A Maize Production Model Using Structural Equation Modeling in Chicontepec, Veracruz, Mexico

Modelo de producción de maíz con ecuaciones estructurales en Chicontepec Veracruz, México

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Key words: transplanting, flowering, fruiting, stages, physiology.

Abstract: This article models corn production in Chicontepec, Veracruz, using structural equation modeling, based on the factors identified in the literature review, which are: organization, yield, support policies, production costs, climatic conditions, and marketing. The objective was to validate, using SPSS software, 324 questionnaires completed by corn producers. Additionally, confirmatory factor analysis was performed using the scientific software LISREL for analysis and modeling with structural equation modeling (SEM), in accordance with (Littlewood & Bernal, 2014) . Its originality lies in the fact that, after obtaining the results of the field study, the variables were validated in the LISREL software using statistical techniques—confirmatory factor analysis and structural equation modeling—to obtain the final model. The method used was the hypothetical-deductive and descriptive approach. The relevant findings are that, of the six independent variables studied, two were validated: yield and production. The variables support policies, production costs, climatic conditions, marketing, and organization do not explain the dependent variable, production. Two possible scenarios are conceived: that the production variable is explained solely by the yield variable because it is a multidimensional variable, or that the other variables need to be redesigned. Among the limitations of the research, the field research process was not easy, as it was difficult to obtain information from producers due to the mistrust generated by the political climate.

Keywords: Lisrel, structural equations, confirmatory factor analysis

Resumen: En este artículo se modela la producción de maíz en Chicontepec Veracruz con ecuaciones estructurales, a través de los factores que incidieron en el análisis de la literatura las cuales son: Organización, rendimiento, políticas de apoyo, costos de producción condiciones climáticos, y comercialización. El objetivo consistió en validar a través el software SPSS, 324 test contestados por los productores de maíz, así mismo se realizó el análisis factorial confirmatorio con el software científico LISREL para el análisis y modelación con ecuaciones estructurales o structural ecuation modeling (SEM), de acuerdo con (Littlewood & Bernal, 2014). Su originalidad radica en que después de obtener los resultados del estudio de campo se sometió a la validación de las variables en el software Lisrel con las técnicas estadísticas; análisis factorial confirmatorio y ecuaciones estructurales para obtener el modelo final. El método que se utilizó fue el enfoque hipotético deductivo y descriptivo. Los resultados de relevancia de hallazgos encontrados, es que de las seis variables independientes estudiadas, se validaron dos, rendimiento y producción, las variables; políticas de apoyo, costos de producción, condiciones climáticas, comercialización y organización no explican a la variable dependiente producción se concibe dos posibles situaciones; que la variable producción sea solamente explicada por la variable rendimiento debido a que es una variable que toma muchas dimensiones o que las demás variables requieran ser rediseñadas. Dentro de las limitaciones de la investigación el proceso de investigación de campo, no fue fácil obtener información de los productores dada a la desconfianza generada por ambientes políticos.

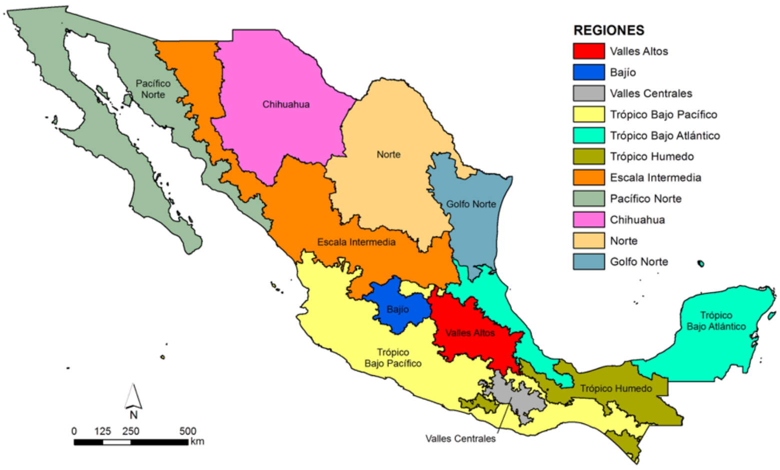
Palabras clave: Lisrel, ecuaciones estructurales, factorial confirmatorio

Introduction

Corn cultivation in Mexico takes place in diverse geographical contexts—altitude, latitude, climatic conditions, temperature, humidity, and soil type—ranging from traditional farming practices to the use of production technologies in some states.

