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Article

Characterization of *Moringa oleifera* commercial crops in southeastern Mexico

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Abstract

Moringa oleifera Lam. is a species native to India, used in many countries for its great commercial potential in the diet and its health benefits. In Mexico, its cultivation, use, and commercialization has spread in the last 10 years. This study aimed to characterize the commercial crops of *Moringa oleifera* in the south-southeast of Mexico. A structured questionnaire was used and 27 commercial moringa producers were interviewed in the states of Veracruz (18.52%), Oaxaca (22.22%), Guerrero (22.22%), Chiapas (18.52%), and Yucatán (18.52%). The research was carried out in the south-southeast of Mexico in April and May 2018. Descriptive statistical analyses were performed. It was found that 81% of the producers sell moringa products, for medicinal purposes (100%), food (85%), bioenergy (19%), fodder (14%), flocculant (11%), and for honey production (4%). The products marketed are leaves (89%), seeds (70%), and seedlings (56%). It is concluded that the cultivation of moringa in the south-southeast of Mexico for commercial purposes in different presentations and uses is booming. For several producers, this plant represented a business opportunity.

Keywords:

marketing, organization, production, tropical agroecosystem.

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Introduction

Moringa oleifera Lam. is a tree native to the tropical dry forests of the lowlands of northwestern India (Estrada-Hernández *et al*., 2016). It is cultivated in tropical and subtropical climates, from sea level to altitudes of 2 000 m (Leone *et al*., 2015). Nonetheless, crop performance is affected as altitude increases (Olson and Alvarado-Cárdenas, 2016). Due to its diversity and potential uses (medicinal, food, fodder, bioenergetic, flocculant, industrial, biofertilizer, and bioadsorbent), this plant has become a business opportunity in several countries, including Mexico (Velázquez-Zavala *et al*., 2016).

Its leaves contain significant levels of proteins, carbohydrates, vitamins, minerals and phenolic compounds (Peñalver *et al*., 2022). This plant was introduced through the Mexican Pacific coast during the voyages of the Nao of China (Olson and Fahey, 2011). It should be noted that the semi-arid and subhumid tropics of Mexico have the right conditions for the cultivation of this plant (Olson and Fahey, 2011). Olson and Alvarado-Cárdenas (2016) point out that this plant has been cultivated with great success and its use has increased in Mexican society in the last 10 years.

However, the good acceptance of this plant among producers is not a guarantee of good agronomic management. Gandji *et al*. (2018) describe that some producers who market moringa products do not have sufficient knowledge or carry out inefficient practices to obtain a vegetative material in quantity and quality. In addition, the agronomic management and production situation of moringa in the south-southeast of Mexico, particularly in commercial plantations, has not been characterized.

The importance of developing research related to the management and marketing of moringa lies in a rural development program that benefits producers (Seifu and Teketay, 2020). Currently, at the international level, the sale of commercial products made from moringa has increased substantially. It is common to see the sale of capsules and dehydrated leaves as a food supplement in health food stores and shopping centers. In the case of Mexico, there is little or no information on who is producing moringa for commercial purposes, the products they made and what the attributes of these producers are.

This study aimed to characterize the commercial crops of *M. oleifera* in the south-southeast of Mexico in terms of socioeconomic characteristics of the producers, level of agronomic management of the plantations, and diversity of the products processed and marketed.

Materials and methods

Study area

This study focused on knowing the agronomic management practices at the field level and the challenges faced by producers in terms of cultivation and marketing through the application of a structured questionnaire in the south-southeast of Mexico in April and May 2018. The research focused on producers who had moringa plantations for commercial purposes in the south-southeast of Mexico. To identify the existing commercial moringa plantations in the south-southeast of Mexico, an Internet search was carried out with keywords such as *Moringa oleifera*, sale of products, and commercial crops in the south-southeast of Mexico.

