (Barreda-Castillo *et al.*, 2023a); furthermore, it has been observed that exposure to temperatures equal to or greater than 32 °C affects the viability of pollen, as well as the formation and maintenance of fruits (Hernández-Hernández, 2018; Iftikhar *et al.*, 2023; Menchaca-García, 2018). The susceptibility of vanilla culture may not be limited to temperature or just to Mexico, since another vulnerability scenarios have been observed, like in Puerto Rico (Bayman, 2018), or Indonesia (Pinaria *et al.*, 2010), where the root-stem rot disease caused by *Fusarium oxysporum* f. sp. vanillae significantly reduced the vanilla production.

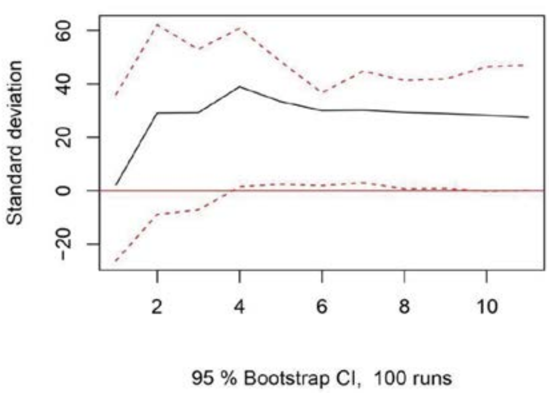

Figure 4. Orthogonal impulse associated with the ARIMA (1,1,1) model, representing the effect of temperature variation on vanilla production in Mexico. The solid line shows the moving averages associated with the model, whereas the dashed lines indicate the response to stochastic variations in temperature.

Due to the observed fragility of the vanilla crop, it is recommended to implement a series of mitigation actions at present. These actions can be considered from the following perspectives:

Genetic: It is important to rescue the use of cultivation with wild species and varieties, which may be more tolerant to new future environmental conditions (Flanagan *et al.*, 2018; Jackson *et al.*, 2007). Species such as *V. pompona* Schiede or *V. odorata* C. Presl, both aromatic vanillas, might be considered for cultivation (Maruenda *et al.*, 2013; Watteyn *et al.*, 2023). In addition, it is necessary to obtain vanilla plants from seed to increase genetic diversity in this crop, and thereby obtain individuals with better responses to biotic and abiotic stress scenarios (Menchaca-García *et al*, 2011; Yeh *et al.*, 2021). Likewise, a hybridization program for species that could provide greater resistance to temperature increases is considered necessary, since these species may also incorporate other aromatic properties for the market (Barreda-Castillo *et al.*, 2023b; Menchaca-García, 2018).

Cultivation Method: Due to its growth on tree supports, the trend of vanilla cultivation in traditional regions has been on citrus monocultures, which have been severely affected by rising temperatures and do not provide sufficient shade from insolation (Estudillo-Hernández *et al.*, 2019). So, management alternatives can be proposed to continue vanilla cultivation. An example of this is establishing cultivation in forest regeneration zones or secondary growth areas (also called "acahual"), where the surrounding vegetation provides shade at different canopy levels and contributes to creating microclimatic zones that help lower the temperature (Hernández-Hernández, 2018a; Ramos-Prado *et al.*, 2023).

Technology: If the trend in vanilla cultivation is to remain in traditional sites (from 0 to 400 meters above sea level), where an increase in temperature has been observed (Armenta-Montero *et al.*, 2022; Soto-Arenas and Dressler, 2009), it will be necessary to establish it using shade nets ranging from 50 to 80%, implemented with sprinkler irrigation systems in order to help to mitigate insolation but, on the other hand, it increases the investment in cultivation (van Noort, 2018).

Cultivation Zones: With the current trend of climate change, there is an observed shift in vanilla cultivation to higher-altitude areas, exceeding even 1000 meters above sea level (Menchaca-García *et al.*, 2019). Thus, it is necessary to implement studies that determine the geographical zones where vanilla plants can thrive, showing appropriate growth, flowering, and fruiting based on environmental tolerance ranges. Likewise, farmer training is essential to consider cultivating vanilla in areas where it has traditionally not been grown (Chambers, 2019).