Based on the above description, these are classified into 11 regions corresponding to relatively homogeneous geographic areas in terms of the climatic, agroecological, and socioeconomic factors that influence maize production in Mexico (Donnet, 2012).

Figure 1. Corn-growing regions in Mexico.



Source: The market potential of improved maize seeds in Mexico (CIMMYT 2012) cited by Donnet, et al. (2012).

Figure 1.5 shows a map of the United Mexican States, illustrating the maize-growing regions, which are divided into eleven regions: Valles Altos comprises the states of Tlaxcala, Hidalgo, San Luis Potosí, and Puebla; Bajío comprises the states of Guanajuato and Querétaro; Central Valleys comprises the states of Northern Oaxaca, Northern Guerrero, Puebla, Southern , Tlaxcala, Mexico City, Morelos, and the State of Mexico; Lower Pacific Tropics comprises Guerrero, Jalisco, and Michoacán; the Lower Atlantic Tropics include the states of Yucatán, Quintana Roo, central Campeche, and northern Veracruz; the Humid Tropics include the states of Chiapas, Tabasco, northern Oaxaca, and southern Puebla; Intermediate Zone includes the states of Zacatecas, Durango, Aguas Calientes, San Luis Potosí, and Northeast Sonora; North Pacific includes Northwest Sonora, Sinaloa, Baja California Norte, and Baja California Sur; Chihuahua includes the state of Chihuahua, northern Coahuila, northern Tamaulipas, and northern Nuevo León; the Northern Gulf region includes the states of Tamaulipas and Nuevo León.

Corn production in the state of Veracruz, Mexico, is concentrated in approximately 20 municipalities. Likewise, the 10 municipalities with the highest production over the last five years are: Papantla, San Andrés

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Tuxtla, Minatitlán, Soteapan, Las Choapas, Hueyapan de Ocampo, Álamo Temapache, Texistepec, Perote, and Tierra Blanca.

In Mexico, corn has been part of the daily diet since ancient times. Understanding corn production in different regions could facilitate decision-making at the local, regional, and national levels to increase or ensure the necessary yield results, as is done in other countries. This research aims to model the variables that influence corn production in the municipality of Chicontepec, Veracruz.

Although the municipality of Chicontepec is not among the top 10, it is a major corn producer and has significant potential. It would be of utmost importance to develop projects at all three levels of government to revitalize corn production and support farmers' livelihoods.

According to Rodríguez (2012), the state of Veracruz, with a population of 7.6 million, consumes approximately 1.2 million tons of corn.

Veracruz accounts for 5.7% of Mexico's total corn production. Additionally, it is noted that in some areas there are two types of corn production: the commercial system and the subsistence system; the former is market-oriented, as production aims for the intensive use of resources to benefit producers, while the latter is based essentially on the intensive use of family labor, as is the case in the municipality of Chicontepec, Veracruz (Agriculture in Mexico, 2015) .

Corn varieties in Veracruz: Tuxpeño, Celaya, Cónico, Cónico Norteño, Chalqueño, Elotes Cónicos, Elotes Occidentales, Olotillo, Bolita, Dzit-Bacal, Nal-Tel, Pepitilla, Mushito, Cacahuacintle, Palomero, Tepecintle, Arrocillo Amarillo, Olotón, Coscomatepec (Serratos, 2009).

In a survey conducted in the state of Veracruz in the so-called Priority Attention Zones of the Center for Studies on Sustainable Rural Development and Food Sovereignty (CEDRSSA) of the Chamber of Deputies; Mexico City, they found localities where 75.9% of the population lived in poverty and 25.5% in extreme poverty; within these, there are 94.8 million corn producers who produce 610,200 tons of corn with a yield of 2.24 tons per hectare and 53.7% of production for subsistence consumption; human consumption of corn in these 43 ZAP municipalities is estimated at 214,300 tons (CEDRSSA, 2020)

The three main corn-producing municipalities in the state of Veracruz, which remained among the top three during the Spring–Summer and Fall–Winter 2019 cycle in the category of irrigated and rain-fed grain corn, are as follows: San Andrés Tuxtla, Papantla, and Soteapan;

however, there are 17 out of 212 municipalities in the state of Veracruz that are dedicated to and contribute significantly to corn production; among this group is the municipality of Chicontepec de Adalberto Tejeda.

