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Article

MicMac strategic variables to reduce pollution in papaya cultivation in Cotaxtla

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Abstract

The municipality of Cotaxtla, Veracruz contributed 50% of the national papaya production, that is, 49 thousand tonnes per year. This production could decrease due to the presence of contaminants in the crops that inhibit the morphological and physiological development of the plant in addition to degrading soil and water. This research aimed to identify: 1) the factors of change involving new phenomena related to the cultivation of papaya (*Carica papaya* L.) and 2) the strategic variables that characterize the production system in the municipality of Cotaxtla, Veracruz The study was conducted from October 2023 to March 2024 in the municipality of Cotaxtla, Veracruz, and a foresight methodology was used, participatory workshops were held to explore the factors of change and identify the strategic variables that influence decision-making focused on reducing the risks of contamination of the product, soil, and water. The structural analysis or 'MicMac' method was used and 44 factors of change and five strategic variables of greater influence and dependence were identified. According to the logical syntax, through adequate training in the management of agrochemicals and their hazardous solid waste and the incorporation of good agricultural practices, the risks of contamination will be reduced, production will be increased, and quality and competitiveness in the market will improve. This knowledge allows us to design actions to reduce the risks of contamination in the papaya cultivation in the municipality of Cotaxtla, Veracruz.

Keywords:

Carica papaya L., collective reflection, hazardous solid waste, papaya producers.

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Introduction

Papaya (*Carica papaya* L.) is the third most consumed fruit in the world, hence its economic importance in the international market. It is produced in more than 60 countries, with the largest producers being India, Brazil, Indonesia, Nigeria, and Mexico (Valencia *et al*., 2017). The state of Veracruz contributes around 50% of the national production, of which the municipality of Cotaxtla contributes 49 000 t year^{-1} (SAGARPA, 2019). According to Vinay *et al*. (2024), this production could decrease due to the presence and toxicity of heavy metals in the cultivation water, such as cadmium (Cd) and chromium (Cr). These exceed the maximum permissible limits for consumption and irrigation and increase the risks and damage to the health of consumers and inhabitants of the municipality of Cotaxtla, Veracruz.

Agrochemical pollution has become a global environmental concern (Cajamarca *et al*., 2020). There are several factors that contribute to the increase in their use and the severity of their effects, derived from the excessive use of these products to control pests and diseases in crops (Ortíz *et al*., 2014). As the world's population grows, so does the demand for food, implying an increased use of agrochemicals in agricultural production.

A common practice among farmers is the burning of empty containers, which release toxic substances that pollute the soil and affect the quality of crops (Miranda *et al*., 2022). In addition, when these containers are buried, the residual chemicals leach into underground aquifers, polluting water intended for human consumption (FAO, 2021). This situation represents a serious risk to health and the environment.

As mentioned by Galaviz *et al*. (2011), the quality of the groundwater that supplies agricultural activities in the central area of the Gulf of Mexico is impacted by pollutants derived from the agronomic management of crops in concentrations that exceed the limits established by national and international regulations. This indicates that there is a risk for the inhabitants of the central area of the Gulf of Mexico, where the municipality of Cotaxtla is located, who use groundwater as their only source of drinking water supply.

In Mexico, according to some scientific reports, the use of around 186 highly hazardous pesticides has been identified, some of which have been banned in Europe due to their carcinogenic effects (ATSDR, 2024).

As indicated by SAGARPA (2013) data, around 50 million empty containers of pesticides were generated in Mexico, equivalent to approximately 6 020 t. Of which 85% are plastic, 14% metal, and only 1% paper. Unfortunately, several of these empty containers are discarded as common garbage without farmers using the appropriate protective equipment when handling them. This practice exposes farmers to inhaling or absorbing chemical residues, which can lead to serious long-term health problems.

According to the compendium of WHO and other UN guidelines on health and the environment, between 2000 and 2020, there were more than 1 000 chemical-related incidents globally, affecting more than 1.85 million people (CIED, 2018). It is estimated that, every year, 2 million people die due to one of the more than 200 foodborne diseases, from diarrhea to cancer, representing 25% of all existing pathologies (WHO, 2020). Faced with this problem, it becomes necessary to guarantee the food safety of consumers and the health of the producer when carrying out agricultural activity.

In this sense, there is a voluntarist current of thought based on identifying possible futures, choosing the most convenient one, and building it from the present. In other words, for foresight, the future is constructed by social actors from the present and occurs to the extent that it was prepared through precise actions (Mojica, 2010). This research aimed to identify the factors of change that involve new phenomena related to the cultivation of papaya (*Carica papaya* L.) and the strategic variables that characterize the production system in the municipality of Cotaxtla, Veracruz.