Once the sites, people, and companies were identified, they were contacted by telephone and email, explaining the purpose of the research, and requesting their cooperation to carry out the corresponding interview. Thus, 27 commercial moringa plantations were identified in the states of Veracruz (V), Oaxaca (O), Guerrero (G), Chiapas (C), and Yucatán (Y). Each crop was identified with locality, municipality, state, longitude, and latitude (Table 1).

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Table 1. Location of *M. oleifera* crops in the south-southeast of Mexico.

No	Crop	State	Municipality	Locality	Longitude	Latitude
1	V1	Veracruz	Soledad de Doblado	El Progreso	-96.4022719	19.0818742
2	V2	Veracruz	Paso del Macho	Loma Pelada	-96.5398368	18.9258796
3	V3	Veracruz	Tierra Blanca	Colonia Pemex	-96.3429545	18.435
4	V4	Veracruz	Misantla	Santa Cruz Hidalgo	-96.8628092	19.9555656
5	V5	Veracruz	Emiliano Zapata	La Cumbre	-96.6447222	19.3911111
6	O1	Oaxaca	Santa María Zacatepec	El Rosario	-97.9805556	16.8583333
7	O2	Oaxaca	Villa de Tututepec de Melchor Ocampo	Santa Rosa de Lima	-97.6133333	16.0675
8	O3	Oaxaca	Juchitán	Rancho S/N		
9	O4	Oaxaca	Santa Cruz Xoxocotlán	San Juan Bautista La Raya	-96.7280556	16.9791667
10	O5	Oaxaca	Santa María Huatulco	La Herradura	-96.3658333	15.7772222
11	O6	Oaxaca	Mariscala de Juárez	Guadalupe la Huertilla	-98.1088889	17.8513889
12	G1	Guerrero	José Azueta	San José Ixtapa	-101.6083333	17.7008333
13	G2	Guerrero	Petatlan	Rancho Nuevo	-101.2319444	17.4613889
14	G3	Guerrero	Acapulco	Costa Azul	-99.8430556	16.8636111
15	G4	Guerrero	Petatlan	Petatlan		
16	G5	Guerrero	Acapulco de Juárez	Colonia Salto	-99.766111	16.864444
17	G6	Guerrero	Acapulco de Juárez	Parrotillas	-99.6977778	16.8216667
18	C1	Chiapas	Tuzantán	Villa Hidalgo	-92.374722	15.108056
19	C2	Chiapas	Tuxtla Gutiérrez	Colonia La Salle	-93.0868889	16.7429444
20	C3	Chiapas	Tuxtla Gutiérrez	Barrio Sabal		
21	C4	Chiapas	Villa Corzo	Hoja blanca	-92.9663889	16.0511111
22	C5	Chiapas	Acala	20 de noviembre		
23	Y1	Yucatán	Tzucacah	Tzucacah	-89.0391111	20.0720278
24	Y2	Yucatán	Mérida	Frac. el Parque	-89.5872222	20.9711111
25	Y3	Yucatán	Peto	Teshan	-88.62125	20.1486389
26	Y4	Yucatán	Mérida	Col. Mercedes Barrera		
27	Y5	Yucatán	Baca	Felipe Carrillo Puerto	-89.60700993	20.9954688

The plantations included in the study were geographically located through the ARCgis program, version 10.5 (ESRI, 2016) (Figure 1). The climatological data layers were obtained from Uniatmos (uniatmos.atmosfera.unam.mx/) and through the Qgis program, version 3.0.2, data on mean temperature, altitude, and average annual precipitation of the geographically located cultivation sites were obtained.