Veracruz is ranked as one of the states with the greatest potential to excel in the agricultural, livestock, forestry, and fishing sectors, accounting for 96.29% of the production value in these sectors.

However, it faces significant challenges due to its structural characteristics, including inefficient marketing systems, difficulties in accessing government resources, and potential misuse of those resources. These issues result in products with no added value, low yields, narrow profit margins, and consequently, low income levels.

Perhaps the opportunities for developing the rural sector include, among others, leveraging the capacity and diversity of existing natural resources, surpluses of primary production, available human potential, water resources in a sustainable manner, and the robust education and research system throughout the state.

In the state of Tlaxcala, Lazos (2014) notes that the annual harvest ranges between 100,000 and 120,000 hectares. It is confirmed that yields were previously higher; the decline was due to a lack of credit, low corn prices, and the high frequency of natural disasters, hectares.

In the study "Analysis of Corn Production Costs in the Bajío Region of Guanajuato" by Guzmán, De la Garza, González, & Hernández (2014), the authors break down and analyze corn production costs for a spring-summer production cycle using three technologies: rainfed, irrigated with livestock, and irrigated without livestock. the results show that, among marketable inputs, fertilization represented the highest cost for the producer; it accounted for 75% of total costs per hectare under the two contexts in which the three technologies were analyzed, both excluding and including the planted area.

(Barajas, Vazquez, Sapien, & Gutierrez, 2015) Given that the price of corn grain has been falling every year, this led corn producers in the municipality of Papantla, in northern Veracruz State, to begin considering the sale of corn leaves as an additional source of income alongside the sale of corn grain. The model includes facilities for bleaching with the aim of adding value for export so that the product can compete. At the macro level, the following is recommended:

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equitable distribution of resources between the north and south of the country across various programs.

In 2018, Mexico had a total consumption of 44.1 billion tons; in 2019, it increased to 44.5 billion tons, an increase of 400,000 tons; currently, Veracruz contributes 5% of the country's corn production (Agency for Agricultural Marketing Services and Market Development, 2020) .

Table 1.1 explains the factors or variables identified in the literature review for this study.

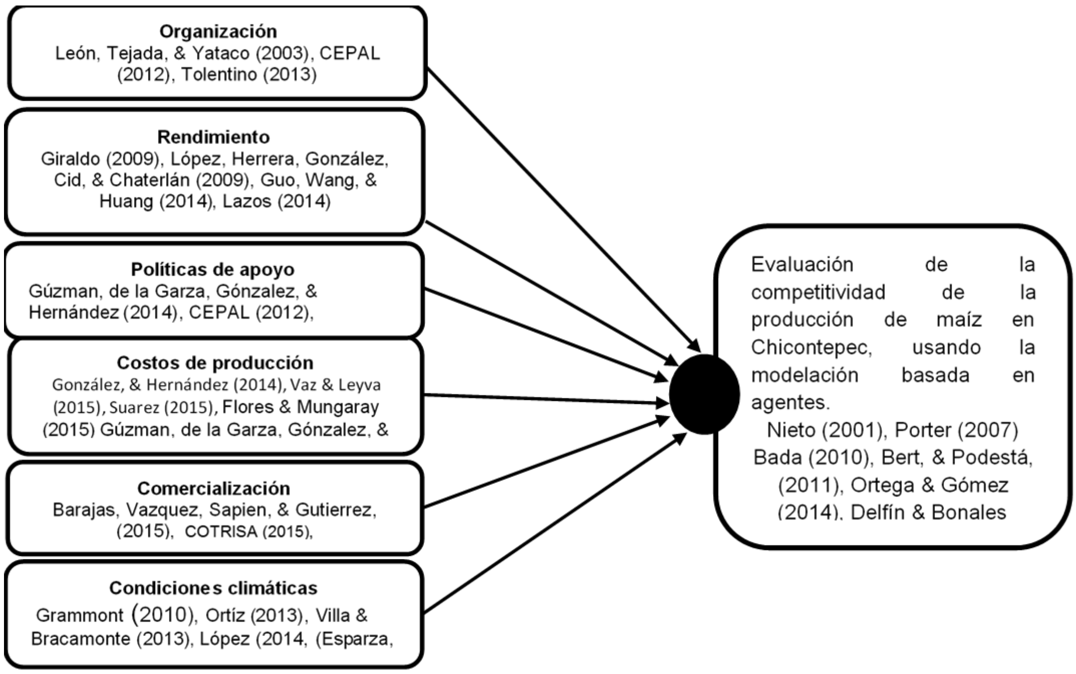
Table 1. *Variables in the corn production process.*

