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SOCIOECONOMIC AND COMPETITIVE IMPORTANCE OF THE PRODUCTION CHAIN OF GARLIC (*Allium sativum*) IN ZACATECAS, MEXICO

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ABSTRACT

Zacatecas is the main garlic producing state in Mexico, so it is pertinent to locate the positioning of the production chain in the agricultural and livestock sector of the state, with the aim of suggesting strategies that foster its participation in the markets. The objective was to determine the socioeconomic and competitive importance of the garlic chain in the state of Zacatecas, to have information that supports the design of strategies and actions directed at maintaining or improving its positioning in the farming sector of the state. The methodology from the International Service for National Agricultural Research (ISNAR) was used to organize hierarchically the production chains in Zacatecas, based on weighted criteria, and to locate each chain in a quadrant of the strategic positioning matrix. The garlic production chain was placed in quadrant I, considering it as sustainable, so it has socioeconomic importance (0.05) and is competitive (2.93). To maintain this position, the actors who participate in the chain must work in agricultural practices that contribute to its positioning, with sustainability and adaptation to climate change. It is advisable to incentivize innovation and to generate new products, to take advantage of the attributes of garlic.

Key words: innovation, ISNAR, quadrant, positioning.

INTRODUCTION

Agriculture in Mexico is an activity that generates employment in rural and urban areas, contributes to economic growth, and to welfare in the population. The most important agricultural production chains in 2023, of annual and perennial cycle, were: grain corn (34.6%), grasses and grasslands (13.2%), grain sorghum (6.7%), bean (5.4%), sugarcane (4.2%), cherry coffee (3.4%), grain wheat (2.8%), green fodder corn (2.7%), green fodder oats (2.4%), and alfalfa (2.0%) (SIAP, 2024). The total agricultural surface was 32.5 million hectares, of which 21% were irrigated and 79% rainfed. Coria-Páez *et al.* (2023) mentioned that, under rainfed conditions, there is great heterogeneity of producers with higher levels of rurality and marginalization, reduced production scales, and without the capacity to gain access to inputs or capital goods, which results in precarious production conditions that prevent them from increasing their productivity; by contrast, in the irrigation production systems, the conditions of development are better.

Zacatecas is a state with important agricultural production; the crops which stand out in terms of production values are chili pepper, bean, corn, peach, grape, red tomato, and garlic (SIAP, 2024). However, it is also a state that faces numerous challenges associated with agriculture, as it is a predominantly arid and semiarid region with an average annual rainfall of 463 mm, indicating low availability and a greater dependency on underground water. Thus, from the volume allotted (1,467.1 hm^3), 90.5% is destined to agricultural activity (Comisión Nacional del Agua, 2013).

The state is characterized by being the main garlic (*Allium sativum* L.) producer in Mexico, with around 3,900 ha planted in the state. This represented 46.1% of the surface planted for 2023, and 55.5% of the national production (SIAP, 2024). Garlic is a common condiment of Mexican cuisine, and healing properties are attributed to it for cardiovascular diseases, antimicrobial, anti-inflammatory, and antiasthma activity (Bustamante *et al.,* 2022).

Garlic production represented in 2023 an economic spillover for the state of slightly over 1,000 million pesos (SIAP, 2024); there is, in addition to this, the amount of labor that is used for its planting, harvesting, and packaging. Although it is an important productive activity, it faces challenges such as insufficient adoption of technological innovations in the production part, impact from pests and diseases, agroclimatic adversities, and scarce added value that is given to the primary product (Sánchez-Toledano *et al.,* 2022). To face these problems, analysis is required that allows identifying the needs of the production chain and seeking solutions with the various actors that participate in it.

There are various studies related to the analysis of production chains and their strategic positioning in the agricultural dynamic, among them, the ones that stand out were performed by Tovar *et al.* (2018), González *et al.* (2022), and Sánchez-Toledano *et al.* (2022). Starting from estimating diverse indicators of socioeconomic importance and competitiveness, these studies identified and prioritized technological, training, and research needs, as well as diverse strategies to improve the sustainability of the chains.

Production chain analysis in the farming sector is important because it allows establishing strategies that contribute to an efficient management of economic, social, and environmental resources. Similarly, a balance in the research activities must be established, directed at productivity in close relation with nutritional quality and in the benefit of the consumer (Rincón *et al.,* 2004).