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Materials and methods

A foresight methodology was used, which is based on norms, values, or strategies that allow us to elucidate the process of building the future (Miklos and Tello, 2012). The main unit of analysis was the papaya (*Carica papaya* L.) cultivation in the municipality of Cotaxtla, Veracruz. The strategic foresight is of a mixed type (qualitative and quantitative) and was developed through the following workshops: 1) factors of change workshop: with the participation of 30 papaya producers, the critical points that allow recognizing the conditions of papaya (*Carica papaya* L.) cultivation were explored and 2) strategic variables workshop: classified according to the influence that some variables exert or receive on others, considering the network of relationships described by the MicMac structural analysis matrix, which consists of raising the structural analysis matrix to a power of successive values (Godet, 2007). This analysis was carried out in the following phases.

Stage 1. Identification of variables

This stage had the participation of 25 producers, who, through collective reflection, made a homogeneous list of internal and external variables that characterize the cultivation of papaya (*Carica papaya* L.), addressing the following question: what are the economic, technological, social, and environmental factors that condition the evolution of papaya cultivation in the municipality of Cotaxtla, Veracruz In this way, the product obtained was a list of factors that allowed establishing the difference between the internal and external variables, which are those that characterize the subsystem under study and those that constitute its context, respectively (Riquelme *et al*., 2019).

Stage 2. Description of the relationships between the variables

Structural analysis allows the relationships between variables to be identified through a two-entry table called a structural analysis matrix. The producers rated the matrix, the filling was qualitative. For each pair of variables, the following question is posed: is there a direct influence relationship between variable i and variable j? If the answer was negative, its value is 0, otherwise, when asked if this direct influence relationship is weak, a value of 1 is assigned; medium and strong, 2 and 3, respectively. This procedure not only makes it possible to avoid errors but also to order and classify ideas by creating a common language within the group of producers. In addition, it allows us, in most cases, to redefine certain variables and consequently refine the analysis of the system (Godet and Durance, 2011).

Stage 3. Identification of strategic variables

The structural analysis software of Matrice d' Impacts Croisés Multiplication Appliqués à un Classement (MicMac) was used, which is a matrix multiplication applied to a classification as a tool to organize collective reflection. This is obtained after raising the matrix to a power. The comparison of the hierarchy of variables in the different classifications (direct, indirect, and potential) is a process that allows us to confirm the importance of certain variables and reveals others, which, due to their indirect actions, did not manifest themselves in the direct classification.

In the interpretation of structural analysis, two concepts converge: mobility and dependence. Mobility is the impact that one variable has on others. Dependence is defined as the subordination of one variable with respect to the others. The results in terms of influence and dependence of each variable are represented on a Cartesian plane, in which the abscissa axis corresponds to dependence and the ordinate axis to mobility and influence. This made it possible to determine the most influential and the most dependent factors. The strategic or key variables are, finally, those that contain the highest scores of influences and dependence.

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Results and discussion

Identification of variables

Expert producers in the cultivation of papaya (*Carica papaya* L.) with decision-making capacity in the municipality of Cotaxtla, Veracruz, chose 44 factors of change divided into four dimensions (Table 1, 2, 3, 4 and 5).

Table 1. Factors of change in the economic dimension.

Economic phenomena					
1	Competitiveness (quality and prices)	6	Selling (intermediaries)	11	Cultivated varieties
2	Destination market of production	7	Transportation costs	12	Input price (agrochemicals)
3	Production (yield tonne/ha)	8	Sale price	13	Seed origin
4	Production costs in (the field)	9	Own land or rented land	14	Technical advice (they request or receive)
5	Diversification (sales byproducts)	10	Subsidies for production	15	Training
				16	Machinery

Table 2. Factors of change in the social dimension.

Social phenomena					
17	Schooling (basic, high school, higher)	20	Social responsibility (agrochemical marketers)	24	Lack of fieldwork personnel
18	Environmental culture	21	Gender equity	25	Social media advertising campaigns
19	Social wellbeing (generated by agricultural activity)	22	Migration	26	Producer association
		23	Age of the producer		

Table 3. Factors of change in the environmental dimension.

Environmental phenomena					
27	Climate change	31	Source of supply of water for human consumption	35	Analysis of water from purifying plants
28	Soil degradation	32	Irrigation water management	36	Soil and water analysis
29	Organic agriculture	33	Use of good agricultural practices (GAPs)	37	Collection centers
30	Soil, water, and air pollution	34	Hazardous waste management (agrochemical containers)		

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Table 4. Factors of change in the technological dimension.

