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Sustainability Assessment of Two Farming Systems

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ABSTRACT

Objective: To assess the sustainability of two agricultural production systems (native and improved maize) using the MESMIS methodology.

Design/Methodology/Approach: Understanding the social, economic, and environmental factors that make up the production systems, as well as their management methods, in the municipality of Jilotepec, State of Mexico enables the development of sustainable rural development strategies. The study included 30 production systems and compared the level of sustainability between producers of native and improved maize. In September 2022, information was collected in the field, through participatory workshops, semi-structured interviews, and surveys. Additionally, soil sampling was carried out to analyze soil fertility.

Results: The two systems studied have high agricultural production costs and are highly dependent on external inputs, especially those that use improved maize. Most of the systems depend on external economic income. Agriculture is increasingly exposed to drought conditions and changes in rainfall patterns, forcing the population to implement adaptability measures. Owning livestock is an important economic support for production systems. The regional soil is fertile and suitable for growing maize. The perception of happiness among the interviewees is high; they consider their quality of life to be good and therefore do not migrate.

Findings/Conclusions: This study is the result of an integrated analysis of several methodologies used in the sustainability indicators measurement.

Keywords: Rural development, sustainable agriculture, happiness, MESMIS.

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INTRODUCTION

The concept of sustainability has great relevance for the preservation of the diverse lifeforms that exist in our planet; as a social being, man plays a major role, since environmental problems mainly have an anthropogenic origin. These severe environmental problems are awakening a worldwide social conscience to protect and care for the environment.

This is evident in the academic, political, and economic discussions that seek to achieve a harmonious relationship between society and nature (Fonseca-Carreño *et al.* 2020; Javier-Sarandón, 2020).

Sustainability is a relatively new concept. It is a response to the industrial revolution that began to generate negative effects on the environment in the mid-18th century. It began to be openly discussed with the Brundtland report (1987), during the creation of the World Commission on Environment and Development. The discussion focused on satisfying the needs of the current and future human population from three approaches: economic, environmental, and social (González-Esquivel *et al.*, 2006). Noguera *et al.* (2020) point out that "sustainability is a proposal based on environmental rationality, promoting political and social change. On the one hand, from the economic point of view, it seeks the participation of native people and farmers, with the aim of achieving a fair redistribution of wealth and other forms that respect the resilience of ecosystems. On the other hand, from the environmental and cultural point of view, it should include the richness of cultural diversity. It also relates nature with culture, seeking a re-appropriation of nature and life".

Martínez-Castillo *et al.* (2016) mention that "the sustainability of production systems refers to their capacity to maintain their productivity despite major disturbances, both economic and natural, external or internal". This definition implies that the natural, social, economic, and technical characteristics of a production system, along with the pressures or interventions it experiences, will determine its level of sustainability.

Javier-Sarandón (2020) points out that "agricultural production systems that make an intensive use of external inputs have negative consequences, because they are degrading and polluting the environment. This deterioration process is increasingly evident and puts the maintenance of ecosystem balances and human life at risk." Likewise, Borras *et al.* (2012) mention that "agriculture and sustainable rural development have had an increasingly major role in the discussions about potential alternatives to face the challenges posed by the environmental, climate, energy, financial, and food crisis." Linares-Díaz (2019) points out that agriculture plays such a key role in the alleviation of world hunger that the 17 Sustainable Development Goals (SDGs) proposed by the United Nations, in its 2030 Agenda for Sustainable Development, included "end hunger, achieve food security, and improved nutrition and promote sustainable agriculture." Furthermore, to achieve this goal, fundamental changes in production and in current agricultural policies are necessary. These changes must be focused on sustainable agriculture by addressing its 3 pillars: social, economic, and environmental (Wiget *et al.*, 2020; Purvis *et al.*, 2019).

Maize is the most important agricultural product in Mexico, from a food, industrial, political, and social point of view. It is grown practically all year round and in wildly diverse agroclimatic conditions, under rainfed and irrigated systems, and in more than half of the country's agricultural area (7.4 million ha) (SIAP, 2023). Mexico is the center of origin of maize; currently, 59 native breeds have been identified and hundreds of varieties have been adapted to each region or climate (CONABIO, 2008). *Criollo* or native breed sowing contributes significantly to the food security of the poorest rural strata of the country, whose production is focused on self-consumption, either for themselves or for livestock (Turrent-Fernández *et al.*, 2012). In turn, improved maize (hybrids) —whose harvest is destined for sale and which largely satisfy the needs of Mexican agroindustry— occupies only 20% of the total area sown with maize (SIAP, 2023), basically under artificial irrigation systems and with high production and input costs (Turrent-Fernández *et al.*, 2012).

