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ANALYSIS OF THE AMARANTH VALUE CHAIN IN THE STATE OF MEXICO

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ABSTRACT

The objective of this research was to analyze the amaranth value chain in the State of Mexico, considering the relationships established between actors, their functions, and the factors that affect competitiveness. Two working panels were formed in April and October 2023, with the participation of 17 experts on the subject. Surveys were conducted from May to September 2023, with input suppliers, producers, collectors, processors, consumers, and government institution agents. It was found that the relationships between input and agricultural machinery suppliers and producers are commercial; government institutions offer advice and generate research, such as adapting implements, together with large producers. The organization is informal, made up of 10 to 15 producers, without considering a legal entity. Of the survey respondents, 4% reported being involved in grain collecting or marketing, while 92% seek marketing channels through their own means. The collectors set the price of the grain. Processors establish links with large producers; however, with medium and small producers, these relationships are almost nonexistent. A financing scheme for amaranth production is required, as well as the adoption of technologies appropriate to the region; agroindustries are absent. The need for formal organizations to generate economies of scale and create an amaranth production system stands out.

Keywords: actors, profitability, relationships and links.

INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO, 2024) emphasizes that amaranth is a highly relevant agricultural product, recognized for its versatility of uses and its significant nutritional value, especially due to the quality and quantity of its proteins. This crop can grow under conditions of scarcity, showing tolerance to drought and adverse environments, with yields equal to or even higher than those of other grains under similar circumstances. This makes it a strategic crop for production and consumption in marginalized regions of the country (Barrales *et al*., 2010); it is also a viable alternative to address global problems, thanks to its remarkable adaptability to diverse environmental conditions and production systems (Espitia *et al*., 2018).

In Mexico, amaranth is produced mainly in six states: Puebla, Tlaxcala, State of Mexico, Mexico City, Oaxaca, and Morelos, with a national average yield of 1.66 t ha^{-1}. In 2023, the State of Mexico ranked as the third largest producer nationwide, concentrating its cultivation in 10 municipalities in the state (Servicio de Información Agroalimentaria y Pesquera-SIAP, and Sistema de Información Agroalimentaria de Consulta-SIACON, 2023). Although zones with great potential for amaranth cultivation have been identified, the planted area at the state level is still limited, with less than 3,500 hectares. However, production in the state has shown sustained growth between 2000 and 2023 (SIAP-SIACON, 2023), driven largely by its high profitability, which makes it an attractive suggestion for local producers.

According to Ayala *et al*. (2014), amaranth is a profitable option in central Mexico, especially in areas that lack irrigation systems. However, from a competitive perspective, its value chain faces significant challenges. These difficulties are largely due to the fact that the crop is grown in small communities with limited natural and technological resources. Furthermore, these regions do not have adequate financing to access new technologies that could improve both amaranth production and processing (Ayala *et al.*, 2012; Ayala *et al*., 2016).

In the State of Mexico, one of the main problems identified is the poor integration of the value chain, which highlights the lack of economies of scale and the insufficient organization among the actors involved in the different links. This disconnection hinders the optimization of resources and the maximization of benefits for participants (Ayala *et al*., 2016); therefore, the amaranth value chain in the state is considered to have a nearly nonexistent integration.

The objective of the study was to analyze the amaranth value chain in the State of Mexico, identifying the actors, their relationships and functions, as well as the limitations on both the productive activity and the inter-institutional strategies. In addition, it was sought to determine the profitability of the crop to propose strategies that contribute to improving the competitiveness of the value chain.

THEORETICAL FRAMEWORK

Amaranth (*Amaranthus* spp.) is one of the oldest crops in Mesoamerica. It is said to have been the staple food of the Aztecs, Incas, Mayans, and hunter-gatherer peoples. The first records of this plant date back ten thousand years, and its role in the diet was as important as that of corn and beans (Asociación Mexicana del Amaranto [AMA], 2003). It is estimated that they produced 15,000 to 20,000 tons per year. After the arrival of the Spanish in America, an intense exchange of crops began, with some crops gaining importance while others almost disappeared. The customs were significantly rooted in

the communities, and its consumption was maintained for centuries by small farmers (Huerta *et al.*, 2012).

According to the Senate of the Republic (2019), amaranth in Mexico is considered among the products proposed to be part of the list of strategic crops, in Article 19 of the Sustainable Development Law. Furthermore, the grain is far from being as important as other crops like corn, beans, etc., so there must priorities for its mechanization, transformation, and commercialization; in addition to its importance as part of the identity of pre-Hispanic cultures, its origin, and mainly , its nutritional characteristics.