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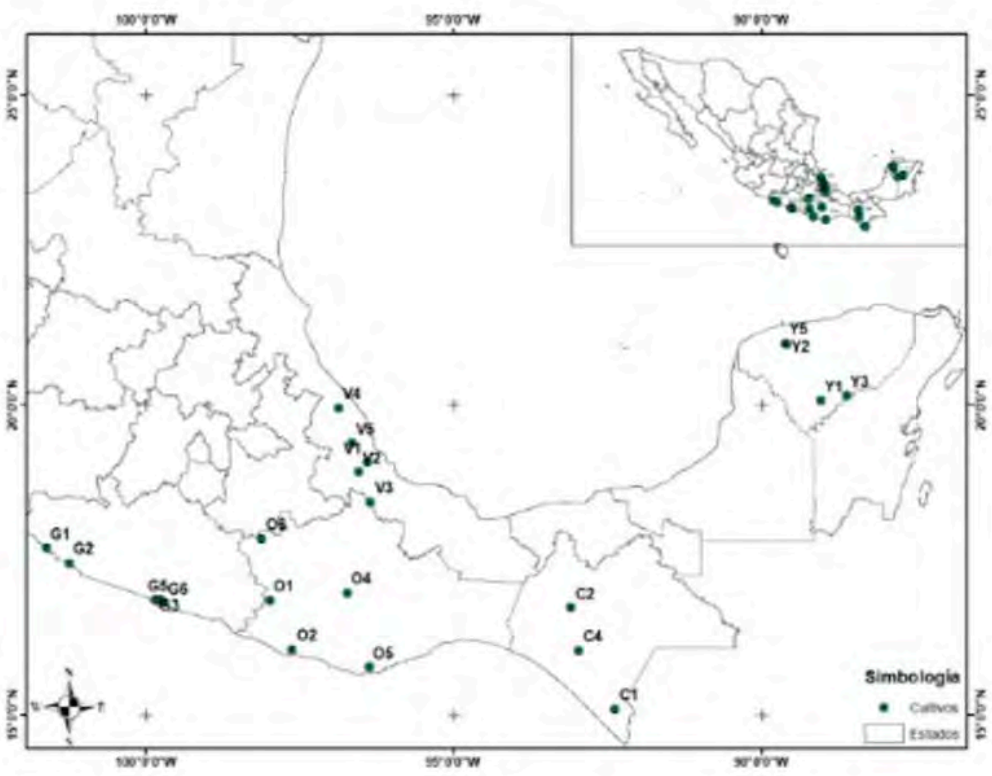
Figure 1. Geographical location of the evaluated commercial moringa crops in the south-southeast of Mexico.



Sample selection and survey development

The selection of the sample was intentional (directed), with the selection criteria being the commercial purpose of the crop and geographical location. The 27 moringa producers interviewed correspond to 80% of the producers with commercial plantations in the south-southeast of Mexico. A structured questionnaire was designed in order to collect information that would allow us to know the characteristics of the moringa cultivation (Flick, 2006).

The questionnaire included the following sections: 1) profile of the interviewee; 2) profile of the farm; 3) process of adoption of the species; 4) agronomic management of the crop; 5) postharvest management; 6) commercial aspects and 7) organization and training. The questionnaire was applied through personalized interviews and telephone communication. All the interviewees showed willingness to be interviewed and the time of the interview varied depending on the means of communication.

In this work, the presence of several species associated with moringa crops was identified. The associated crops were lemon (33.33%), orange (11.11%), corn (11.11%), chili (3.7%), stevia (11.11%), pitaya (3.7%), basil (3.7%), neem (3.7%), papaya (7.41%), mangosteen (3.0%), bay cedar (3.7%), and coffee (3.7%).

Data analysis

The interview provided qualitative and quantitative information. The survey data were recorded in a spreadsheet of the Excel program, version 2016. Descriptive statistics were performed to determine the frequency for each response.