Given the relevance of the native maize production system in Mexico, Fonseca-Carreño *et al.* (2020), González-Esquivel *et al.* (2006), and other authors have analyzed the sustainability of maize production systems (basically aimed on self-consumption or carried out by small producers), focusing on proposals for food strategies and the analysis of the role of family members in production, as well as on the different social, economic, and political participants involved in the production system.

In agricultural production, establishing some technical concepts is important for an adequate agronomic management of crops. The concept of soil fertility or fertile soil is one of the most widely used in agricultural and forestry contexts. In this sense, Astier-Calderón *et al.* (2002) mention that "soil is a core component of the agroecosystem; therefore, it is necessary to characterize and define its condition, in order to evaluate its sustainability". Regarding soil fertility parameters, Domingo-Santos *et al.* (2006) indicate that water absorption, retention, and supply are fundamental ecological missions of the soil; they are so important that, among the variables used to estimate soil degradation, those related to soil availability are considered even more important than those related to nutrient availability. Soil water is an important ecological factor and, therefore, it is essential to determine the volumes that soil can hold, as well as the proportion of this water that is available to plants.

The economic dimension of sustainability is one of the main challenges faced by agricultural production. Food generation should not only be productive, but also profitable, fair, and sustainable (Uzcanga-Pérez *et al.*, 2020; Bonilla-Bolaños *et al.*, 2019). Masera *et al.* (2008) mention that the sustainable system design should be oriented towards small producers with scarce economic resources; reduce production costs; increase benefits through productivity; conserve traditional agricultural management lore; and offer access to inputs, food, and market.

Agriculture is a social production system where human beings interact with nature. People who participate in this production should feel fully satisfied with their lives. This sense of satisfaction will be called happiness in the rest of this paper. Happiness is a complex concept that has been addressed as the goal of human life, ever since the time of the Greek philosophers. Alarcón (2006) and Beytía *et al.* (2011) defined happiness as the degree to which a person appreciates the totality of their present life in a positive way and experiences pleasurable affections. Therefore, establishing methodologies for measuring happiness in the population is an important step to study the socioeconomic determinants of happiness and to guide public policies towards the improvement of subjective well-being. Fernández-Berrocal *et al.* (2009) mention that, "from a psychological-positive perspective, a happy person would have many positive experiences and few negative ones, perceiving themselves as satisfied with their life as a whole; therefore, happiness is a subjective state of the individual that is a direct result of their self-report".

Assessing the sustainability of 2 production systems (native maize and improved maize) with the MESMIS methodology determines the status of the sustainability components of production systems and will be the starting point for the identification of those aspects that —if improved (in case of weaknesses) or exploited (in case of strengths)— can balance the social, economic, and environmental aspects of the systems and eventually lead to an integral development of the production systems involved.

MATERIALS AND METHODS

Location: El Saltillo is a community that belongs to the municipality of Jilotepec, State of Mexico, located 90 km northwest of Mexico City (Figure 1). It has an area of 1,384 ha, with a population of approximately 870 inhabitants (INEGI 2021). It is a rural area with a low population density, where agriculture (mainly maize) is carried out under a rainfed regime.

Figure 1 shows the spatial distribution of the 30 production systems under study. The selection methodology used for the assessed systems was first applied to all the systems that use improved maize (7). Subsequently, the best spatial distribution within the community that uses native maize (23) was determined. The participants were contacted and invited to participate in the present study.