In the specific case of the garlic production chain in Zacatecas, analysis that allows for having real information is necessary to reinforce and direct the efforts towards technological innovation with high probabilities of economic, social, and environmental impact (Barrera-Perales *et al.,* 2021). Therefore, in this study, the objective was to determine the socioeconomic and competitive importance of the garlic chain in the state of Zacatecas, with the aim of having information that supports the design of strategies and actions directed at maintaining or improving its positioning in the state's farming sector. The hypothesis was that the garlic production chain is strategic for the state, given its socioeconomic importance and competitive situation.

THEORETICAL FRAMEWORK

A production chain is a system that brings together interrelated economic and social actors, which participate articulately in activities that add value to a good or service, from its production until it reaches the consumers. The actors involved are suppliers of inputs and services, transformation, industrialization, transport, logistics, and other support services, such as financing (García-Winder *et al.,* 2009).

Díaz *et al.* (2021) mentioned that analysis of agricultural production chains shows the relationships there are between their links and actors, contributing to the design of economic policies related to local development and food security. Therefore, to promote the growth of agricultural production chains, strengths and weaknesses must be identified, considering changes in the environment to adapt to new needs and requirements of the crops. This will allow sustainable, continuous production (Zaldívar *et al.,* 2021).

Analyzing the level of integration of agrifood chains in the agricultural and livestock sector will allow establishing strategies that contribute to an efficient management of economic, social, and environmental resources. This will allow a better design of policies and public actions for the agricultural sector, and of programs and interventions that should generate dynamic effects that improve the income, wellbeing, and quality of life in the rural sector (INEGI, 2019).

A methodology used for the analysis of agrifood chains is the International Service for National Agricultural Research (ISNAR) method, which is based on establishing the positioning of the chains, based on two dimensions of support: socioeconomic importance and competitiveness (Tovar *et al*., 2018). The dimension of socioeconomic importance is composed of the criteria of size, dynamism, and specialization; and the competitiveness dimension is integrated by productivity, sustainability, and commercial performance (Loeza-Deloya *et al.,* 2016).

In the dimension of socioeconomic importance, the condition of the social and economic situation of the chain is measured, defined by the contribution of this production activity to the generation of monetary resources and employment, and which is reflected in the welfare of society. On the other hand, competitiveness is considered the dynamic capacity that a spatially located agrifood chain has to maintain, expand, and improve its participation in the national and international market in a continuous and sustained way, through production, distribution, and sale of goods and services in the time, place, and way requested (Bustamente *et al.*, 2022).

METHODOLOGY

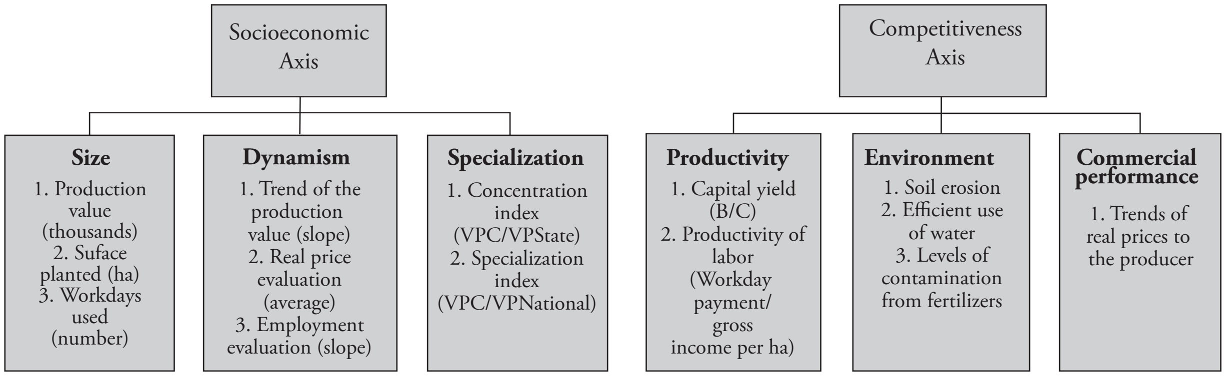
Zacatecas is a state found in the North-Center region of Mexico (Figure 1), and it produces an agricultural, livestock, and fishing volume of more than 7 million 556 thousand tons (SIAP, 2024). In addition, it contributes more than 61 thousand tons of garlic to its own consumption and of other states; the main producing municipalities are Villa de Cos, Calera, Pánuco, Fresnillo, and Guadalupe (SIAP, 2024).