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Results and discussion

The states of Oaxaca and Guerrero were represented by 22.22% of the survey participants and the states of Veracruz, Chiapas, and Yucatán by 18.52% each. The altitude (masl), mean temperature (°C), and annual precipitation (mm) were determined in each commercial crop. The environmental factors for the crops were V1 (67 masl, 26 °C, and 1 039 mm), V2 (210 masl, 25 °C, and 1 134 mm), V3 (50 masl, 26 °C, and 1 658 mm), V4 (202 masl, 23 °C, and 1 886 mm), V5 (349 masl, 25 °C, and 894 mm), O1 (341 masl, 26 °C, and 1 603 mm), O2 (17 masl, 28 °C, and 1 302 mm), O4 (1 507 masl, 21 °C, and 634 mm), O5 (175 masl, 26 °C, and 1 016 mm), O6 (1 081 masl, 24 °C, and 623 mm), G1 (21 masl, 27 °C, and 1 015 mm), G2 (10 masl, 27 °C, and 905 mm), G3 (124 masl, 27 °C, and 1 146 mm), G5 (17 masl, 27 °C, and 1 122 mm), G6 (19 masl, 27 °C, and 1 114 mm), C1 (134 masl, 27 °C, and 3 456 mm), C2 (525 masl, 25 °C, and 930 mm), C4 (570 masl, 25 °C, and 1 830 mm), Y1 (40 masl, 26 °C, and 1 168 mm), Y2 (8 masl, 27 °C, and 1 002 mm), and Y3 (29 masl, 26 °C, and 1 219 mm).

Differences were found in temperature, altitude, and average annual precipitation. Regarding the geographical location of the crop, it was found that it develops in temperatures between 13 °C and 34 °C and an annual average rainfall of 905 to 3 456 mm. Although the moringa plant has a high acclimatization capacity, its production can be affected by soil type, altitude, precipitation and geographical location (Olaoye *et al*., 2021). Carrión *et al*. (2022) describe that a large percentage of the territory of the state of Veracruz has favorable climatic conditions for the cultivation of moringa. This is particularly easy in subhumid tropical climates.

Interviewee profile

Eighty-seven percent of the producers were men and 13% women. The average age of the producers was 51.6 years, with a minimum and maximum of 21 and 87 years. The levels of education identified were: bachelor's degree (37%), high school (26%), postgraduate studies (18%), elementary school (11%), and junior-high school (7%). Bachelor's degree studies correspond to agronomy engineering (19%), administration (11%), education (7%), psychology (7%), a 4% is represented by bachelor's degrees in accounting, civil engineering, chemical engineering, electrical engineering and 41% have no higher education.

Authors such as Mota-Fernández *et al*. (2019) identified a high level of education in moringa producers in the state of Veracruz. The activities identified were agriculture (33%), trade (22%), teaching (15%) and beekeeping, trainer, coffee taster, project coordinator, student of agronomy engineering, livestock farming, manager and person in charge of industrial maintenance represented 4%. Producers engaged exclusively in agriculture had better management of moringa crops than those who perform other trades. This was observed based on the information obtained in the interview.

Farm profile

Regarding the type of land tenure, 59% were small property, 33% ejido, 4% both (small property and ejido) and 4% communal. The average area for the cultivation of moringa was 1.3 ha, with the largest and smallest area being 11 and 0.001 ha, respectively. The date of establishment of the crops was from 2008 to 2017. The largest number of plantings occurred in 2013 and 2015, with 18.5%. Regarding participation in moringa cultivation, 81% stated that it is a family business and 19% mentioned that the participation corresponds only to producers.

The associations represent an advantage for obtaining several products on the same area since some producers have small areas. Moringa can be used as a polyculture in alleys and live fences or associated, facilitating its adoption by farmers. The advantages of associating crops with moringa are that it allows controlling pests, optimizing the use of soil and water, reducing wind and water erosion, and improving the conditions of other crops on farms or in family gardens (Gadzirayi *et al., 2013). Nevertheless, the spatial and chronological arrangement and planting density are key in this aspect.*

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Species adoption process

Regarding the adoption of moringa by producers, it took place through various means. Fifty-nine percent learned about the species through third parties, including researchers, technicians, producers, and traders and 41% through publications on the Internet. One hundred percent of the producers mentioned knowing at least one use of moringa. The uses of moringa were represented as follows: medicine (100%), food (85.18%), flocculant (11.11%), fodder (14.81%), bioenergy (18.51%), and beekeeping (3.7%). All the interviewees mentioned that they consume various parts of the plant such as leaves (88.88%), seeds (55.55%), flowers (3.7%), and stem as a tea (3.7%). The frequency of moringa consumption per week was seven times (48.15%), one time (25.93%), two times (11.11%), three times (7.41%) and four times (7.41%).