The amaranth value chain, faces significant challenges from a competitiveness perspective, especially considering that cultivation is carried out in small communities under conditions of scarcity (De la O *et al*., 2012). The value chain describes the activities required to produce a product, from conception to consumption (Nutz and Sievers, 2016); it describes a set of actors who interact with each other to increase the product's value through links (Acosta, 2006). Each stage—conception and design, production of the good or service, transport of the merchandise, consumption, handling, and final recycling—is referred to as a link.

Understanding crop growth is essential for the value chain, since it allows identifying opportunities to improve the yield and to optimize resource use. According to Ayala *et al*. (2016), increasing amaranth productivity is based on the adoption of technological innovations adapted to the specific characteristics of the production zones. To analyze the impact of factors such as yield, innovation, and harvested area on the growth of a crop's production, the Factor Determination methodology is used, which allows calculating the degree of individual influence of these indicators or their combined effect on amaranth production growth (Contreras, 2000). The analysis focuses on three main aspects: the adoption of technological innovations considering the characteristics of the production zones (Estrada *et al.,* 2006), the reduction in cultivated area, and the possible interaction between both factors (Ayala *et al*., 2016).

Extensive growth is associated with an increase in production, derived from the expansion of harvested area, which may reflect a possible technological obsolescence. In contrast, intensive growth is associated with an increase in production through yield improvements, suggesting a more advanced technological level. Combined growth implies an increase in both area and yield (Zarazúa *et al*., 2009; Ayala *et al.,* 2017).

To analyze and characterize value chains or complex systems, the panel discussion technique is used, which involves bringing together a group of specialists who, through active group intervention, issue a collective opinion

on the topic at hand. Franco *et al*. (2018) describe this tool as an adaptation of the "Delphi" methodology, used to obtain consensual and reliable responses from a group of experts. This approach promotes meaningful building of group knowledge.

Within the framework of the amaranth value chain analysis, a profitability calculation was performed with the objective of better understanding the relationship between the income generated and the costs involved in the productive activities. Profitability is defined as "the relationship between income and costs generated by the use of company assets in productive activities" (De la Hoz *et al*., 2008). According to Sánchez (2002), profitability is conceptualized as an indicator that measures the efficiency in the use of capital employed, allowing to compare options or assess the effectiveness of the activities carried out.

METHODOLOGY

Factor decomposition for the analysis of production growth.

The degree of influence that the factors of yield, cultivated area, and combined effect have had, as indicators of innovation, was determined during the period 1986-2022 in the State of Mexico. The formula by Contreras (2000) was modified, and data from SIAP-SIACON (2023) were taken for amaranth production.

$$P_t = Y_0\left(A_t - A_0\right) + A_0\left(Y_t - Y_0\right) + \left(A_t - A_0\right)\left(Y_t - Y_0\right) \quad (1)$$

where P_t is the Total Production Increase for the analysis period; $Y_0(A_t\text{-}A_0)$ Quantifies the contribution of the harvested area; $A_0(Y_t\text{-}Y_0)$ Quantifies the contribution of yield; $(A_t\text{-}A_0)$ $(Y_t\text{-}Y_0)$ If the total increase in production for the period 1986-2022 is equal to 100%, it is possible to determine whether the growth has been intensive or extensive (Ayala *et al*., 2017).

For the value chain study, the panel methodology was used, a methodology commonly used in research and projects to analyze and characterize value chains or complex systems. Two panel discussions were held in the months of April and October 2023, in the State of Mexico. The first panel discussion (April 2023) aimed at providing guidance to the team about the fundamentals, principles, and concepts necessary to characterize the amaranth value chain in the State of Mexico. In the second panel discussion (October 2023), the actors who participated in the first panel reconvened. In addition, representatives from the different links in the value chain participated: 20 producers, 2 input suppliers, 2 processors from Mexico City, a marketer, and 5 representatives from government institutions [Instituto Nacional de Investigaciones

Forestales, Agrícolas y Pecuarias (INIFAP), Secretaría de Agricultura (SADER), Universidad Autónoma Chapingo (UACh), and Colegio de Postgraduados (COLPOS)] and those interested in the topic.
In the field work, surveys were designed and applied, the content of which considered the following categories:

- Actors and functions: The agents and the functions that each of them performs were identified through the questions asked and the search for information on the Amaranth Product System.
- Horizontal relationships and ties: The interactions between agents or actors and their level of organization were described.
- Primary information on the national market: Relevant information on the national market, consumption, and attributes of the products offered was analyzed.
- Critical support services: Information was collected related to financial services related to access to credit.
- Technical assistance services: Information regarding technical advisory services was presented to producers.
- Quality management services: Regulatory instruments were sought for product transformation.
- Business intelligence: An analysis was conducted to learn about consumer culture, amaranth quality, and its properties.
- Logistics and storage: The actors involved in this area were identified.