Data collection instrument

The ISNAR methodology was used, which consists in organizing hierarchically the different production chains in the state of Zacatecas according to weighted criteria, so that the chains that are strategic for the state can be identified through a matrix (Rincón *et al.,* 2004). In this sense, there was an attempt to understand the position of the garlic chain. The methodology consists of two axes: a) socioeconomic relevance, where three criteria are analyzed to define whether it is a justifiable productive activity; and b) competitive relevance, which explains the capacity of the chains to face the challenges for change and their ability to adapt (Figure 2).

Figure 2 shows that each criterion is explained by indicators that are handled quantitatively. Integration of the information for different production chains in the state of Zacatecas covered the period of 2010-2023, indicated in the Agrifood and Fishing Information System (*Sistema de Información Agroalimentaria y Pesquera*, SIAP, 2024). A discussion group was formed (*n*=20) with producers and researchers from the National Institute of Forestry, Agriculture and

Source: prepared by the authors.
Figure 1. Location of the study zone.



Source: prepared by the authors.
Figure 2. Criteria and variables that make up the socioeconomic and competitiveness axes.

Livestock Research (*Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias*, INIFAP), from the Experimental Field in Zacatecas. This group had as objectives: 1) to define the agricultural chains of greatest importance for the state; and 2) to assign a weight to each of the indicators, according to their knowledge; the sum of weights should be 100 (the weights defined by the group are presented in Table 1).

Table 1 shows the various procedures used in the estimation of indicators, such as linear regression to estimate trends, averages, trend line measurements, production costs, and profitability analysis. Then, the indicators were weighed for each production chain defined by the discussion group. The result obtained was normalized to mean zero and standard deviation one, and a positioning matrix was generated with the two reference axes, to proceed to order the chains according to their relevance.

RESULTS

The discussion group selected the production chains that, in their opinion, ought to be evaluated in this study, according to previous knowledge about the technical part and their impact on society. Therefore, the chains evaluated were bean, garlic, green chili pepper, onion, red tomato, green tomato, lettuce, carrot, prickly pear, peach, grape, guava, apple, fodder oats, fodder corn, grain corn, and grain barley.

The analysis allowed defining the weighted criteria for the different chains for the different chains in the state of Zacatecas, considering their socioeconomic and competitive importance (Table 2).

The total weighted and standardized results of the different agricultural chains were defined in Table 3. Garlic cultivation in Zacatecas was positioned as the second most important agricultural chain in the state, after bean. Its importance

Table 1. Base information for the positioning of agricultural chains in the state of Zacatecas, Mexico.

		Axis 1: Socioeconomic importance			
Criterion	Score	Indicator	Argumentation	Weight	Procurement method and analysis
Size	0.3	Production value	The production value reported by SIAP (2024) was used.	5	Analysis of secondary sources (average).
		Surface occupied	Surface that the crop occupies in the state, according to SIAP (2024)	5	Analysis of secondary sources (average).
		Workdays used in the activity	It was estimated from the workdays required by hectare and then multiplied by the surface of each production chain.	5	Analysis of secondary sources and information from experts (average).
Dynamism	0.4	Trend of the production value	A simple linear regression was calculated for each chain, and the slope of the linear model was used as the value that represents the rate of change in prices.	6	Secondary sources and application of the linear regression model Y=a+b*Trend+e.
		Evolution of the real prices	The mean and standard deviation of the last ten years of production were calculated.	7	Analysis of secondary sources and measurements of linear tendency.
		Evolution of employment	A simple linear regression of employment was estimated, generated in the state by the production chain.	7	Information from secondary experts and application of the linear regression model Y=a+b*Trend+e.
Specialization	0.3	Concentration	It is the relation between the production value of the chain and the total production value of the chains in the state.	8	Secondary sources (VPC/VPE).
		Specialization index	It is the relation between the production value of the chain in the state and the total national production value of all the states in the country.	7	Secondary sources (VPE/VPN).

Table 1. Continuation.