Through the survey carried out, it was identified that the knowledge of moringa is focused on food and medicinal uses, and very little on the following uses: bioenergetic, bioadsorbent, flocculant, and industrial. A high impact of moringa as a commercial crop due to its demand and also a lack of scientific information about industrial uses were observed. Therefore, there is a knowledge gap among producers about the different uses and added value of this multipurpose tree.

In this sense, Thurber and Fahey (2009) point out that the diffusion of innovations theory could support the establishment of a structured technology transfer program for the crop and its uses. To do this, it is necessary to understand the socioeconomic characteristics of producers (Fadoyin *et al*., 2014) and the current demand in the market in order to predict the level of acceptance and highlight the economic importance.

Agronomic crop management

It was found that the seed for the establishment of the crops comes from the states of Chiapas, Guerrero, Michoacán, Nuevo León, Oaxaca, Sonora, Sinaloa, Veracruz, and Yucatán in addition to the United States of America. All crops were established between 2008 and 2017. The year of cultivation, management conditions, and production records prevent comparison between populations. The producers mentioned that the demand for the seed is permanent and many times they are not able to meet the market demand.

The way of establishing the crops was through seed (93%) and both seed and cuttings (7%). Producers mentioned that the easiest way is through seed; however, vegetative reproduction is also a viable option when there is little availability of seeds or when the average temperature did not allow germination. The management of plants in the nursery phase is characterized by the use of substrate (compost, cane filter cake, and vermicompost), where 33% of producers stated that they use a substrate made from local resources such as soil and compost.

In the case of irrigation, 100% irrigate the plants in the nursery phase at least once a day. In the field phase, 67% of the interviewees stated that their crop has an irrigation system. The type of irrigation was 55% sprinkler, 39% drip, and 6% hose irrigation. This activity prevents water stress and leaf loss during the dry period. Nonetheless, many are unaware of the water requirements in the leaf production, flowering, and fruiting stages. In this research, it was identified that crops without irrigation have fewer harvests per year.

The effect of irrigation on this crop is a relevant topic to investigate. Tshabalala *et al*. (2020) cite that the acceptable annual precipitation range for moringa production fluctuates between 700 and 2 200 mm. In this research, it was identified that most of the commercial crops evaluated are within this range. Mabapa *et al*. (2017) indicated that the availability of soil moisture has a positive effect on leaf productivity.

Drip irrigation is the most efficient way to provide moisture to the moringa crops in the southeast since most of the crops are located in areas where water is limited. Muhl *et al*. (2013) state that low humidity conditions (300 mm) allow a greater number of flower buds and an irrigation of 900 mm allows a greater number of fruits. In terms of fertilization, 63% have fertilized at least once in the entire production period. The type of fertilizer used is 81% granulated, 13% liquid and 6% foliar.

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The products for fertilization were divided into compost and vermicompost (33%), liquid humus and urea with 13%, and triple 17 with 7%. Manzano-Gómez *et al*. (2021) mention that the use of biofertilizers favors growth, survival, biomass production, and the chemical composition of the leaves. Moringa does not have the ability to fix nitrogen and phosphorus and therefore requires fertilization (Mudyiwa *et al*., 2013). Motis and Reader (2019) suggest that a fertilization with NPK (15:15:15) contributes to the growth of moringa.