The above allowed obtaining the map of the value chain. The surveys were applied from May to September 2023, directed at each of the actors in the chain: producers (20) from the municipalities of Amecameca, Temamatla, Juchitepec, and Tepetlixpa, located in the State of Mexico; transformers (2); collectors; consumers (30); researchers, government representatives (5) [INIFAP, UACh, SADER, University of Lausanne (UNIL), COLPOS]. The survey is used when there is not enough informative material on certain aspects there is interest in researching, or when information cannot be obtained through other techniques, which allows collecting information from primary and updated sources (Rojas, 2013). A non-probabilistic sampling of expert selection was used (Pimienta, 2000).
The calculation of profitability was conducted with producers who participated in the panel sessions and had an equivalent technological level, in-depth knowledge, and access to information on the technical parameters and production costs. The methodology proposed by Agro-prospecta allows for obtaining, through consensus among participating producers, specific

production costs for a given agricultural cycle. These data are essential to determine crop profitability (Red Mexicana de Investigación en Política Agroalimentaria–Agroprospecta; 2010; Ireta *et al*., 2015).
The production costs were divided into direct costs: seeds, fertilizers, machinery rental, labor, etc., and indirect costs: land rental and general expenses such as transport and hauling of inputs, and logistics for grain commercialization. To calculate the total income per hectare, the average rural price for the area and the average amaranth yield per hectare were used, using data provided by the producers. To do this, the following algebraic expressions were used, which are based on the economic theory by Krugman and Wells (2006), and Samuelson and Nordhaus (2010).

$$CT = PxX \tag{2}$$

where *TC*: total cost of production; *Px*: price of input or activity *X*; *X*: activity or input.

The total income per hectare was obtained by multiplying the crop yield by its market price. The algebraic expression is:

$$IT = PyY \tag{3}$$

where TI: total income ($ ha^{-1}); *Py*: market price of the crop ($ t^{-1}); Y: crop yield (t ha^{-1}).

Finally, the profitability is equal to:

$$\text{Rentabilidad} = IT - CT \tag{4}$$

where *TI*: total income ($ ha^{-1}); *TC*: total cost of production.

The producers who were interviewed belong to the amaranth-producing municipalities of Amecameca, Temamatla, Juchitepec, and Tepetlixpa, located in the State of Mexico (Figure 1), according to data found in (SIAP-SIACON, 2023). The geographic coordinates of the State are 23.6345° N 102.5528° W [Secretaría del Medio Ambiente del Estado de México (SMA), 2006].
To analyze the data, descriptive statistics were used, which are oriented toward the presentation of data that allows summarizing or describing their behavior (Posada, 2016). Descriptive statistics integrates methods to describe a data set; measures of central tendency and dispersion with ungrouped data

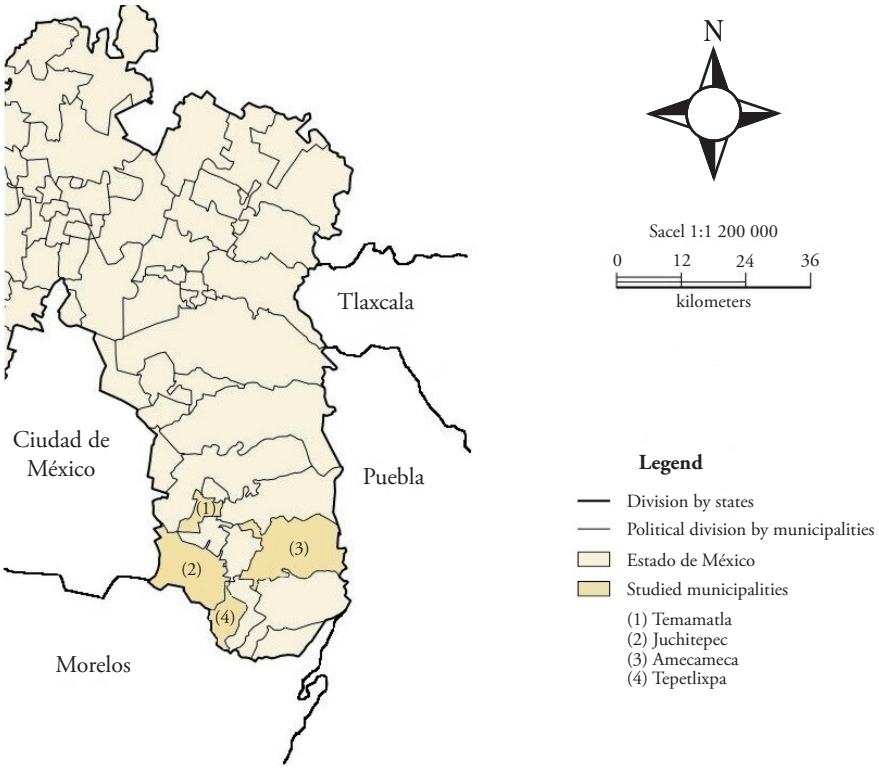


Figure 1. Map of the location of the study area.
Source: prepared by the authors with information from INDESOL (2016).

were used for this study, such as the arithmetic mean and range (Infante and Zárate, 1990).

