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Technological characterization of the production units of tomato under greenhouse in Puebla

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Abstract

This work describes the technological characteristics of the tomato production units (UPJ) (*Lycopersicon esculentum* Mill.) under greenhouse and the socioeconomic characteristics of the producers, in four municipalities of the state of Puebla. The data were obtained from a sample of producers, with a reliability of 95% and precision 10% of the value of the average of the greenhouse surface. 103 producer surveys were applied in the second half of 2017. A technological index (IT) was constructed from variables of technological management and equipment. 25% of UPJ use low technological levels, 66% medium levels and 9% high levels. The explanation of the technological level used by the UPJ was estimated with a Probit interval regression model. The level of education, the experience in greenhouse production and the size of the greenhouse have a significant influence ($p \leq 0.5$). Therefore, it is concluded that the technological level in the production units, as well as the school level, the cultivated area and the experience in greenhouse production by the producers, are factors closely related to the productivity of the crop. Based on these results, strategies can be developed and implemented to provide advice and training in the proper use of the technologies and equipment necessary to achieve high homogeneous yields in the area.

Keywords: agricultural production unit, protected agriculture, tomato.

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Introduction

In recent decades, agriculture has made use of new technologies, mainly plastics, which, combined with knowledge in crop production, have allowed a new way of producing, known as protected agriculture (PA) (Bastida, 2011).

The PA is growing, in 1980 Mexico had 300 ha, in 2008 with 10 000 ha and in 2017 with 42 215 ha. Of these, 39% corresponded to shade mesh. 45% to greenhouses and the remaining 16% to a micro tunnel, macro tunnel and pavilion (SIAP, 2020). However, the National Agricultural Survey (INEGI, 2018) revealed that in 2016 there were 57 928 ha of PA and of these, 13 694 ha were greenhouses. National production in PA amounted to 3.2 million t in 2016 (INEGI, 2018). The cultivation of tomato (*Lycopersicon esculentum* Mill.) In PA represents 70% of the cultivated area.

In the state of Puebla, there were 1 285 ha of PA in 2016 (SIAP, 2020). The predominant type of structure is the greenhouse, with 72% occupancy in the production units (INEGI, 2018). The value of the production of this vegetable in 2014 was 443 million pesos (SIAP, 2014). The harvested area and crop yield in the state has changed, for 2013, there were 300 ha planted and an average yield of 175.44 t ha^{-1}, while in 2014, 359.46 ha were registered with an average yield of 169 t ha^{-1} (SIAP, 2014).

In greenhouse tomato production, technology is an especially important component to improve productivity and yields (Padilla *et al*., 2010). To comprehensively analyze greenhouse tomato production, it is necessary to focus on technology and its relationship to productivity. Technology is a set of techniques that allow the practical use of scientific knowledge (Burge-Smani and Wheelwright, 2004; Real Academia Española, 2018). Technology means the systematic application of scientific knowledge or other organized knowledge to practical tasks (Galbraith, 1980).

For its part, productivity is considered as the way to use production factors in the generation of goods and services to obtain benefits and is summarized as the ratio between the products generated and the productive inputs used (Fontalvo-Herrera *et al*., 2017; Valbuena *et al*., 2018). Greenhouse productivity can be increased through the incorporation of better technologies.

According to Díaz *et al*. (2018) the differences in productivity between the greenhouse production units can be explained by the level of technology they use in the production process. In this sense, Ortiz *et al*. (2013) found that the higher the level of technology adoption, the higher the productivity, expressed in higher performance and income of the productive units.

It should be noted that, in the production units, there are various technological levels that are closely related to crop management, understood as the various activities that the crop requires. These activities include land preparation, planting, fertilization, cultural work, pest and disease control and management, and harvesting. This, considering the optimal time for the proper execution of techniques and tasks that tomato cultivation requires for its production, optimizing the use of available inputs and resources (FAO, 2010; INIA, 2017).

To recommend the use of technology and the type of management that the production units must carry out, the characterization and stratification of the production units is essential. This will make it possible to form relatively homogeneous groups, for the application of efficient crop management recommendations (Muñoz *et al*., 2015). The classification of the production units must be done considering the technological level (Hernández-Ruiz *et al.*, 2018). On the above, Levitan and Werneke (1984) mention that technology and education allow to generate differences in productivity over time.

The technological characterization of tomato production will allow understanding the dynamics and operation of the crop in the context of its development, evolution and change in order to achieve plans and programs for groups with similar characteristics (Valerio *et al*., 2004). Therefore, this research aims to characterize the technological level of tomato production units (UPJ) in four municipalities of Puebla and to identify the sociodemographic and economic variables that explain technological behavior.

Materials and methods

Location of the study area

Aquixtla and Tetela de Ocampo are located in the northern part of the state of Puebla, between 1 200 and 3 200 meters above sea level. The climate of these municipalities is of the sub-humid temperate type with temperatures ranging from 12 to 20 °C. Precipitation varies from 600 to 1 600 mm. Aquixtla has 7 386 inhabitants and Tetela de Ocampo 24 459 inhabitants (INEGI, 2009). For its part, Tecamachalco and Tochtepec are located in the center of the state of Puebla, they have a temperate sub-humid climate with rains in summer (100%), with temperatures ranging between 14 and 18 °C and a precipitation of 500 to 700 mm. Tecamachalco has 64 380 inhabitants and Tochtepec 18 205 inhabitants (INEGI, 2009).

The total population considered were 338 greenhouse producers in the state of Puebla registered in the national protected agriculture information system (SIAPRO, 2011), which allowed locating the municipalities with the highest number of units. The target population of the study were producers from the municipalities of Aquixtla, Tetela de Ocampo, Tecamachalco and Tochtepec, which represent 43.5% of the surface of greenhouses with tomatoes in the state of Puebla (SIAP, 2014).