The MESMIS Framework integrates the environmental, social, and economic spheres to the concept of sustainability. Seven attributes are measured based on the sustainability characteristics of productive systems: a) productivity, b) stability, c) resilience, d) reliability, e) adaptability, f) self-management, and g) equity. The sustainability indicators to be assessed must be immersed in at least one of the attributes. The six following elements constitute the MESMIS work phases: 1) definition of the systems to be worked on; 2) determination of critical points of the system; 3) selection of strategic indicators; 4) measurement and

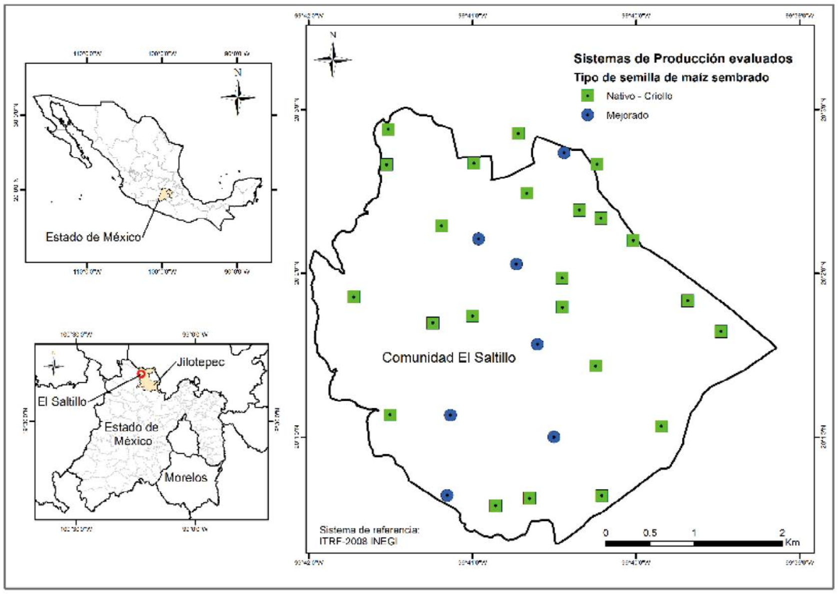

Figure 1. Location of the community of El Saltillo, Jilotepec, State of Mexico and spatial distribution of the assessed production systems.
Source: Figure developed by the authors based on cartographic data from Marco Geoestadístico 2021 (INEGI).

monitoring of indicators; 5) integration of results; and 6) conclusions and recommendations (Masera *et al.*, 1999).

For Phase 1, diagnostic work was carried out on October 2021, enabling the definition of phases 2 and 3. In September 2022, phase 4 was carried out, which included the collection of information in the field. The interview and oral communication technique was the data collection tool chosen for this study (Geilfus, 2002). It consisted of semi-structured questions addressed to members of each family, with topics related to producer data, agricultural production and yields, agricultural and livestock production costs, diversification of economic income, and perception and adaptability to climate change. A survey was applied to different members of each production system in order to measure the perception of happiness. The data used to calculate the Grain Yield Potential (GYP) were collected from the plots of the families interviewed and the collected soil samples were sent to a specialized laboratory to determine their fertility parameters.

Soil water holding capacity was considered as one of the indicators in the environmental field and refers to the difference between field capacity (FC) and wilting point (WP), which are the limits that define the water requirement for the optimal development of a crop —*i.e.*, the water contained between FC and WP is the water that can be absorbed by the crop's root system (Liu *et al.*, 2019). The diversification of livestock species represents a process of sustainability of the production system. González-Flores *et al.* (2020) highlight that species diversity is a strategy that guarantees the sustainability of agroecosystems. In the same sense, Sullivan (2003) indicates that the diversification of livestock species reduces risk or vulnerability, makes the system resilient, and increases sustainability. The Shannon-Weaver index was used to measure the number and diversity of livestock species in production systems.

Within the economic indicators, the Grain Yield Potential (GYP) was calculated, applying the following formula.

$$GYP = \frac{pd \times cp \times gc \times tgw}{Gh} \qquad \text{(LGSEED. 2020)}$$

Where GYP=is the grain potential yield, pd=plant density per hectare, cp=number of cobs per plant, gc=number of grains per cob, tgw=Thousand Grain Weight, and Gh=number of grains per hectare.

The agricultural production cost refers to the outlay or expenses that each system makes when producing maize, with the understanding that a sustainable system should allow for low production costs and high yields. Data refer to input (fertilizers, herbicides, and seeds) and machinery (tractors and harvesters) costs.

Economic income diversification refers to the number of jobs outside the production system held by its members. External labor costs refer to the economic disbursement that the systems make to hire day laborers or agricultural laborers. They are one of the highest economic expenses of the system.