CONCLUSIONS

Vanilla cultivation follows a seasonal behavior, and in turn is influenced by variations in temperature. The model that describes the behavior of the crop was ARIMA (1,1,1) with three orders of lag, which indicates that the current vanilla production is a function of both the production and the thermal variation of the last three years.

The forecast for vanilla production in Mexico indicates a reduction, compared to current production. Furthermore, the vanilla crop is considered to be susceptible to stochastic variations in temperature. Therefore, it is recommended that actions be taken now regarding genetic improvement, new forms of cultivation, investment in technology, or establishing new cultivation areas, all with the aim of conserving this important crop in Mexico.

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Writing, JMBC and RAMG; Visualization, JMBC and RAMG; Supervision, RAMG. All authors have read and accepted the published version of the manuscript."
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REFERENCES

Armenta-Montero, S; Menchaca-García, R; Pérez-Silva, A; Velázquez-Rosas, N. 2022. Changes in the Potential Distribution of Vanilla planifolia Andrews under Different Climate Change Projections in Mexico. IJMS. 14. 2881. Doi: https://doi.org/10.3390/su14052881

Hatfield, JL; Prueger, JH. 2015. Temperature extremes: Effect on plant growth and development. *Weath. Clim. Extr.* 10. 4-10. Doi: https://doi.org/10.1016/j.wace.2015.08.001

Heino, M; Guillaume, JHA; Müller, C; Iizumi, T; Kummu, M. 2019. A multi-model analysis of teleconnected crop yield variability in a range of cropping systems. *Earth Syst. Dyn.* 11. 113-128. Doi: https://doi.org/10.5194/esd-11-113-2020

Raza, A; Razzaq, A; Mehmood, SS; Zou, X; Zhang, X; Lv, Y; Xu, J. 2019. Impact of Climate Change on Crops Adaptation and Strategies to Tackle Its Outcome: A Review. *Plants. 8*(2). 34. Doi: https://doi.org/10.3390/plants8020034

Barreda-Castillo, JM; Menchaca-García, RA; Lozano-Rodríguez, MA. 2023a. Effect of temperature on roots and shoots formation in three vanilla species (Orchidaceae) under controlled conditions. *Trop. And Subtrop. Agroecos.* 26. 1-7. Doi: http://doi.org/10.56369/tsaes.4855

Hernández-Hernández, J. Mexican Vanilla Production. In Handbook of Vanilla Science and Technology, 2nd ed.; Havkin-Frenkel, D, Belanger, F, Eds.; Wiley: New York, United States of America, 2018a; 3-26. Doi: https://doi.org/10.1002/9781119377320.ch1

Teoh, ES. Orchids as aphrodisiac, medicine or food. Springer: Singapore, 2019; 109-130. Doi: https://doi.org/10.1007/978-3-030-18255-7

SEMARNAT. 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. Secretaría del Medio Ambiente y Recursos Naturales. http://dof.gob.mx/nota_detalle.php?codigo=5173091&fecha=20/12/2010

IUCN. 2022. Vanilla planifolia. Available in https://www.iucnredlist.org/species/103090930/172970359

Hernández-Hernández, J. Vanilla diseases. In Handbook of Vanilla Science and Technology, 2nd ed.; Havkin-Frenkel, D, Belanger, F, Eds.; Wiley: New York, United States of America, 2018b; 181-190. Doi: https://doi.org/10.1002/9781119377320.ch2

Kouri, EH. 2000. La vainilla de Papantla: agricultura, comercio y sociedad rural en el siglo XlX. *Sig. Hist. 1*(3). 105-130.

Lubinsky, P; Romero-González, G; Heredia, S; Zabel, S. Origins and patterns of Vanilla cultivation in tropical America (1500-1900): No support for an independent domestication of Vanilla in South America. In Handbook of Vanilla Science and Technology, 2nd ed.; Havkin-Frenkel, D, Belanger, F, Eds.; Wiley: New York, United States of America, 2018; 121-146. Doi: https://doi.org/10.1002/9781119377320.ch8

Grisoni, M; Nany, F. 2021. The beautiful hills: half a century of vanilla (***Vanilla planifolia*** Jacks. ex Andrews) breeding in Madagascar. *Gen. Res. Crop Evol.* 68. 1691-1708. Doi: https://doi.org/10.1007/s10722-021-01119-2

Hernández-Hernández, J; Lubinsky, P. Vanilla production in Mexico. In Vanilla, Odoux, E, Grisoni, M, Eds.; New York, United States of America, 2011; 335-347.