RESULTS

Amaranth production in the State of Mexico

The growth of amaranth production at the state level is influenced by various factors, among which those that stand out are increases in harvested area, yield levels, or a combination of both (Venezian and Gamble, 1969). According to data from SIAP – SIACON (2023), corresponding to the period 1986-2022, yield per hectare in the State of Mexico has increased at an average annual growth rate (AAGR) of 3.2%, while total production grew at a rate of 27.7%. Fieldwork revealed a low adoption of innovations and technological packages by producers, reflected in slower yield growth compared to total production, as indicated by official figures.

By applying the factor decomposition methodology (Table 1), it is observed that the total increase in production for the same period is due in 67.4% to the

Table 1. Decomposition of growth factors in the period 1986.

	Contribution of the surface area	Contribution of yield	Combined effect of surface area and yield	Total production increase for the period 1986-2022
Value	75.66	41.75	242.985	360.395
%	21.0	11.6	67.4	100.0

Source: prepared by the authors with data obtained from SIAP-SIACON (2023).

combination and interaction between the increase in the area planted and the improvement in crop yields, 21% corresponds exclusively to the increase in the cultivated area, and the remaining 11.6% to the increase in yields.

Amaranth value chain in the State of Mexico

The map of the amaranth value chain in the State of Mexico was generated (Figure 2), which shows the actors, their functions, the support services, and their relationships in the product's flow from production to the final market.

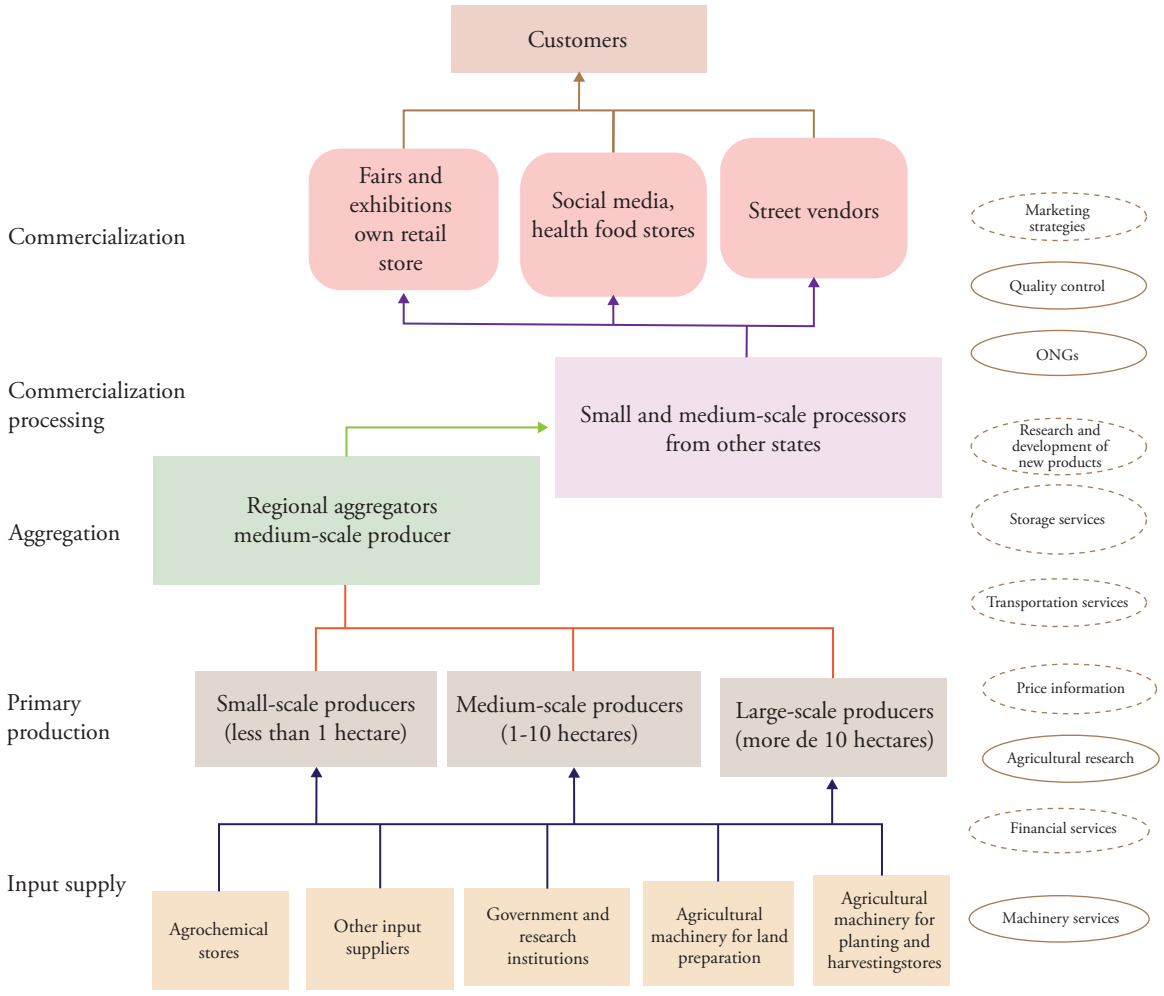
The amaranth value chain in the State of Mexico is made up of six links. The first is integrated by suppliers of agricultural inputs and equipment, such as agrochemical stores and some research institutions. The second is occupied by producers, and the third by collectors; the fourth link is made up of agroindustries. The fifth link comprises the marketing channels that bring the final product to the consumer. On the left side are all the stakeholders within the system. The sixth link is composed of consumers.