Technological phenomena							
38	R + D + I +TT	40	Equipment for the application of agrochemicals	42	Emerging technologies	44	Research infrastructure (experimental field)
39	Communication routes	41	Precision agriculture	43	Technology adoption		

The collective reflection carried out by the producers through the prioritization of the factors of change, considering the efficiency, profitability, and sustainability of production, resulted in the 25 most relevant and important strategic variables that condition the future of the crop, along with the abbreviation used in the matrix for their analysis (Table 5). These represent the social, economic, environmental, and technological phenomena of the papaya (*Carica papaya* L.) cultivation environment in the municipality of Cotaxtla, Veracruz

Table 5. Most relevant and important variables of papaya (*Carica papaya* L.) crops in Cotaxtla, Veracruz, with their abbreviation used in the matrix.

Factors of change		Abbreviature	Factors of change		Abbreviature
1	Competitiveness	Competenci	14	Seed origin	Orig-Semil
2	Training	Capacitación	15	Organic agriculture	Agric-Orga
3	Climatic change	Camb-Clima	16	Irrigation water management	Manj-Aguri
4	Soil degradation	Degr-Suelo	17	Good agricultural practices	B-P-A
5	Pollution	Contaminac	18	Destination market	Merc-Dest
6	Hazardous waste management	MAN-REC-PE	19	Input price	Prec-Insu
7	Equipment for agrochemicals	Equiagrqui	20	Technical advice	Ases-Tecni
8	Precision agriculture	Agric-Prec	21	Gender equity	Equi-Gener
9	Subsidies for production	Subs-Produ	22	Migration	Migración
10	Sale price	Prec-Venta	23	R+D+I+T+T	I+D
11	Environmental culture	Cult-Ambie	24	Communication routes	(Vias-Comun)
12	Production	Producción	25	Selling	Comerciali
13	Production costs	Cost-Prod			

Description of the relationships between the variables

A double-entry matrix was obtained, which shows the ratings assigned by the producers under the criterion of the question: Is there a direct influence relationship between variable i and variable j? (Figure 1).

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Figure 1. Matrix of ratings assigned by producers for factors of change. Values: negative responses (0), direct influence: weak (1); medium (2); and strong (3).

	1 : COMPETENCI	2 : CAPACITACI	3 : CAMB-CLIMA	4 : DEGR-SUELO	5 : CONTAMINAC	6 : MAN-REC-PE	7 : EQUIAGRQUI	8 : AGRIC-PREC	9 : SUBS-PRODU	10 : PREC-VENTA	11 : CULT-AMBIE	12 : PRODUCCIÓN	13 : COST-PROD	14 : ORIG-SEMIL	15 : AGRIC-ORGA	16 : MANJ-AGURI	17 : B-P-A	18 : MERC-DEST	19 : PREC-INSU	20 : ASES-TECNI	21 : EQUI-GENER	22 : MIGRACIÓN	23 : I+D+I+TT	24 : VIAS-COMUN	25 : COMERZIALI
1 : COMPETENCI	0	3	2	3	3	3	2	3	3	3	2	3	3	3	3	3	3	2	3	3	1	1	2	3	3
2 : CAPACITACI	3	0	2	3	3	2	3	3	3	2	3	3	3	2	3	2	3	1	3	3	2	1	2	2	2
3 : CAMB-CLIMA	2	2	0	3	2	3	1	2	1	2	3	3	1	1	3	2	3	1	1	2	1	1	3	2	2
4 : DEGR-SUELO	3	3	3	0	3	3	1	2	2	2	3	3	2	2	2	2	2	0	1	3	1	1	2	1	1
5 : CONTAMINAC	3	3	2	3	0	3	2	2	2	2	3	2	2	1	2	2	2	1	2	3	1	1	3	2	1
6 : MAN-REC-PE	3	2	3	3	3	0	3	3	2	2	3	1	2	2	3	2	3	1	1	3	0	0	2	1	1
7 : EQUIAGRQUI	2	3	1	1	2	3	0	2	2	2	2	2	2	2	1	2	3	1	2	3	1	0	3	1	1
8 : AGRIC-PREC	3	3	2	2	2	3	2	0	2	1	2	2	2	3	3	2	2	2	2	2	1	0	3	3	2
9 : SUBS-PRODU	3	3	1	2	2	2	2	2	0	1	2	2	2	2	2	2	2	1	2	2	0	1	2	1	2
10 : PREC-VENTA	3	2	2	2	2	2	2	1	1	0	1	2	3	3	2	2	2	2	3	2	0	1	2	2	3
11 : CULT-AMBIE	2	3	3	3	3	3	2	2	2	1	0	2	1	2	3	3	2	2	1	2	1	1	2	1	1
12 : PRODUCCIÓN	3	3	3	3	2	1	2	2	2	2	2	0	3	2	3	2	3	2	3	2	1	1	2	2	3
13 : COST-PROD	3	3	1	2	2	2	2	2	2	3	1	3	0	2	1	2	2	3	3	3	0	1	2	2	2
14 : ORIG-SEMIL	3	2	1	2	1	2	2	3	2	3	2	2	2	0	3	2	2	2	2	2	1	1	3	2	3
15 : AGRIC-ORGA	3	3	3	2	2	3	1	3	2	2	3	3	1	3	0	2	2	2	2	2	1	1	2	2	2
16 : MANJ-AGURI	3	2	2	2	2	2	2	2	2	2	3	2	2	2	2	0	3	1	1	2	1	1	2	2	1
17 : B-P-A	3	3	3	2	2	3	3	2	2	2	2	3	2	2	2	3	0	2	2	2	0	1	2	2	2
18 : MERC-DEST	2	1	1	0	1	1	1	2	1	2	2	2	3	2	2	1	2	0	2	2	1	0	2	2	2
19 : PREC-INSU	3	3	1	1	2	1	2	2	2	3	1	3	3	2	2	1	2	2	0	2	0	0	2	2	2
20 : ASES-TECNI	3	3	2	3	3	3	3	2	2	2	2	2	3	2	2	2	2	2	2	0	1	1	1	2	1
21 : EQUI-GENER	1	2	1	1	1	0	1	1	0	0	1	1	0	1	1	1	0	1	0	1	0	1	1	1	1
22 : MIGRACIÓN	1	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	0	2	2	1
23 : I+D+I+TT	2	2	3	2	3	2	3	3	2	2	2	2	2	3	2	2	2	2	2	1	1	2	0	2	2
24 : VIAS-COMUN	3	2	2	1	2	1	1	3	1	2	1	2	2	2	2	2	2	2	2	2	1	2	2	0	2
25 : COMERZIALI	3	2	2	1	1	1	1	2	2	3	1	3	2	3	2	1	2	2	2	1	1	1	2	2	0