Varia ble	**Empirically Verified Findings**
Organ izatio n	This is the amount of corn grain per hectare produced by a region based on the variety or type Veracruz: Tuxpeño, Celaya, Cónico, Cónico Norteño, Chalqueño, Elotes Cónicos, Elotes Occider Palomero, Tepecintle, Arrocillo Amarillo, Olotón, Coscomatepec
Yield	This refers to the corn production process, which may rely on technologies such as rain-fed farmi there are six programs supporting agricultural activity; one of them is the irrigation modernizatio to SAGARPA (2016).
Suppo rt Polici es	These are the laws that regulate and require different levels of government to implement program
Produ ction Costs	Production costs include: labor, fertilizers, land preparation machinery, harvesting machinery, see
Clima tic condit ions	These are meteorological phenomena (temperature, humidity, atmospheric pressure, precipitatio harvest (Esparza, 2012), (Grammont, 2010), (Ortíz, 2013), (Villa & Bracamonte, 2013), (López, 2
Mark eting	These are meteorological phenomena (temperature, humidity, atmospheric pressure, precipitation, (Esparza, 2012), (Grammont, 2010), (Ortíz, 2013), (Villa & Bracamonte, 2013), (López, 2014). Facts based on conjecture, but not proven

Source: Prepared by the author based on the literature review.

The variables to be used in this research are shown in the ex ante diagram in Figure 1.1; they are grounded in the theoretical and contextual framework and the state of the art presented previously, which will serve to describe the evolution of corn production in the municipality of Chicontepec using agent-based modeling.

Figure 2. Ex-ante diagram



Source: Prepared by the author based on the theoretical framework presented in this research

Figure 2.3 shows the ex-ante diagram based on the empirical evidence documented in the state of the art. From this perspective, this research adopts an approach focused on the evolution of competitiveness in corn production in Chicontepec, Veracruz, considering the independent variables of organization, yield, support policies, production costs, marketing, and climatic conditions.

Methodology

The formal research method, employing a sequential design, represents a set of systematic, empirical, and critical research processes involving the collection and analysis of qualitative and quantitative data, as well as joint conclusion and discussion, to draw inferences from all the information gathered.

In the first stage, the context of the research topic was reviewed from the perspectives of international, national, regional, and local corn production; the local component corresponds to corn production in the municipality of Chicontepec.

The theoretical framework and state of the art were reviewed, taking into account the following: competitiveness, agricultural competitiveness, competitiveness of corn production, and agent-based modeling.

The second stage included the problem statement, general and specific objectives, the definition of the study method and type of research, as well as the determination of the sample size of male and female producers engaged in corn production in the municipality of Chicontepec.

In the third stage, which involved data collection, studies were conducted in several communities within the municipality of Chicontepec, both in Spanish and in Nahuatl—the latter being the native language of the study population. Statistical analysis was then performed using SPSS to assess the validity of the instrument, the degree of correlation between independent and dependent variables, and the model will be validated against the theory through confirmatory factor analysis, structural equation modeling, and the agent-based model.

Given the characteristics and nature of the problem addressed in this research, the study will have a quantitative and qualitative approach, as it will describe the evolution of competitiveness using a measurement instrument that applies statistical techniques and tests; subsequently, the characteristics or qualities of the data will be analyzed based on the results obtained.

The research is mixed-methods and explanatory in nature, as it employs a structural and statistical approach; so it may become descriptive and correlational, as it addresses the questions raised regarding the variables to describe the relationship in terms of the magnitude of each variable, as well as the use of multivariate statistical techniques to test and estimate causal relationships based on statistical data and qualitative assumptions about causality.

Analysis of complex systems, as agent-based modeling will be used to simulate the production or behavior of agents in corn production.

The variables in this research are grounded in the contextual framework of corn production, as well as in the theoretical framework and state of the art, which is developed to measure the competitiveness of corn producers in the municipality of Chicontepec using agent-based modeling.