Criterion	Score	EJE 2: Competitiveness Indicator	Argumentation	Weight	Procurement method and analysis
Productivity	0.3	Capital yield	Corresponds to the estimated index in terms of the benefit-cost rate.	7	Data on production costs and profitability analysis is measured.
		Productivity of the workforce	It is the rate between costs paid for workdays divided by the gross income per hectare.	8	Data on production costs and income is measured.
Environmental	0.35	Soil erosion	It was estimated from the universal equation of soil loss; in this case, the mean value of state erosion by chain was used.	9	Information from experts (average).
		Efficient use of water	Information on the values of consumptive use was used, estimated by sixteen researchers from the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). In this case, an inverse value was used to favor the chains that make a more efficient use of the resource.	9	Information from experts (average).
		Levels of contamination from the use of fertilizers	Researchers were consulted, who have worked in fertilization and have identified the mean values of nitrogenous fertilization. An inverse value was used to favor those of lower nitrogen use.	8	Information from experts (average).
Commercial performance	0.35	Commercial performance	The trend of real prices to the producer was used; the slope of a linear regression of the values of price was calculated and considered as the rate of change.	9	Secondary sources and linear regression Y=a+b*Trend+e.

Source: prepared by the authors.

Table 2. Weighted hierarchical organization matrix of the production chains in the state of Zacatecas, during the period 2010-2023.

Production chains	Socioeconomic importance			Competitiveness		
	Size	Dynamism	Specialization	Productivity	Sustainability	Commercial performance
Bean	4.01	3.44	2.66	1.04	1.22	1.61
Garlic	0.70	0.79	1.72	0.60	4.33	0.65
Green chili pepper	1.65	1.85	2.20	0.52	1.40	0.68
Onion	1.88	0.83	0.47	2.37	1.23	0.31
Prickly pear	0.89	2.04	1.14	1.95	0.39	0.18
Grain corn	1.49	1.41	0.85	0.45	1.65	0.53
Peach	0.48	0.9	0.92	0.97	1.54	1.03
Red tomato	0.84	0.76	0.61	1.56	1.68	0.3
Grape	0.57	0.88	0.43	0.69	1.62	0.97
Fodder corn	0.84	1.00	0.81	0.84	1.65	0.05
Green tomato	0.14	2.25	0.48	0.64	1.11	0.17
Fodder oats	0.75	0.82	0.66	0.91	1.06	0.08
Lettuce	0.14	0.9	0.64	0.62	1.29	0.53
Carrot	0.25	0.55	0.59	1.04	1.56	0.13
Guava	0.15	0.46	0.61	0.44	1.64	0.64
Apple	0.09	0.42	0.03	0.32	1.57	0.53
Grain barley	0.14	0.70	0.19	0.04	1.06	0.63

Source: prepared by the authors.

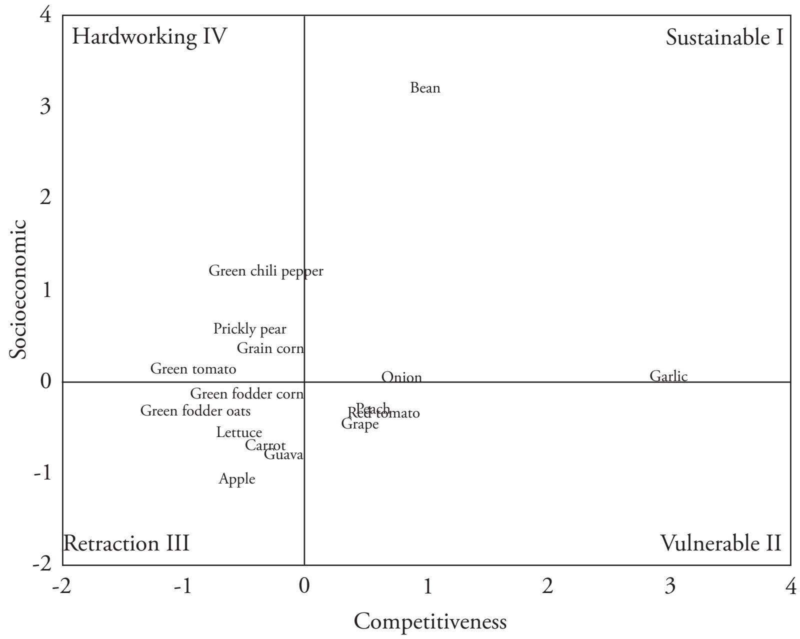
Table 3. Hierarchical organization matrix of the production chains for the period 2010-2023, Zacatecas, Mexico.