The main suppliers of inputs are agrochemical stores, which are sources of fertilizers, insecticides, and herbicides; their activity is limited to the sale of these products. Universities and research centers, such as INIFAP, are also in this link, which have worked on the development of new varieties. In addition, they offer technical support to 4% of the producers surveyed. These producers share the acquired knowledge with their peers through talks or informal meetings.

INIFAP has supported the development of equipment adaptations to mechanize the cultivation, for producers who generally have more than 10 hectares and have the financial means to purchase machinery or implements. Only 8% of producers have seeders and harvesters.

Amaranth producers

Since 2014, ties between amaranth producers have been identified as weak, according to Ayala *et al*. (2016), with the lack of associativity being one of the main problems this link faces. In 2023, 100% of the producers surveyed confirmed that they were not organized under a legal entity. However, small



Source: prepared by the amaranth value chain in 2023.
Figure 2. Map of the amaranth value chain in the State of Mexico.

informal groups of between 10 and 15 producers were found, which were interested in receiving information to improve their agricultural practices. Despite the lack of formal organization, producers encourage collaboration and create support and knowledge networks, although they do not show the commitment necessary to form a formal organization or society. It was mentioned that approximately 10 years ago, a group of 18 producers attempted to form a society, but failed to consolidate due to individual interests.

Two main groups were identified among producers: the first, interested in collaboration and willing to form an association; and the second, with less interest in the information received, suggesting a lack of critical analysis and lower commitment to collective organization. The Ministry of Agriculture

and Rural Development (*Secretaría de Agricultura y Desarrollo Rural*, SADER) promotes the creation of a Product System at the state and national levels. These systems are supported by the Official Gazette of the Federation (*Diario Oficial de la Federación*, DOF, 2001) through the Sustainable Rural Development Law, with the goal of improving the production, productivity, and profitability of key crops in different regions, as established in state programs and with the agreements of the national Product System.

At the national level, there is the Liaison Group for the Promotion of Mexican Amaranth, which includes stakeholders from Mexico City, Tlaxcala, Puebla, Oaxaca, and the State of Mexico. This group establishes dialogue roundtables, lasting no more than two months, with the goal of generating strategies to position amaranth as a strategic product and to improve its competitiveness in the value chain. However, participation in these events by the primary sector in the State of Mexico is limited.

Regarding grain collection, 40% of the producers sell to informal intermediaries, who are responsible for logistics, pricing, and determining the grain's quality. This role generates a bias in profit sharing, since a significant percentage of potential benefits are absorbed by these agents (Gaudin and Padilla, 2020). Only 4% of the producers surveyed are involved in grain collection and commercialization activities. This low participation suggests a limited capacity to exercise control over the marketing process and indicates a high dependence on markets in other states for the sale of their production. The lack of infrastructure and the limited access to direct marketing channels are factors that inhibit the participation of producers in these activities, negatively impacting crop profitability.

Amaranth grain is marketed in the State of Mexico in the traditional way, using 50-kg sacks and artisanal cleaning processes. It was found that 5% of the producers design their own cleaning machines, while others rent threshers. Processed products, such as popped amaranth or flour, are marketed by the same processors. The lack of innovation and technology in the initial processing prevents the sector from offering products of uniform quality and hampers its competitiveness in the market.

Agribusiness

Sixty percent of respondents reported selling their production to agroindustries located mostly in Tulyehualco, Mexico City, and Huazulco, Morelos. Horizontal relationships and ties were identified between producers and processors, some stronger than others. Between large producers and processors, there is support throughout the production cycle, as well as partial payment for production before planting. In the remaining relationships, the quality parameters that

amaranth grain must meet are only informally established; that is, there is no contract guaranteeing the producer that the grain is sold.