The filling of the matrix in general is qualitative, but it can be quantified. Based on the question, is there a direct influence relationship between variable i and variable j? and its possible weightings, five teams were integrated, and each one rated its structural analysis matrix; finally, an average and a final score were obtained, the values of which range from 0 to 3 (Figure 1). In this way, several intensities of direct relationships are distinguished: none (0), weak (1), medium (2) and strong (3).

In classical compliance, these intensities are recorded respectively by their respective values. In this way, a certain dynamic is introduced into the structural analysis and in turn, the sensitivity of some results is contrasted according to the intensity of the relationships considered (Echeverri, 2021).

Identification of strategic variables

Based on the score of the 25 factors of change in the double-entry matrix (Figure 1), the MicMac software was used for structural analysis through a direct and indirect classification of the variables, called the cross-impact matrix, which is obtained after raising its power by comparing the hierarchy of the variables by order of mobility and influence and by order of dependence (Sánchez *et al*., 2021).

The objective of the MicMac method is to identify the most influential and dependent variables (Figure 2) of the object of study. It is understood that the mobility and influential variables are those whose evolution significantly conditions the crop, so much so that the dependent variables are the most sensitive to its evolution (Menni *et al*., 2021).

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Figure 2⇩ Plane of influence-dependence for choosing strategic variables.

In this case, the matrix classifications in this structural analysis clearly indicate the importance of some variables, called 'strategic' (phenomena that are modified by virtue of others), with greater mobility and high dependence, a Pareto of 20% of the 25 initial variables was selected and five strategic variables were obtained (Figure 3) to carry out the exploration of the future of papaya (*Carica papaya* L.) cultivation in the municipality of Cotaxtla, Veracruz, which are: competitiveness, pollution, training, production and good agricultural practices.