Nonetheless, organic moringa production is an area of opportunity for producers in the southeast, particularly if it is aimed at international sales and consumption. The cultural work of the crops was determined by the association of species and the density of plants. This aspect presented great variation due to the fact that there is no control over the activities carried out and the frequency of harvest was determined by the rainy season and the demand for leaves.

The main pests and diseases in the nursery phase were ants (*Atta*) (14.81%), worms (7.41%), butterflies (3.7%), grasshopper (*Sphenarium*) (3.7%), root fungus (3.7%), whiteflies (3.7%), and locusts (3.7%). In the field phase, they were gophers (22.22%), ants (*Atta*) (51.85%), and whiteflies (3.7%). In the postharvest phase, they were fungi (22.22%) and weevils (*Sitophilus*) (3.7%). Due to the lack of individuals at the time of the interview, the taxonomic identification of the species was not carried out. Pests were usually controlled with extracts of neem (*Azadirachta indica*) or cinnamon (*Cinnamomum verum*).

Regarding the use of pesticides, 19% stated that they use organic pesticides and 81% do not use them. Regarding the average days of work used for manual weeding, it was one. The average daily wage is $182.00. The average distance between plants was 1.69 m and between rows 2 m. According to the rating of the leaf product in the field, 55% rated it as good, 19% as very good and 26% as excellent. Seed production is divided as follows: 59% for commercial purposes and 41%is destined for the establishment of new crops.

The production of seed for the commercial part had medicinal purposes. It was identified that producers consume the seed for the treatment of diseases such as diabetes and hypertension. Pirrò *et al*. (2016) mention that the miRNAs contained in moringa seeds can be used to regulate human genes and intervene in processes such as leukemia, cell cycle and protein degradation. These miRNAs decrease the levels of the SIRT1-SIRT7 proteins related to neurodegenerative diseases, cancer, diabetes and obesity.

Postharvest management

It was identified that the process of dehydrating moringa leaves is the most common for commercial purposes. Dehydration in the shade is the most frequent (7%), followed by dehydration in direct sunlight (4%), 11% do not dehydrate the leaf and 4% use a solar dehydration chamber. It was identified that dehydration techniques depend on the advice and technology available to the producer.

In this regard, Ahmed and Langthasa (2022) mention that the dehydration of moringa leaves concentrates nutrients, facilitates conservation and consumption and allows transport to areas where it cannot be grown. However, Ruiz-Hernandez *et al*. (2022) described that dehydrated conditions decrease the amount of nutrients in moringa leaves. During the postharvest phase, fungal contamination was identified due to poor dehydration of the leaves or excess relative humidity of certain regions of the subtropics.

The presence of beetles was also observed in dry leaves and seeds due to inadequate storage conditions or in plants that have dehiscent pods. It should be noted that there are few pests that attack the moringa tree and that such attacks endanger leaf production and product quality. Nevertheless, entomofauna is another aspect that must be investigated to improve postharvest

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management conditions. Regarding the technology used for grinding the leaves, it was found that 22% use a manual mill, 14% a forage mill, and 7% a leaf pulverizing mill and a blender.

Forty-four percent store dehydrated and ground leaves, 30% dehydrated leaves, 11% ground leaves and 15% do not store leaves. The storage material of the leaves is very diverse, 59% use airtight bags, 7% use cellophane bags and 4% use paper bags, airtight bottles, grainpro bags, and transparent bottles. Once dehydrated, they can be ground or stored to be sold in that presentation (Ojiako *et al*., 2011).

Under proper handling and hermetic sealing conditions, the quality of the leaves is maintained for several months. The material for storing moringa leaves must have the ability to protect the quality of the product from the sun's rays as transparent bags promote the loss of vitamins and phenolic compounds (Kashyap *et al*., 2022).