Due to the type of processing used in Mexico, 79.9% of products are produced from popped grains, 17.2% from flour, and 2.9% from extruded grains (Espitia *et al*., 2012). The main products consumed are "alegrías" (sweetened confectionery), churros, cereals, bars, cookies, etc. A medium-high percentage of residents of the State of Mexico do not consume amaranth, mainly due to a lack of awareness of its benefits and historical value. Some producers even confessed to not including amaranth in their diet until after learning about its nutraceutical properties. At the market level, 80% of those who buy amaranth are those who consume it, and the oldest consumers confess to buying amaranth primarily for the quality of the product, regardless of cost and presentation. Others mentioned that they consume amaranth products based on attributes such as flavor, price, or presentation. This information is important to guide communication efforts to generate a consumer culture.

No information was found regarding institutions that offer financing to agents within the different links. Eight percent of producers reported receiving financing from some agrobusinesses (producers with more than 10 hectares). They also mentioned not having access to credit, due to the very high cost of capital. No respondents were found to receive any benefits from the government, such as training in organic production, as offered in the states of Tlaxcala, Hidalgo, and Puebla, and they reported not receiving any financial support or fertilizers. This is because amaranth is not declared as a strategic crop, since it could mean the introduction of subsidies, incentives to improve agricultural practices, and greater integration into financing programs.

Regarding technical assistance and quality management services for medium- and small-scale producers, the fact that they do not receive direct technical assistance is a limitation. They also indicated that there are entities that offer technical assistance, because they are focused on producers of other crops. There is no legal entity that fully supports producers or the innovation of amaranth-based products. Twenty-five percent of producers reported having received some training from INIFAP staff, to implement activities that allow them to improve their crop production.

It was identified that there is no quality and safety homologation for the products; 65% of producers stated that they meet excellent standards of quality such as those established in the applicable Mexican standards: NMX-114-SCFI-2009 and NMX-116-SCFI-2010. In NMX 116, it was found that buyers determine the quality of the grain based on their knowledge, without considering the aforementioned NMX standards.

Business intelligence and logistics

New marketing strategies currently used to promote consumption and new products entering the market, or which are used by large industries through social media, campaigns with recognized brands, and blogs, are far from being implemented in the commercialization of amaranth products, or else are very limited. The marketing channels used include fairs, exhibits, local stores, health food stores, and social media (Instagram, Facebook). However, these lack product quality regulations.

No actors were identified that provide logistics and storage services exclusively for amaranth. Producers mentioned hiring informal logistics services to transport grains to marketing points. The lack of specialized services in the value chain reflects a significant gap in the market. Producers are forced to resort to less efficient solutions to move their product to market, resulting in higher costs and delivery delays. The absence of this link highlights the need to develop a solid infrastructure and service network to support this industry.

Long-time amaranth consumers mentioned including this food in their diet; 20% of the survey respondents stated that identifying the quality of popped amaranth grains with the naked eye is the main factor in purchasing the food. The rest mentioned purchasing an amaranth-based product depending on flavor, price, nutritional properties, and product presentation.

Consumers and non-consumers alike, upon mentioning amaranth, immediately associated it with the sweet confectionary called “alegría” (a bar of the grain with syrup or honey), which is therefore a product with a higher sugar content. The relevance of the “alegría” (meaning joy or cheerfulness) can be seen in the ways amaranth is promoted, since a fair called “The Greatest Joy in the World” is held in Mexico. Likewise, it is very common to find this type of product with vendors and street stalls. At the points of sale visited, it was found that the different forms of amaranth consumption are through sweets such as churros, cookies, breads, wafers, atoles, bars, palanqueta, calaveritas, etc. As of 2019, amaranth is considered part of the basic food basket as “amaranth candy”, given its popular consumption. It’s worth mentioning that the National Academy of Sciences (NAS) considers amaranth to be the most promising plant for combating world hunger.

It was found that there is no amaranth consumption culture that competes under the market price scheme set by the central supply center, where prices lower and shelf life is not regulated. At least 25% of non-consumers surveyed reported having some basic knowledge about the nutritional benefits of amaranth.

Economic profitability

Not all producers require land leasing; this fixed expense represented 14.3% per hectare for those who did. The predominant component of variable expenses was related to agrochemical inputs such as fertilizers, which constituted 37.4% of total costs in the conventional production model. For the case of producers that are undergoing a process of agroecological transition, these inputs were not included.

Labor represented an average of 30% of the total cost of the production cycle. It is important to note that its greatest demand was concentrated in agricultural tasks, such as applying fertilizers, insecticides and pesticides, weeding, and harvesting. Although few producers have adapted agricultural machinery for harvesting, there are still those who prefer to hire day laborers and perform the work manually. This activity requires an average of 15 days per hectare.