The adaptability actions to climate change refer to the measures that each system has implemented to face the undeniable changes in temperature and precipitation patterns in recent years.

RESULTS AND DISCUSSION

As a result of the diagnostic work carried out on October 2021, the main characteristics of the production systems to be assessed were defined (Table 1), during MESMIS phase 2.

Table 1 describes the main characteristics of the assessed production systems. The first system (S1) is made up of 23 producers who use native and rainfed maize, obtain low agricultural yields, and produce for self-consumption. A second system (S2) is made up of the only 7 producers in the community who use improved maize under a rainfed agriculture system. They produce for self-consumption and to feed livestock and they commercialize live cattle, milk, and derivatives as their main source of income.

Table 2 defines 11 sustainability indicators for phase 3 and describes the indicators to be measured.

In September 2022, phase 4 of the field work was carried out and included the collection of information in the field through various techniques, such as participatory workshops, semi-structured interviews, and surveys. Additionally, soil sampling was carried out to analyze soil fertility.

Initial values were quantitative and qualitative and different units of measurement were used. The said values were standardized on the same scale of values for their jointly analysis (phase 5, integration of results). The Reference Interval methodology was used for this purpose (Galván-Miyoshi 2008). The position of a system is determined in relation

Table 1. Main characteristics of the assessed production systems.

Characteristics	**Production systems**	
	Native seed (S1)	**Improved seed (S2)**
Production systems evaluated	23	7
Corn seed used	Native seed	Improved seed
Average corn yield (Ton/ha)	1 to 3	8 to 10
Crops in plot	One (monoculture)	
Purpose of production	Self-consumption and for livestock	
Type of plot work	Yoke and tractor	Tractor, harvester, manual
Type of planting	Manual and tractor	Tractor
Type of fertilization	Agrochemicals	
Type of irrigation	Rainfed irrigation	Rainfed irrigation (and drip irrigation with stored rainwater)
Catte management	Grain and stubble fed, grazes on the field after harvesting	Stable, grain and stubble fed, plus complement
Purpose of cattle	Occasional marketing of live cattle	Marketing on dead wight to abattoirs, milk and derivatives
Type of economic income	Government employees, workers and own businesses	Government employees and own businesses
Type of labor	Family and contracted	Contracted

Table 2. Diagnosis criteria and indicators used to assess the sustainability of production systems.

Indicator	Area	Attribute	Diagnostic criteria	Measurement units
Soil organic matter	Environmental	Productivity, Stability	Soil fertility	% (OM)
Soil's ability to retain water	Environmental	Productivity, Stability	Soil fertility	Difference between CC & PM
Cattle diversity	Environmental	Self-sufficiency, Stability	System self-sufficiency	Shannon-Weaver index
Happiness level of local agents	Social	Resilience, Adaptability	Rol of local actor	Happiness survey
Adaptability actions of CC	Social	Resilience, Adaptability	Rol of local actor	Numbers of adaptability actions of CC
Time dedicated to farming activities, women	Social	Self-sufficiency, Equity	Rol of local actor	Time dedicated to farming activities
Time dedicated to farming activities, men	Social	Self-sufficiency, Equity	Rol of local actor	Time dedicated to farming activities
Cost of agricultural production	Economic	Self-sufficiency, Productivity	System self-sufficiency	Investment ($) in agricultural production
Diversification of economic income	Economic	Self-sufficiency, Productivity	System self-sufficiency	Number of external economic income
Investment in external labor	Economic	Self-sufficiency, Productivity	System self-sufficiency	$ Hiring of external labor (pawns)
Potential grain yield (PGY)	Economic	Self-sufficiency, Productivity	Technical efficiency	Kg ha^{-1} of grain

to a maximum and minimum interval, based on an optimal value (maximum or optimal level reachable by the indicator, shown as V_{max} in Table 3) plus a critical threshold (the worst possible value, shown as V_{min} in Table 3). The value of the maximum and minimum intervals ranges from 0 (the worst value) to 100 (the best value). The following formulas were used for that purpose:

Maximization of the indicator's value

$$LS = \left(\frac{(X - V_{\min})}{(V_{\max} - V_{\min})} \right) * 100$$

Minimization of the value

$$NS = \left(\frac{(V_{\max} - X)}{(V_{\max} - V_{\min})} \right) * 100$$

where: LS is the level of sustainability; V_{min} is the critical threshold; V_{max} is the optimum, and X is the indicator value to be standardized.