Medina-García, G; Ruiz-Corral, JA; Rodríguez-Moreno, VM; Soria-Ruiz J; Díaz-Padilla, G; Zarazúa-Villaseñor, P. 2016. Efecto del cambio climático en el potencial productivo del frijol en México. *Rev. Mex. C. Agr*. 13. 2465-2474.

Hamjah, MA. 2014. Forecasting major fruit crops productions in Bangladesh using Box-Jenkins ARIMA model. *J. Econ. Sust. Dev. 5*(7), 96-107.

Verma, U; Koehler, W; Goyal, M. 2012. A study of yield trends of different crops using ARIMA analysis. *Env. Ecol*. 30. 1459-1463.

Debnath, MK; Bera, K; Mishra, P. 2013. Forecasting area, production and yield of cotton in India using ARIMA model. *J. Sp. Sc. Tech. 2*(1). 16-20.

Suresh, KK; Priya, SRK. 2011. Forecasting sugarcane yield of Tamilnadu using ARIMA models. *Sugar Tech. 13*(1). 23-26. Doi: https://doi.org/10.1007/s12355-011-0071-7

Iqbal, N; Bakhsh, Maqbool, A; Ahmad, S. 2005. Use of ARIMA model for forecasting wheat area and production in Pakistan. *J. Agr. Soc. Sci. 1*(2). 120-122.

Fattah, J; Ezzine, L; Lachhab, A. 2018. Forecasting of demand using ARIMA model. *Int. J. Eng. Buss. Manag*. 10. 1-9. Doi: 10.1177/1847979018808673

Wang, L; Feng, J; Sui, X; Chu, X; Mu, W. 2020. Agricultural product price forecasting methods: research advances and trend. *Brit. F. J. 122*(7). 2121-2138. Doi: https://doi.org/10.1108/BFJ-09-2019-0683

Luis-Rojas, S; Ramírez-Valverde, B; Díaz-Bautista, M; Pizano-Calderón, J; Rodríguez-López, C. 2020. La producción de vainilla (*Vanilla planifolia*) en México: análisis y pronóstico. *Rev. Mex. C. Agr. 11*(1). 175-187. Doi: https://doi.org/10.29312/remexca.v11i1.2065

CONAGUA. 2019. Resúmenes mensuales de temperaturas y lluvia. Available in https://smn.conagua.gob.mx/es/climatologia/temperaturas-y-lluvias/resumenes-mensuales-de-temperaturas-y-lluvias

Undata. 2023. Vanilla. Available in http://data.un.org/Data.aspx?d=FAO&f=itemCode:692&c=2,3,4,5,6,7&s=countryName:asc,elementCode:asc,year:desc&v=1

Tsay, RS. Multivariate Time Series Analysis: With R and Financial Applications; Wiley: Canada, 2014; 27-104.

Hassani, H; Yeganegi, MR. 2020. Selecting optimal lag order in Ljung–Box test. *Phys. A: Stat. Mech. Its Appl. 541*(1). 123700. Doi: https://doi.org/10.1016/j.physa.2019.123700

Granger, WJ. 1969. Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econ. J. Econom. Soc. 37*(3). 424-438. Doi: https://doi.org/10.2307/1912791

R Core Team. 2017. R: A language and environment for statistical computing. Available in https://www.R-project.org/

Stoffer, D, Poison, N. 2023. astsa: Applied Statistical Time Series Analysis. Available in https://CRAN.R-project.org/package=astsa

Hyndman, RJ; Khandakar, Y. 2008. Automatic time series forecasting: the forecast package for R. *J. Stat. Soft. 26*(3). 1-22. Doi: https://doi.org/10.18637/jss.v027.i03

Sax, C; Eddelbuettel, D. 2018. Seasonal Adjustment by X-13ARIMA-SEATS in R. *J. Stat. Soft. 87*(11). 1-17. Doi: https://doi.org/10.18637/jss.v087.i11

Chan, K; Ripley, B. 2022. TSA: Time Series Analysis. Available in https://CRAN.R-project.org/package=TSA