Table 2 shows that the average production cost per ton was MXN $15,682.74. The variability in amaranth production costs among producers is wide, and the costs per ton reported by the surveyed producers ranged from 10,690.00 to 20,340.00 pesos. It is important to note that that payment for consulting is not included in Table 2, since in the State of Mexico, producers mentioned not receiving advice from public or private institutions, which represents an expense for them. The average benefit/cost (B/C) ratio was 1.64, meaning that for each peso invested, 64 cents are earned; this indicates that it is profitable to

Table 2. Calculation of the benefit:cost ratio of amaranth cultivation in the State.

Activity	Average ($)
Land preparation, MXN $ (1)	4,184.00
Sowing (2)	2,495.00
Agricultural tasks, MXN $ (3)	5,525.00
Inputs, MXN $ (4)	8,263.90
Harvest, MXN $ (5)	7,446.00
Direct costs (6) = (1+2+3+4+5), MXN $ ha^{-1}	27,913.90
Land rental (7) MXN $ ha^{-1}	4,166.00
General expenses (8) MXN $ ha^{-1}	2,791.39
Opportunity cost (9)	2,453.63
Indirect costs (10) = (7 + 8 + 9) MXN $ ha^{-1}	9,411.02
Total cost (11)=10+6)	37,324.92
Yield, t ha^{-1} (12)	2.38
Price, MXN $ t^{-1} (13)	25,700.00
Income (14) = (12 × 13) per hectare, MXN $	61,166.00
Profit (15) = (14 – 11) per hectare, MXN $	23,841.08
Cost per ton (16) = (11 ÷ 12), MXN $ t^{-1}	15,682.74
Profit per ton (17) = (13 – 16), MXN $ t^{-1}	10,017.26
Benefit:cost ratio (18) = (13÷ 16), dimensionless	1.64

Source: prepared by the authors using survey data in 2023.

grow amaranth. However, it is important to note that not all producers obtain the same profitability; the interval for the B/C values is wide, from 1.16 to 1.96, which is a function of the techniques that were used during crop management and therefore influenced the yield.

The average yield of 2.38 tons per hectare (t ha^{-1}) is a measure that indicates the average amount of amaranth harvested per hectare of cultivated land. This can vary significantly between producers; the maximum was 3.5 t ha^{-1}, while the minimum yield was 1.5 t ha^{-1}. Ayala *et al.* (2016) mentioned that the technical problems faced by producers are factors that lead to the need to develop a technology transfer program and continuous training; this could detect the needs of the producer in order to improve productivity and yield, as well as minimize risks. This will allow them to have knowledge of the proper use of inputs, since an indiscriminate use is detected. To maximize yield, it is important to accompany with complementary technology and training (Akhter *et al.*, 2020), in addition to developing implements that allow cultural practices to be carried out efficiently.

DISCUSSION

The impact of primary production on the amaranth value chain has increased in recent years. According to Ayala *et al.* (2016), this growth is reflected in the expansion of improved seed varieties and the technical management of the crop in terms of density, nutrition, and health. However, the establishment of irrigation systems is still a limitation, along with the limited use of agricultural machinery. Thus, the lack of access to production technologies has hindered further progress in productivity.

Improvement in productivity depends on the adoption of technological innovations that are recommended based on the characteristics of the production areas (Estrada *et al*., 2006). Despite the growth in total production, there is low technological adoption and limited access to irrigation systems, which constitute key obstacles to increased productivity. According to Muñoz *et al*. (2007), multiple factors intervene in the adoption of technologies, but one of the most important is the participation of trained extension workers familiar with the innovations. The low increase in yields reflects the low adoption of technologies.

It was identified that the main sources of inputs are agrochemical stores. While they do not represent a limitation in terms of availability, their participation in the value chain is limited solely to product marketing, without offering additional services such as technical advice or training.

Institutions play a key role in the development of technology and technical support for amaranth cultivation; however, these efforts are not enough, since

amaranth cultivation in Mexico faces challenges due to a lack of technology, training, and economic and time constraints. It is important for these institutions to work together to obtain better results. Fujun *et al.* (2018) mention that China has made advances in mechanization and innovation thanks to cooperation between the government, industry, universities, and research centers. Studies such as the one by Kutsenko (2018) show that a multi-vector dissemination strategy strengthens the agricultural sector and turns it into an engine for national development.

The lack of association among producers and the limited integration into product systems were found to affect the sector's efficiency and competitiveness, limiting access to government support and development opportunities. The presence of small groups interested in receiving information indicates a potential basis for fostering organization, although a coordinated effort is required to consolidate it. The segmentation of producers suggests the need for differentiated strategies: strengthening the interest of the group willing to associate and generating incentives to involve those who show less interest. Furthermore, the limited participation of producers in the State of Mexico in national initiatives represents a barrier to the competitiveness of the sector in that region. The implementation of a Product System could be a key strategy to strengthen producers' organization and improve their integration into the value chain.