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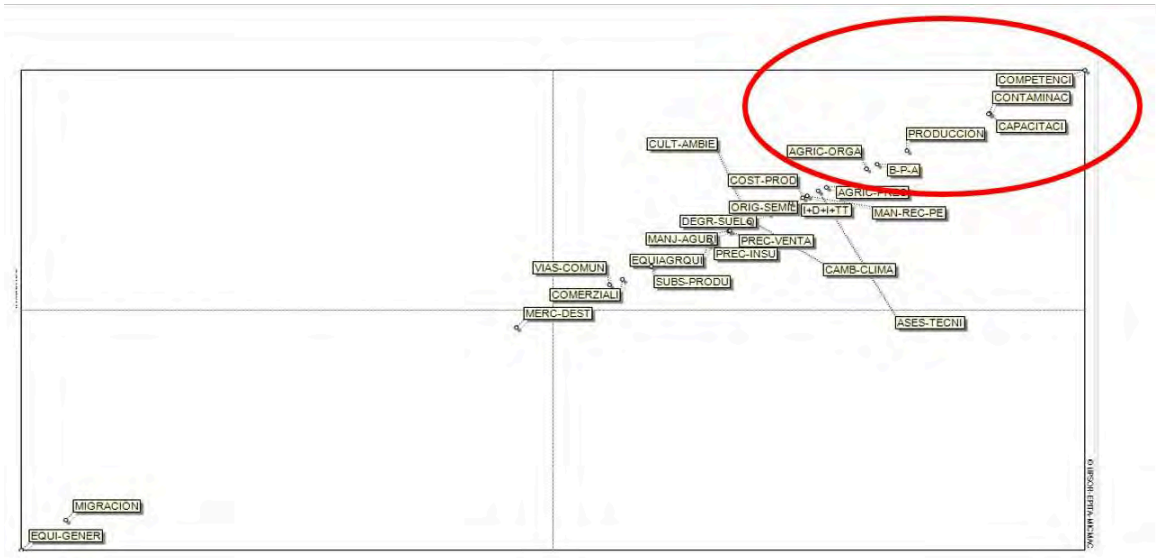
Figure 3. Results of the MicMac analysis in the identification of the strategic variables of papaya (*Carica papaya* L.) cultivation in the municipality of Cotaxtla, Veracruz



These variables exert dependence and influence on others, such as precision agriculture, incorporation of emerging technologies, seed origin, and sale price. According to Hernández and Hurtado (2020), internal variables characterize the system under study, in this case, pollution, production costs, soil degradation, environmental culture, seed origin, and production. As stated by Bernal and Díaz (2020), a positive perception of training can lead to a greater implementation of good agricultural practices (GAPs), which contributed to minimizing the use of agrochemicals and thus reducing soil and water pollution.

According to González (2022), those producers who recognize the importance of GAPs tend to be more proactive in their adoption, which not only improves crop quality but also protects the environment, motivating farmers to invest in more sustainable farming methods. Pollution is a concern that can be perceived in different ways by producers. If farmers consider pollution to be a significant risk to their health and that of their communities, they are more likely to seek alternatives to mitigate this problem. As Inquilla and Mamani (2024) mention, this perception can drive the implementation of practices that reduce pollution, such as the responsible use of agrochemicals and proper waste management. If farmers believe they can improve their production and competitiveness through sustainable and responsible practices, they will be more motivated to implement changes that benefit both their production and the environment.

On the other hand, the external variables are those that constitute its context, such as competition, training, emerging technologies, sale price, selling, climate change, and protective equipment for the application of agrochemicals, in the municipality of Cotaxtla, Veracruz External variables exert greater influence and offer a greater explanation (main determinants of the system); on the other hand, internal variables are the most sensitive to that context.

Contextual variables that do not seem to influence the system studied may be set aside (Ochoa, 2023), in this case, migration, gender equity, communication routes, and destination market. The strategic variables identified deserve to be read in a systemic context made up of themselves, Figure 4, according to the interrelationships of cause and effect, with the aim of respecting the principles of contextuality and complexity on which strategic foresight rests (Villegas, 2021). That is, with more training in the management of agrochemicals (proper disposal of empty containers or hazardous waste) and the application of good agricultural practices, a more competitive pollutant-free production will be maintained or increased in the market.

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Figure 4. Logical syntax of strategic variables.

Conclusions

The perception of producers plays a crucial role in the establishment of strategic variables that impact the cultivation of papaya (*Carica papaya* L.) in the municipality of Cotaxtla, Veracruz. This perception influences how farmers interpret and respond to the challenges and opportunities faced by their crops, which in turn affects decision-making that can reduce pollution risks in the agroecosystem.

The structural analysis identified five strategic variables that define the exploration of the future of papaya (*Carica papaya* L.) cultivation in the municipality of Cotaxtla, Veracruz, which are training, good agricultural practices (GAPs), pollution, production, and competitiveness. They, in their logical order, establish that with more training in the management of agrochemicals (proper disposal of empty containers or hazardous waste) and the application of good agricultural practices, more competitive pollutant-free production will be maintained or increased in the market. Of these variables, training is fundamental in the development of sustainable agriculture since producers who value continuous training are more willing to adopt new techniques and technologies that promote sustainable practices.

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