A model is designed to describe and simulate the conditions under which this agricultural activity takes place in the municipality of Chicontepec.

Within the theoretical framework, information related to the research topic was analyzed in scientific articles found in highly prestigious journal databases regarding the subject of study, which are: competitiveness, agricultural competitiveness, the competitiveness of corn production, and agent-based modeling.

After obtaining the measurement scale for the independent variables and specifying the coding or values, the pilot test was conducted.

It was administered to 324 corn producers, both women and men, from communities in the municipality of Chicontepec, Veracruz, in the language they speak fluently, which is Nahuatl. Annexes III and IV show the operationalization of the independent and dependent variables, and Annex V shows the evaluation instrument for this research.

The following statistical tests were performed:

After administering the 324 surveys to the corn producers, the data were entered into the statistical software SPSS (Statistical Package for the Social Sciences) version 25. The reliability of the measurement instrument was then assessed using Cronbach's alpha, yielding a result of .857 (APPENDIX II), which means that the measurement instrument is reliable because it has a Cronbach's alpha greater than 0.7

Next, confirmatory factor analysis and structural equation modeling were performed.

Results

Based on the validation in the statistical software of the 324 tests answered by the corn producers of Chicontepec, Veracruz, confirmatory factor analysis was performed.

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The results of the confirmatory factor analysis are shown; this is a necessary step for structural equation modeling (SEM), According to (Littlewood & Bernal, 2014) , SEM is a statistical technique that allows for the testing of theoretical models and establishes causal relationships between independent and dependent variables based on a theoretical review. The measurement of these relationships using SEM is performed through the items of the dimensions and indicators outlined in the assessment instrument. The modeling

Thus, structural equation modeling requires two stages: confirmatory factor analysis, which validates the measurement model of the variables or constructs, and the verification of the parameters among the latent variables

Structural equation modeling was performed using LISREL, a scientific software package that allows researchers in the social sciences, management sciences, behavioral sciences, and other fields to evaluate their theories. It is classified as statistical software It can run on 64-bit computers for structural equation modeling and is available for data obtained from surveys on categorical variables, as well as for data from random samples.

Based on the validation of the obtained data, we proceed to design the agent-based modeling of the performance variable and the validated items for the SEM model.

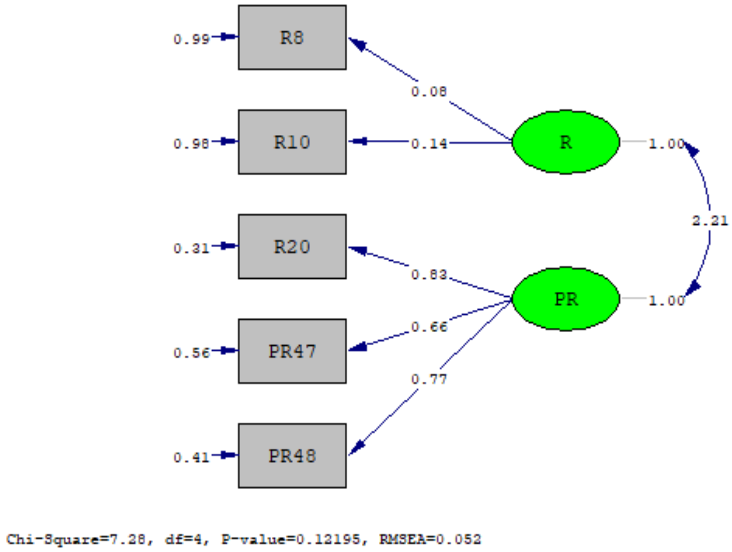
Confirmatory factor analysis.

In the factor analysis, the validity of the results obtained in the field study was verified, classified or categorized with their respective independent and dependent variables based on the dimensions, indicators, and items presented in this research, as shown in Appendices II, III, and V.

In the first stage, several constructs were analyzed simultaneously along with their respective indicators (items), which are O54, O55, O35, O36, O37, O38, O40, O34, and O39 corresponding to the Organization variable; R7, R8, R11, R45, R12, R9, R10, R43, R44, R20, R25, R27, R28, R29, R30, R31, R32, R33, R41, R42, corresponding to the Performance variable; PA24, PA51, PA26, PA50, PA52, PA53, corresponding to the Support Policies variable; CP5, CP1, CP2, CP4, CP6, CP3, corresponding to the Production Costs variable; CO56, CO57, CO58, CO59, for the Marketing variable; CC13, CC14, CC19, CC17, CC18, CC15, CC16, CC23, CC21, CC22, indicators of the Climatic Conditions variable; and PR46, PR47, PR48, PR49, for the dependent variable, corn production.