Production chains	Weighted socioeconomic	Weighted competitiveness	Total weighted summation	Order	Standardized socioeconomic	Standardized competitiveness
Bean	3.38	1.30	4.68	1.00	3.20	0.99
Garlic	1.04	1.92	2.96	2.00	0.05	2.93
Green chili pepper	1.89	0.88	2.78	3.00	1.20	-0.32
Onion	1.04	1.25	2.29	4.00	0.05	0.82
Prickly pear	1.43	0.79	2.21	5.00	0.57	-0.62
Grain corn	1.27	0.90	2.16	6.00	0.36	-0.27
Peach	0.78	1.19	1.97	7.00	-0.30	0.64
Red tomato	0.74	1.16	1.90	8.00	-0.35	0.55
Grape	0.65	1.12	1.76	9.00	-0.47	0.41
Green fodder corn	0.89	0.85	1.74	10.00	-0.14	-0.43
Green tomato	1.09	0.64	1.73	11.00	0.12	-1.07
Green fodder oats	0.75	0.67	1.42	12.00	-0.34	-0.99
Lettuce	0.59	0.82	1.41	13.00	-0.55	-0.51
Carrot	0.47	0.90	1.38	14.00	-0.71	-0.25
Guava	0.41	0.93	1.34	15.00	-0.79	-0.18
Apple	0.21	0.83	1.04	16.00	-1.07	-0.49

Source: Prepared by the authors.

lies in the surface planted and the workforce that it generates throughout its production and later, during its storage period. The cultivation cycle spans from the month of September to the end of May or beginning of June, to later continue with other cleaning tasks and classification in the storehouse. Direct and indirect jobs (≈309 thousand workdays annually) around the crop in Zacatecas highlight the importance and the search for opportunities to maintain or incentivize the productive activity of this crop. In addition, a large part of the cultivation cycle takes place in the winter season, that is, when there are few alternatives for employment in the rural sphere (Velázquez *et al.*, 2008).

The data presented in Table 3 allowed building a positioning graph with four quadrants, according to their socioeconomic and competitiveness relevance for the state of Zacatecas (Figure 3). Garlic cultivation was positioned as a sustainable chain; the positive sign in the socioeconomic axis responded to an increase in the surface established, which showed a mean annual growth of 6.2% during the 2010-2023 period (SIAP, 2024). In addition, for the same period, the yield also showed an increase with a mean annual growth of 2%. The greatest impact of this crop lies in the dynamism that translates into constant positive growth of the price and employment generated, as well as its contribution to the production value of this vegetable in the state. When



Source: prepared by the authors.
Figure 3. Positioning of the garlic chain against other production chains in the state of Zacatecas, Mexico.

it comes to competitiveness, the price was positive and, therefore, the capital yield as well. The use of technological innovations and new varieties in the state have allowed obtaining a harvest during the first week of April, 30 to 45 days before the normal harvesting period for the region of the Zacatecas high plateau. In a normal season, it is harvested from the third week of May to the second week of June in the high plateau region of Zacatecas and regions with similar soil-climate conditions. This has caused a market saturation with the resulting fall of the product's price, up to 50% of what was observed at the beginning of the harvesting period, due to excessive offer in the distribution centers (Sánchez-Toledano *et al.,* 2021; Reveles-Hernández *et al.,* 2012).

DISCUSSION

The garlic chain, together with onion and bean, was located as a chain of strategic importance for the state, both socioeconomic and competitive (Figure 3; Quadrant I). These product systems were positioned in a sustainable market, since there is constant demand. Specifically, in the garlic crop, it was corroborated with statistics from SIAP (2024) that the annual per capita consumption has increased until reaching 723 grams. Although the consumption has increased, the exports of this product have also increased, because Mexico was found as the ninth world exporter of this vegetable, where the main buyer was the United States with 86.8%, followed by Australia with 7.0%, and France with 2.3%. When it comes to imports, the main commercial origins of fresh or refrigerated garlic were Chile, Perú, Argentina, the United States, and China (FAO, 2022). The total commercial exchange of fresh or refrigerated garlic in Mexico (including international purchases and sales) was US$73.8M (Gobierno de México, 2024). In addition, there are other aspects that have had an influence on the better yield, such as the adoption of new varieties. In this regard, Sánchez-Toledano *et al.* (2021) mentioned that the adoption of new varieties is from farmers who, on average, are 55 years old and have known the improved seeds through INIFAP and have been continually trained; they have a planting extension of 21 hectares, each of which generates, on average 15 t ha^{-1}.