The reference values of the indicators of agricultural production cost, external labor cost, and GYP were calculated considering a 20% decrease or increase in relation to the indicator value. In other words, regarding the agricultural production cost and the recommendations for the appropriate dosage application, the investment cost can diminish by 20% or, in the worst-case scenario, increase by 20%.

Regarding the environmental indicators, the two production systems have similar OM% and soil water retention capacity conditions (Figure 2). On the one hand, S1 producers have a greater diversity of cattle, sheep, poultry, and others, because animals represent an investment in case of economic need. On the other hand, S2 producers specialize in cattle

Table 3. Indicators, optimal values, and results of the sustainability assessment with previously standardized values.

Indicator	**System production**		**Reference value**	
	Seed native (S1)	**Improved seed (S2)**	$\mathbf{V_{min}}$	$\mathbf{V_{max}}$
Soil organic matter	56.5	61.7	3	4
Soil's ability to retain water	39.1	64.4	9	12
Cattle diversity	72.6	53.8	0	1
Happiness level of local agents	80.2	79.4	0	100
Adaptability actions to Climate change	37.7	70.8	0	4
Time dedicated to farming activities, women	85.4	60.0	0	100
Time dedicated to farming activities, men	42.7	43.8	0	100
Cost of agricultural production	89.8	23.5	16,449	56,580
Diversification of economic income	21.9	66.7	1	4
Investment in external labor	18.2	97.6	840	9,683
Potential grain yield (PYG)	10.3	76.5	2,819	9,656

for the commercialization of carcasses, milk, and by-products (greater number of livestock, less variety of species).

In the social indicators, inhabitants of the area point out that phenomena such as droughts and frosts have increased, both in frequency and intensity, in the last 10-15 years; therefore, some measures have been taken to reduce the negative effects. Almost all the farmers interviewed (28 out of 30) have built ditches to contain rainwater for livestock and also to use it as auxiliary source of irrigation for crops. Additionally, they have built cisterns and/or bought plastic tanks to store water for domestic use. S2 system has taken

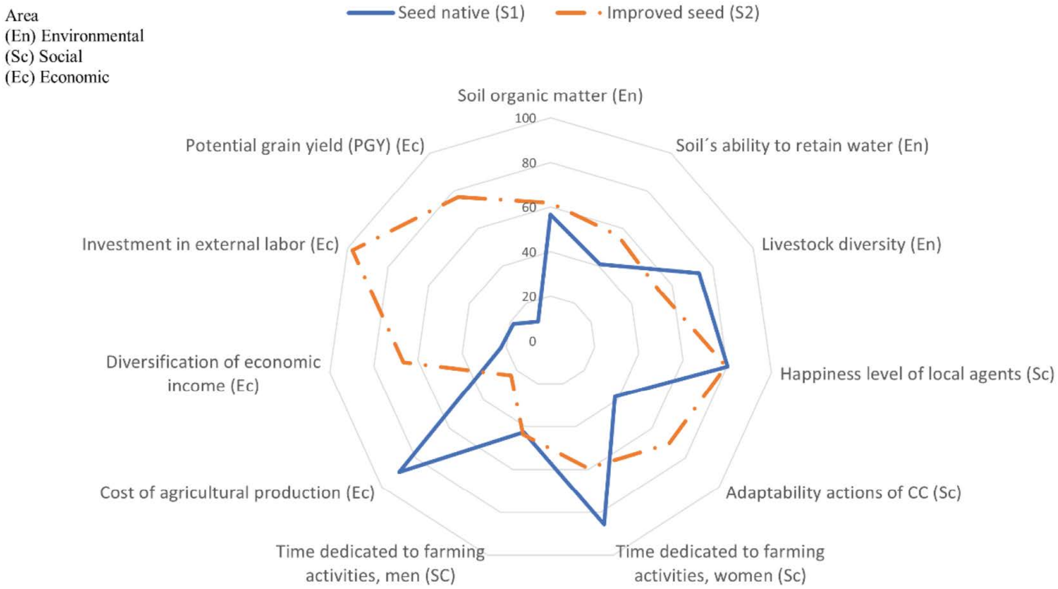

Figure 2. Sustainability evaluation of two agricultural production systems in El Saltillo, Jilotepec, State of Mexico.

more actions to adapt to FC: three producers of this group implemented agricultural drip irrigation systems that take advantage of and make efficient use of the rainwater contained in the watering systems. They have also implemented closed corrals with hermetic roof and floor that allow them to maintain the interior temperature for the benefit of the livestock.