Based on the analysis run in the LISREL software, Figure 1.2 is shown

Figure 3. Confirmatory factor analysis



Source: Author's own work based on the confirmatory factor analysis with latent variables

The yield variable "R" shows a strong positive relationship with item R8 "use of organic fertilizer" and item R10 "use of insecticides to combat pests," as the correlation coefficients in these cases are 0.99 and 0.98, respectively.

As for the production variable "PR," it shows a strong positive relationship with item PR47 "harvest more than one ton per hectare," since the correlation coefficient between these two variables is 0.56

We can also observe that the production variable "PR" shows a weak positive relationship with items R20 "lack of rain does not affect my crop because I have irrigation" and R48 "I harvest more than 2 tons per hectare," since the correlation coefficients are 0.31 and 0.41, respectively.

In an effort to validate these latent variables and the relationship between them, as well as the dependent variable, Figure 1.2. shows the results, where the Yield (R) variable validates items 8 and 10 with reliable values of 0.99 and 0.98; likewise, the dependent variable

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Production (PR) validates the relationship with items 20, 4, and 48, thus establishing two latent variables with their respective indicators.

Likewise, in the figure we can identify four principal indices indicating that the Confirmatory Factor Analysis is valid because the Chi-square value is 7.28, and the RMSEA (Root Mean Square Error of Approximation) value is 0.052, for which the measurement criterion is that a result of 0.8 or less is satisfactory;

The following code was used for the confirmatory factor analysis.

```
Correlation Matrix From File JOSE.COR
 Sample Size 324
 Latent Variables: O R PA CP CO CC PR
 Relationships:
 PR48 PR47 R20 = PR
 R8 R10 = R
 Number of Decimals = 3
 Wide Print
 Print Residuals
 Path Diagram
 End of Problem
 Sample Size = 324
```

Table 3*: Correlation matrix resulting from confirmatory factor analysis (CFA).*

	R8	**R10**	**R20**	**PR47**	**PR48**
R8	1,000				
R10	**0.011**	1,000			
R20	0.178	0.270	1,000		
PR47	0.167	.178	**0.537**	1,000	
PR48	**0.069**	0.215	**0.638**	**0.525**	1.000

Source: Results of confirmatory factor analysis

In the correlation matrix in Table 1.2, it can be seen that the strongest correlations occur between item R20 "the lack of rain does not affect my crop because I have irrigation" and PR47 "I harvest more than one ton per hectare" and PR48 "I harvest more than two tons per hectare"; At the same time, it is observed that the latter items mentioned have a strong correlation with each other.

On the other hand, the weakest correlations are between item R8 "I use organic fertilizer" and items R10 "I use insecticides to control pests" and PR48 "I harvest more than two tons per hectare"

Structural Equation Modeling (SEM).

Structural equation modeling (SEM) has the capacity to model constructs, which are referred to as latent or hidden variables in the individual modeling of the structural model; these are estimated in the model based on the variables measured in the indicators, allowing for the estimation of the model's average reliability.

In the literature review, latent variables or constructs were identified by specifying the dimensions and indicators that explain their relationship, as proposed in the ex ante model

From this perspective, all those presented in this study were analyzed.

Figure 4. Final model obtained from the LISREL software.

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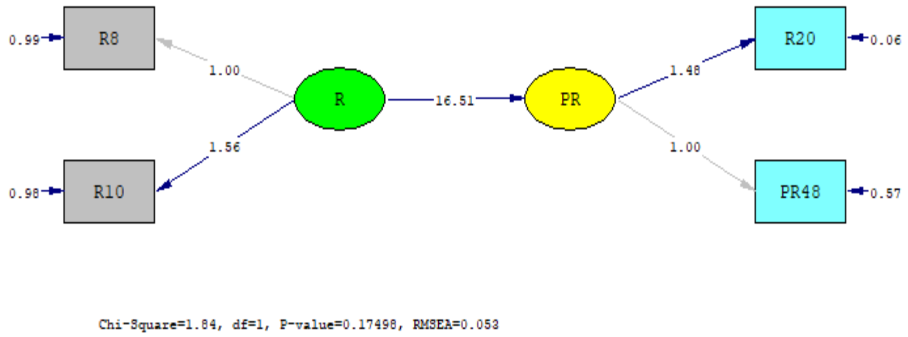

Source: Author’s own work. Result: Structural Equation Modeling (SEM).