Commercial aspects

The moringa products marketed are leaves (88.89%), seeds (70.37%), and seedlings (55.56%). The average price per kilogram of moringa seeds varies and can reach a price of $2 161.00; most producers offer it in presentations of 50 to 100 seeds. Some sell the seeds at $1.00 per unit. The average cost of the moringa seedling is $30.00, with $10.00 being the minimum price and $50.00 being the maximum. Sixty-seven percent stated that they give added value to moringa. For example, dehydrated leaf (66.67%), meal (37.04%), capsules (37.04%), tea sachets (7.41%), soaps (7.41%), shampoo (7.41%), creams (3.7%) and oil obtained from seeds (3.7%).

The media used for the dissemination of the products were internet (81.84%), radio (7.41%), TV (3.7%), newspaper (7.41%), talks (23.63%) and flyers (29.63%). The average price per kg of dehydrated leaves was $1 333.00. The average number of capsules per bottle was 80 units, with the minimum being 30 and the maximum 150. Regarding the average cost of a bottle of capsules, it was $141.00, with presentations from $50.00 to $250.00. The price of each product is determined by handling and presentation. Twenty-three percent of the interviewees stated that they have a registered trademark and among them are Humar, MorinJic, MoringaGela, Amor Mixteco, viDa Moringa and Ocho Venados.

Ninety-three percent of producers responded that they sell their product directly in the local market. Seventy percent use the Internet to publicize and market their products. Of the total leaf production, the average marketed is 57%, and producers attribute it to the saturation of the market with moringa products and the disparity in the prices offered.

The frequency of marketing of the products is 55% eventually, 33% every year, and 12% do not sell leaves or only when they have excess production because they are used for livestock feed purposes. The commercialization of moringa seed oil in the south-southeast is low due to the lack of technology and diffusion. This represented a problem that can be solved through the development of prototypes focused on the extraction and transformation of oil.

Studies such as that by Leone *et al*. (2016) mention that the oil and nutrients contained in the seed have multiple benefits for human health. Moringa products are often marketed locally and the use of digital media to promote their products is becoming more common. Producers mention that the acceptance of the product has been good, but its price is affected by the increase in supply in the market. The perception that producers have about the moringa crop is positive due to its rapid growth and high tolerance to drought.

This is coupled with its high response to resprouting in the face of extreme pruning, allowing a greater number of harvests per year (Abdoun *et al*., 2022). Regarding the level of acceptance of the product, producers commented that the level of acceptance is high (67%), regular (22%) and low (11%). Ninety-three percent of the producers have a positive perception of the moringa crop, and they point out that it is a profitable crop and that the only limitation is the marketing channel.

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Organization and training

Ninety-six point three percent stated that they do not belong to any organization of moringa producers and only in the state of Guerrero was an association identified. Eighty-one percent mentioned not having received any training for crop management. One hundred percent mentioned that they have not received financing from the government for crop management.

The producers stated that profitability depends on the dissemination of the products, the agronomic management, postharvest, and quality and variety of products marketed. Therefore, training is of great importance throughout the production process. Among the training needs expressed were agronomic management (44%), postharvest management (22%), forms of exploitation (11%), consumption (7%), forum for the exchange of experiences (4%), moringa varieties (4%) and marketing (4%).

Similar studies in countries such as Nigeria conclude that production, processing and marketing processes, investment, land disposal, density, variety and quality control are the main problems for producers (Ojiako *et al*., 2011). This problem is similar for producers in the southeast since, in the absence of a producers' association, a moringa value chain, sources of financing and technical advice, they are vulnerable in the competitive environment (national and international) to products imported from other countries.

Conclusions

The commercial production of moringa in the south-southeast of Mexico is mainly focused on food and medicinal uses. The diversity of processed products allows for greater profits and new consumer markets. Moringa is grown in different states of the south-southeast of Mexico and with proper management, it is possible to obtain satisfactory yields and higher nutritional quality of leaves and seeds. There is a differentiated level of intensification in the management of moringa induced by its commercialization. Finally, moringa is perceived as a promising crop and for several producers, this plant represents a business opportunity.

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