Trapletti, A; Hornik, K. 2023. tseries: Time Series Analysis and Computational Finance. Available in https://CRAN.R-project.org/package=tseries

Pfaff, B. Analysis of Integrated and Cointegrated Time Series with R, 2nd ed.; New York, United States of America, 2008, 73-90. Doi: https://doi.org/10.1007/978-0-387-75967-8

Iftikhar, T; Majeed, H; Waheed, M; Zahra, SS; Niaz, M; AL-Huqail, AA. Vanilla. In Essentials of Medicinal and Aromatic Crops; Zia-Ul-Haq, M, Abdulkreem-AL-Huqail, A, Riaz, M, Farooq-Gohar, U., Eds.; Springer: Switzerland, 2023; 341-372. Doi: https://doi.org/10.1007/978-3-031-35403-8_14

Gobierno de México. 2023. Vainilla mexicana, con amplio potencial productivo y preferencia en los mercados internacionales: Agricultura. Available in https://www.gob.mx/agricultura/prensa/vainilla-mexicana-con-amplio-potencial-productivo-y-preferencia-en-los-mercados-internacionales-agricultura?idiom=es#:~:text=De%202017%20a%202021%2C%20México,superior%20a%20las%20417%20toneladas.

Borbolla-Pérez, V; Iglesias-Andreu, LG; Luna-Rodríguez, M; Octavio-Aguilar, P. 2017. Perceptions regarding the challenges and constraints faced by smallholder farmers of vanilla in Mexico. *Env. Dev. Sust*. 19. 2421-2441. Doi: https://doi.org/10.1007/s10668-016-9863-y

Ellestad, P; Pérez-Farrera, MA; Forest, F; Buerki, S. 2022. Uncovering haplotype diversity in cultivated mexican vanilla. *Am. J. Bot. 109*(7). 1120-1138. Doi: https://doi.org/10.1002/ajb2.16024

Ranadive, AS. Quality control of Vanilla beans and extracts. In Handbook of Vanilla Science and Technology, 2nd ed.; Havkin-Frenkel, D, Belanger, F, Eds.; Wiley: New York, United States of America, 2018; 239-260. Doi: https://doi.org/10.1002/9781119377320.ch15

Suárez-Barrios, R. 2015. El agroecosistema vainilla de dos regiones de México, un estudio histórico comparativo siglo XX. Master's Thesis. Colegio de Postgraduados, Fabio Altamirano, Veracruz, México. 06 de junio de 2015.

Vera-Cortés, G. 2007. Vulnerabilidad social y desastres en el Totonacapan una historia presente. Doctoral thesis. Universidad Autónoma Metropolitana, Iztapalapa, Ciudad de México, México. Junio de 2007.

Luo, H; Xu, H; Chu, C; He, F; Fang, S. 2020. High temperature can change root system architecture and intensify root interactions of plant seedlings. *Fr. plant Sci*. 11. 160. Doi: https://doi.org/10.3389/fpls.2020.00160

Reddy, KR; Brand, D; Wijerwardana, C; Gao, W. 2017. Temperature effects on cotton seedling emergence, growth, and development. *Agr. J*. 109. 1379-1387. Doi: https://doi.org/10.2134/agronj2016.07.0439

Bayman, P. The history of Vanilla in Puerto Rico: diversity, rise, fall, and future prospects. In Handbook of Vanilla Science and Technology, 2nd ed.; Havkin-Frenkel, D, Belanger, F, Eds.; Wiley: New York, United States of America, 2018; 111-120. Doi: https://doi.org/10.1002/9781119377320.ch7

Pinaria, AG; Liew, ECY; Burgess, LW. 2010. *Fusarium* species associated with vanilla stem rot in Indonesia. *Aust. Plant. Path*. 39. 176-183. Doi: https://doi.org/10.1071/AP09079

Flanagan, NS; Chavarriaga, P; Mosquera-Espinosa, AT. Conservation and sustainable use of vanilla crop wild relatives in Colombia. In Handbook of Vanilla Science and Technology, 2nd ed.; Havkin-Frenkel, D, Belanger, F, Eds.; Wiley: New York, United States of America, 2018; 85-110. Doi: https://doi.org/10.1002/9781119377320.ch6

Jackson, LE; Pascual, U; Hodgkin, T. 2007. Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agr. Ecos. and Env*. 121. 196-210. Doi: https://doi.org/10.1016/j.agee.2006.12.017