According to the structural equation modeling in Figure 1.3, the only independent variable that explains production (dependent variable) is yield.

The complete model, which considers the variables Support Policies (SP), Production Costs (PC), Climatic Conditions (CC), Marketing (MO), Organization (O), and Yield (Y) (independent variables), does not explain PR due to two possible situations:

1. That the dependent variable (PR) is explained solely by the independent variable (R), since it is a variable that encompasses many dimensions, indicators, and items, making it a highly relevant variable for SEM modeling.

2. PA, CP, CC, CO, and O need to be redesigned.

3.- CP, CC, O, and PA are independent variables of Performance (R), and therefore it is necessary to redefine the model in further research.

Correlation Matrix From File JOSE.COR

Sample Size 300

Latent Variables: O R PA CP CO CC PR

Relationships:

PR48 = 1*PR

R20 = PR

R8 = 1*R

R10 = R

PR = R

Number of Decimals = 3

Wide Print

Print Residuals

Path Diagram

End of Problem

Sample Size = 324

The most important indicators validating the model are described below:

1.-It can be observed that the CHI-SQUARE value is 1.845; therefore, it can be concluded that this is an acceptable model.

Normal Theory Weighted Least Squares Chi-Square = 1.840 (P = 0.175)

2.-Root Mean Square Error of Approximation (RMSEA) = 0.0530

We can see that RMSEA = 0.0530, which indicates that it is satisfactory; this means there is no need to adjust the model

Root Mean Square Error of Approximation (RMSEA) = 0.0530

3.-In this case, we observe that the Normed Fit Index (NFI) = 0.989, which means that the theoretical model improves the fit relative to the null model to an acceptable degree.

Normed Fit Index (NFI) = 0.989

4.-As we can see, the CFI = 0.995, which is a value very close to 1; this means that the comparison between the theoretical model and the null model has a good fit.

Goodness of Fit Index (GFI) = 0.997

Table 5. *Correlation matrix; structural equation modeling (SEM)*

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	R20	PR48	R8	R10
R20	1,000			
PR48	**0.638**	1,000		
R8	0.174	0.118	1,000	
R10	0.273	0.184	**0.011**	1,000

Source: Author's own work, based on SEM analysis

In correlation matrix 1.3, it can be observed that, among all possible item combinations, the highest correlation is between R20 "lack of rain does not affect my crop because I have irrigation" and PE48 "I harvest more than two tons per hectare," which means that having irrigation increases production by more than two tons per hectare; Conversely, the lowest correlation is between item R8 "use of organic fertilizer " and R10 "I use insecticides to combat pests," which means that using little organic fertilizer also leads to using little insecticide.

Conclusions

Based on the general objective of this research to "design a competitiveness model for corn production in Chicontepec, regarding types of organization, support policies, climatic conditions, production costs, yield, and marketing, using agent-based modeling," the agent-based model was designed based on the two variables validated in the confirmatory factor analysis and structural equation modeling. Additionally, six specific objectives were formulated with six research questions that allowed for the formulation of hypotheses.

Data collection was conducted using a measurement instrument administered to 324 small-scale corn farmers in the municipality of Chicontepec. The data obtained were subjected to statistical tests, and the variables were validated using the scientific software LISREL to design the agent-based model.

Regarding the fulfillment of the general and specific objectives, it is concluded that:

The general objective was achieved by designing the agent-based model based on the SEM validation of the yield and production variables with their respective indicators: "lack of rain affects my crop" with a correlation of 1.000, "I harvest more than one ton per hectare" with a correlation of 0.638, and "I harvest more than 2 tons per hectare" with a correlation of 0.525. On the other hand, there is a weak correlation with "use of fertilizers"; however, it was taken into account for the simulation because it is a relevant input for yield according to Table 4.2; From the two variables mentioned, the following parameters were used for the simulation: available land area, rainfall, fertilizers, planted area, and planting cycle; "support programs" were also taken into account as a complementary factor.

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