In the state of Zacatecas, diverse varieties of garlic have been generated, whose main distinctive characteristics are homogeneous growth and maturation of plants, cloves with more compact and homogeneous distribution than other varieties, which makes the bulbs heavier, as well as higher yield than other varieties established in the state of Zacatecas (Reveles-Hernández *et al.,* 2011). In addition, the new varieties that have excellent commercial characteristics, such as pink-violet coloring and 13 cloves per bulb on average, guarantee good acceptance in the market (Reveles *et al.,* 2017). Thus, the search for technological innovations has allowed strengths in the concentration and specialization levels, because there is a significant participation in the national sphere and a clear opportunity of positioning in the global market.

In recent years, the conventional management of vegetable production has been questioned by consumers who demand practices from producers that are environment-friendly, such as a decrease in the use of agrichemicals, the efficient use of irrigation water, and soil conservation, among others. This has forced the suggestion of sustainable production, as well as gradually adapting management to technologies that tend to improve the production quality of soils (Bonisoli *et al.,* 2024).

Sustainability in the garlic chain reflected an efficient management of soil, water, and pollution levels. In the production system, it is convenient to prepare a sowing bed that provides good development conditions, avoids erosion, and gives support from the start of cultivation. This will also favor uniform germination, which provides favorable conditions for root and bulb development, which at the same time eases conditions for good water drainage (El-Beltagi *et al.,* 2022). In addition, garlic has a low capacity to absorb soil nutrients because of a relatively undeveloped root system. Therefore, for an adequate development of the plant and high-quality production, an adequate and balanced supply of nutrients is necessary (Pączka *et al.,* 2021).

Drip irrigation offers advantages as a method of water application for garlic production (Barrios-Díaz *et al.,* 2006). Water is applied to the root zone of the plant through transmitters that control the same discharge in any place of the plot. Garlic is a bulb crop with superficial roots and is sensitive to the conditions of water stress, particularly during the initiation and bulb development. Therefore, efficient irrigation is necessary to improve bulb development (Gupta *et al.,* 2022). In addition to water, liquid fertilizers can be led to the place where it is needed. The drip irrigation systems help to distribute water and fertilizers in the plot with greater efficiency, which translates into higher yield, better bulb quality, and water saving (Mariani *et al.,* 2022).

Efficient and conscious use of agrichemicals, such as pesticides and synthetic fertilizers, to decrease environmental degradation is essential. Applying principles of ecology and agronomy, understanding agroecosystems, will promote lower degradation, improving rural production and reinforcing food sovereignty from and for the local scope (Wezel *et al.,* 2009).

Therefore, for the garlic production chain to continue in a sustainable state, it is necessary to promote the incorporation of these suggestions, as well as to analyze future research lines in the cultivation and strategies for the transference of appropriate technology, investment and counseling, linked to the fact that farmers do not always have the financial conditions to implement technological innovations in their plot.

In addition, the inclusion of technologies for the generation of new garlic-based products is key to increasing the socioeconomic and production importance in the primary link. Some studies point to the properties of garlic, among them the one by Regalado *et al.* (2023), where the antimicrobial and anti-inflammatory properties are highlighted as ideal to look after respiratory diseases. Likewise, it has bioactive compounds that help to reduce glucose, lipids, oxidative stress, and which favor the increase of insulin (Zaldivar-Ortega *et al.,* 2023). This places garlic as a vegetable with broad potential, to be used in the pharmaceutical industry, along with the importance it has as an ingredient in gastronomy and traditional medicine, to be used as functional and nutraceutical food.

CONCLUSIONS

The garlic production chain was found in a sustainable position due to its socioeconomic and competitive importance in the state of Zacatecas. The economic contribution to the production value and generation of paid employment fostered this position. However, it is necessary to continue transferring technologies to optimize the water resource, increase the yield, decrease pollution levels, address consumer preferences, improve bulb quality in post-harvest, and promote value chains of new products.

The generation of improved varieties of garlic in the region offers the opportunity to obtain high yields and quality, which will allow incorporation of it to the market under better conditions. It is important to continue making water consumption more efficient, as well as the rational use of agrichemicals, with the tendency to replace them for organic ones, to maintain their environmental relevance.

The studies, with emphasis on attaining socioeconomic development and reaching food sovereignty, must analyze the adaptation of the crop to climate change, the creation of innovative food systems, and the study of added value. The economic and social analysis, and the creation of an inter-institutional environment between research centers, universities, companies and direct producers, will provide strategies that benefit all the actors that are involved in the garlic agrifood chain.

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