Women play a key role in the operation of the systems. In the S1 system, they take care of the livestock and housework. When they are not studying, young women spend part of their afternoons doing housework and looking after the livestock. In the S2 system, women are hired to help with housework. Men work outside the house and only look after the fields during the weekends, causing a shortage of agricultural laborers, making it more expensive. Overall happiness levels are high for both systems. Aspects such as low noise levels, tranquility, freedom to do things their own way, low levels of violence and crime, and sufficient economic and natural resources, as well as nearby schools and sources of employment, constitute the basis of an overall feeling of a high-quality life, despite the roughness or complications of life in the countryside.

S1 system obtained high levels of sustainability related to agricultural production costs (lower economic investment), while S2 system had high costs in agricultural inputs. There is high dependence on external agricultural inputs. Both systems use agrochemicals such as urea, ammonium sulfate, diammonium phosphate (DAP) and herbicides. Nevertheless, there is evidence that reducing the use of agrochemicals and replacing them with organic fertilizers and sustainable agroecological practices is necessary to produce positive effects on soil conservation and fertility.

The use of technology and agrochemicals results in high maize yields and grain production, but it also increases production costs. Sangermán-Jarquín *et al.* (2009) point out that the use of technologies is an essential factor for greater profitability; however, there is a trend towards the increase of production costs as more developed technology is used and towards a decrease in costs when less developed technologies are used. Consequently, systems of group S2 are not very sustainable in terms of agricultural production costs, given the strong economic investment involved.

In the community, grain is the most important part of the maize crop since it is used for human consumption and also as part of the feed for livestock. Grain is the only form in which farmers commercialize maize; therefore, having high or acceptable maize grain yields guarantees, to a certain point, food self-sufficiency. However, it is also an indicator of soil health or fertility. The grain yield potential indicator was lower than average for all systems, especially for the native maize system. On the one hand, 2022 was a dry year and the delay in rainfall caused five native maize producers to lose their whole harvest and, on the other hand, during the field work stage, the rest of the producers mentioned that the drought "had an impact on maize production, it was a bad year." S2 system has a higher grain yield potential, probably due to the type of maize (improved maize) and the number of agrochemicals used, in addition to the drip irrigation system implemented by some farmers. S1 system turned out to be not very sustainable, as a result of the need to hire more agricultural laborers; although family work is a core part of this system, the work itself is not mechanized enough. On the contrary, S2 system turned out to be more sustainable because they hire fewer laborers and almost all their work is mechanized.

CONCLUSIONS

In the two assessed production systems, aspects such as low sustainability (*e.g.*, high production costs, high dependence on external inputs, high dependence on external labor, and vulnerability to climatic conditions) stand out; although other aspects (*e.g.*, high soil fertility, high perception of happiness and quality of life, and high diversity of livestock) are also emphasized.

Some agricultural practices that involve the use of agrochemical, such as herbicides and fertilizers, clearly degrade the soil, water, and natural capital; therefore, it is necessary to implement agroecological practices that are not only more environmentally friendly, but also encourage increased agricultural yields. As part of the initial agreements with producers, they were given the results of the soil fertility analyses. Two types of recommendations were made regarding the application of fertilizer or herbicide doses. The aim was to establish the necessary doses and to reduce agricultural production costs and the environmental impact.

S1 production systems are highly vulnerable, because the investment in labor, money, and effort is not proportional to the production obtained. Native maize sowing is a cultural issue that can be abandoned or changed for a more profitable activity.

Identifying climate change indicators will allow the creation of future scenarios, the implementation of adaptability actions, and the exploitation of changes in an effective and concrete manner that favors the conservation of native maize.

By assessing different elements present in a production system (such as happiness, soil fertility, grain yields, livestock diversity, perception and adaptability to climate change, time dedicated to farming by women and men), as well as production expenses, this study is the result of the integrated analysis of several methodologies used to measure sustainability indicators.

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