The amaranth market is increasingly wider, primarily due to the socioeconomic opportunities offered by the crop (Sánchez *et al.*, 2016). It is crucial for producers to acquire skills and resources that allow them to become integrated into other links of the value chain, increasing their autonomy and improving their capacity for negotiation. Dependence on intermediaries limits the producers' room for maneuver in price negotiations, reflecting an asymmetry in the distribution of power within the value chain.

Commercialization, especially on a small scale, leads to dependence on intermediaries, just as the lack of policies that regulate product traceability and a poor integration into the value chain. Sánchez *et al.* (2015) mention that the producer's income is affected mainly because the intermediary monopolizes the seed at low prices paid to producers, to later obtain a generous profit from the processors. This link does not have a regulated structure, nor policies that promote the organization of the actors within the chain, which hinders the access of products derived from amaranth to international markets. According to Ayala *et al*. (2014), the commercial link is one of the most vulnerable within the chain, so it is essential to promote its strengthening and to ensure a constant supply of raw material for the different markets.

The current situation places producers at a disadvantage compared to those who grow strategic crops, which can lead to a reduction in planted area and,

consequently, in their national production. This reflects a lack of integration of amaranth into national agricultural development policies, generating a limited financing structure, especially for small-scale producers. The absence of financial institutions willing to support this sector or of accessible financing programs fosters a situation of vulnerability. Although some agroindustries offer financing, this is focused only on large-scale producers, excluding small producers, who are less able to compete in a market characterized by its high dependence on investments in inputs and technology.

Studies are needed to identify potential customers, as well as their tastes and preferences, in order to find other market niches. Ayala *et al.* (2016) mentioned that the lack of detailed information on who the final consumers of amaranth are and how they behave in terms of preferences and purchasing habits, as well as the absence of solid marketing strategies, represent significant challenges for the successful commercialization of this product. Achieving the identification and a better understanding of consumers and developing effective marketing strategies are key aspects to foster amaranth consumption and maximize its market potential. It will be important to implement strategies that promote amaranth consumption, considering it a food and not a treat.

In recent years, there has been growing interest in promoting and increasing the consumption of this grain, both nationally and internationally, given its nutritional properties. This would be an opportunity to incorporate this species into the general population's diet, with the goal of exploiting its nutritional wealth: it is necessary to promote its consumption in grain form, to increase its demand.

According to Padilla and Oddone (2016), strengthening the value chain by overcoming the restrictions it faces is a greater contribution to the economic and social development of the territory in which it operates. This transformation can occur through better coordination between the actors in the chain, the incorporation of new productive and supportive actors, and the economic and social scaling of the links and the chain as a whole. Economic scaling, on the other hand, is understood as the transition towards activities of greater technological complexity, the improvement of products or services offered by the chain, or the more efficient manufacture of goods or provision of services (Padilla and Oddone, 2016).

Amaranth has everything it needs to be a staple crop in Mexico; however, support programs are needed to boost its production, processing, marketing, and promotion. Otherwise, this would extend the list of failed attempts to make the amaranth value chain a sustainable option in the Mexican agrifood sector (Ayala *et al.*, 2014).

CONCLUSIONS

In the amaranth value chain, ties between each of the links are weak, with commercialization being the weakest in the value chain. At the level of producer, the lack of organization among producers has prevented a consolidated legal entity from being established, making it difficult for them to obtain government support such as financing, training, consulting, and inputs to improve their productivity. The study reveals a low adoption of sustainable agricultural practices among the region's producers. Producers employ methods with a high environmental impact, such as excessive use of agrochemicals, lack of crop rotation, and inadequate soil management. The implementation of agricultural insurance, through public institutions or in collaboration with the private sector, provides producers with greater financial security and contributes to the sector's stability.

The collector assumes transportation costs that medium- and small-scale producers cannot afford. Furthermore, they determine the purchase price of amaranth, thereby reducing producers' profits. The ties between the primary and processing sectors are not homogeneous; some are closer than others, and more than 90% of the ties are commercial.

Although agribusiness plays an important role within the amaranth value chain, no agribusiness players were identified from the State of Mexico. Therefore, the greatest economic benefits accrue to other states. The creation of agribusinesses, to the extent possible, could benefit the people of the State of Mexico by creating job opportunities.

Given the low demand for amaranth products among residents of the State of Mexico, marketing channels are limited and poorly regulated. Prices for quality products compete with those offered through informal channels such as street vendors and central markets, where prices are often very low.

Although amaranth cultivation is profitable for the region, the value chain is poorly integrated to promote the economic and social development of rural communities, and to preserve an invaluable cultural and culinary treasure.

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