Maruenda, H; del Lujan-Vico, M; Householder, JE; Janovec, JP; Cañari, C; Naka, A; Gonzalez, AE. 2013. Exploration of *Vanilla pompona* from the Peruvian amazon as a potential source of vanilla essence: quantification of phenolics by HPLC-DAD. *F. Chem*. 138. 161-167. Doi: https://doi.org/10.1016/j.foodchem.2012.10.037

Watteyn, C; Reubens, B; Azofeita-Bolaños, JB; Solano-Campos, F; Pérez-Silva, A; Karremans, AP; Muys, B. 2023. Cultivation potential of Vanilla crop wild relatives in two contrasting land use systems. *Eu. J. Agr.* 149. 126890. Doi: https://doi.org/10.1016/j.eja.2023.126890

Menchaca-García, RA; Ramos-Prado, JM; Moreno-Martínez, D; Luna-Rodríguez, M; Mata-Rosas, M; Vázquez, LM; Lozano-Rodríguez, MA. 2011. *In vitro* germination of *Vanilla planifolia* and *V. pompona* hybrids. *Rev. Col. Biotec. 13*(1). 80-84.

Yeh, C; Chen, K; Lee, Y. 2021. Asymbiotic germination of *Vanilla planifolia* in relation to the timing of seed collection and seed pretreatments. *Bot. Stu*. 62. 6. Doi: https://doi.org/10.1186/s40529-021-00311-y

Barreda-Castillo, JM; Monribot-Villanueva, JL; Velázquez-Rosas, N; Bayman, P; Guerrero-Analco, JA; Menchcaca-García, RA. 2023b. Morphological and physio-chemical responses to PEG-induced water stress in *Vanilla planifolia* and *V. pompona* hybrids. *IJMS*. 24. 4690. Doi: https://doi.org/10.3390/ijms24054690

Menchaca-García, RA. In vitro propagation of Vanilla. In Handbook of Vanilla Science and Technology, 2nd ed.; Havkin-Frenkel, D, Belanger, F, Eds.; Wiley: New York, United States of America, 2018; 181-190. Doi: https://doi.org/10.1002/9781119377320.ch12

Estudillo-Hernández, M; Rodríguez-Cabrera, R; Velázquez-García, PE; López-Castro, D; Elorza-Martínez, P. 2019. Establecimiento de *Vanilla planifolia* Andrews en acahual intercalado con *Glicidia sepium* y *Citrus cinensis*. *Rev. Biol. Agr. Tux. 7*(1). 13-18. Doi: https://doi.org/10.47808/revistabioagro.v7i1.135

Ramos-Prado, JM; Romero-Hernández, E; Sánchez-Morales, P; Jiménez-García, D; Hipólito-Romero, E. 2023. biocultural and socioeconomic dimensions of sustainability in agroforestry systems diversified with cacao and vanilla. *Rev. Mex. C. Agr. 14*(3). 401-412. Doi: https://doi.org/10.29312/remexca.v14i3.3093

Soto-Arenas, MA; Dressler, RL. 2009. A revision of the mexican and central american species of *Vanilla plumier* ex miller with a characterization of their its region of the nuclear ribosomal DNA. *Lankesteriana. 9*(3). 285-354. Doi: https://doi.org/10.15517/lank.v0i0.12065

van Noort, F. Vanilla in Dutch greenhouses: a discovery-from research to production. In Handbook of Vanilla Science and Technology, 2nd ed.; Havkin-Frenkel, D, Belanger, F, Eds.; Wiley: New York, United States of America, 2018; 157-164. Doi: https://doi.org/10.1002/9781119377320.ch10

Menchaca-García, RA; Moreno-Martínez, D; Barreda-Castillo, JM; Pérez-Silva, A; Lozano-Rodríguez, MA. 2019. Vainilla, café y cítricos: triángulo amoroso. *C. y el H*. 32. 28-33.

Chambers, AH. Vanilla (Vanilla spp.) Breeding. In Advances in plant breeding strategies: industrial and food crops, Al-Khayri, JM, Jain, SM, Johnson, DV, Eds.; Springer: Switzerland, 2019, 707-734. Doi: https://doi.org/10.1007/978-3-030-23265-8_18