Simple random sampling was used. The sample size of 103 producers was calculated with simple random sampling, with precision of 10% of the average of the surface of greenhouses in the state and reliability of five percent.

The unit of analysis in the study, UPJ, represents the economic unit that occupies a given set of land (s), infrastructure, machinery and equipment. that are used during agricultural and non-agricultural activities by the family group. This family group is governed under the same administration, in which certain relationships of design, organization, decision-making and execution prevail (Martínez *et al*., 2014).

The data were obtained through a questionnaire applied directly to the producer in the second half of 2017. This questionnaire was made up of 177 questions, divided into: a) sociodemographic aspects of the producer; b) land tenure and production experience; c) technical aspects of the greenhouse; d) production aspects (sowing, soil preparation, cultural work and nutrition); and e) additional equipment in the greenhouse. With these data, a technological index (IT) was constructed to represent the technological level of each UPJ. The IT was made up of two sub-indices, the technological management index (IMT) (Table 1A and 1B) and the equipment index (IEQ) (Table 2).

Table 1A. Components of the technological management index.

CAT*	Type	Value**
Genetic material	Hybrid	1
	Variety	2
	Variety-hybrid	3
Transplant age	30-50 days	1
	20-30 days	2
	10-20 days	3
Number of plants per square meter	From 1 to 4 plants m^2	1
	From 5 to 8 plants m^2	2
	From 9 to 12 plants m^2	3
Irrigation frequency	Every third day	1
	Diary	2
	According to the needs of the plant	3
Stem pruning	Three to more stems	1
	To a stem	2
	To two stems	3
Pollination	Manual vibration of the plant (paleo and shaking threads)	1
	Alternation between manual vibration and bumble bees	2
	Single use of bumblebees and air sprayer to pollinate	3

*= component and technological activity; **=assigned value.

Table 1B. Components of the technological management index.

CAT*	Type	Value**
Transplant height	Less than 15 and more than 26 cm	1
	From 21 to 25 cm	2
	From 15 to 20 cm	3
Pruning of sprouts, leaves and thinning	Bud pruning only or leaf pruning only or raleo only	1
	Pruning of leaves and sprouts or pruning of leaves and thinning or pruning of sprouts and raleo	2
	Pruning of leaves, sprouts and raleo	3

CAT*	Type	Value**
Number of prunings performed in the cycle	Less than 20 prunings	1
	From 20 to 24	2
	More than 24	3
Soil	Padding inside the premises or soil disinfection only or only application of fertilizers prior to planting	1
	Plant padding and disinfection or padding and application of previous fertilizer or soil disinfection and application of previous fertilizer	2
	Plant padding, soil disinfection and application of fertilizer before planting	3

*= component and technological activity; **= assigned value.

Table 2. Components of the equipment index.

Equipment	Value
Scale	1
Manual spray backpack	1
Mercury thermometer	1
Digital thermometer (hygrometer)	2
Soil hygrometer	2
Conductivity meter	2
Peachmeter	2
Parihuela	3
Motor spray backpack	3
Gas burner	4
Computer	4
Computerized irrigation	4
Fan heater	4

Elaboration based on García *et al*. (2011), modified for the study area.

Technological management index

This index concentrates on the cultural tasks carried out by producers, since there is no reference to a technological management package validated by any government or research entity in the study area.

For its construction, the index proposed by Ortiz (2005) was taken into account based on the cultural work carried out on the plant and the technology used. Ortiz proposal (2005) had adaptations from Carrillo *et al*. (2003) in the planting density component, by Martínez *et al*. (2005) in genetic material used and by Ucan *et al*. (2005) in the components of pruning, thinning and irrigation. In addition, the construction of the Index incorporated the opinion of leading producers in the study area in the context of crop management, assigning a value to each component (minimum (1), intermediate (2) and maximum (3)) within of the work performed. For the IMT analysis the following formula was applied: IMT= X - Min / Max - Min.

Where: IMT= is the technological management index; X= is the ∑ of the accumulated values of the 10 cultural practices or tasks carried out by tomato producers; Min= is the minimum value of the accumulated points for each case equal to 10; and Max= is the maximum value of the accumulated points equal to 30.

Equipment index

The IEQ was built assigning a value to the number of additional equipment to the irrigation system in the greenhouses. A range of values was established according to the importance and degree of complexity of each team, with maximum 4 and minimum 1 (García *et al*., 2011). For its calculation, the following formula was applied: IEQ= X - Min / Max - Min.

Where: IEQ= is the equipment level; X= is the ∑ of the accumulated values of the 13 additional equipment to the irrigation system in the greenhouse; Min= is the minimum value of the accumulated points for each case equal to 1 and Max= is the maximum value of the accumulated points equal to 33.

Once the UPJ equipment index was obtained its frequency and percentage of presence in the study area were described.

Technological index

IT is the arithmetic average of the IMT and IEQ value. This is because, in the opinion of experts (agronomists specializing in greenhouse tomato production), both are decisive for productivity. An ordered Probit regression model was used to explain IT behavior. This model allows the calculation of the predicted probabilities for each category of the dependent variable and its marginal effects.

The Probit model has a symmetrical bell-shaped distribution (Greene, 2008). The marginal effect means that a change of one unit in the explanatory variable will lead to an increase or decrease in the predicted probability equal to the size of the marginal effect. The choice of this model is due to the advantages that it represents in its functional form since the estimated probabilities are in the range 0-1 and it allows capturing nonlinear effects of the explanatory variables on the explained variable (Long, 1997).

The variables with which the empirical model was estimated are described in Table 3. The specification is as follows:

$$ITi = b_0 + b_1 EDAD1 + b_2 EDAD2 + b_3 ESC1 + b_4 ESC2 + b_5 ESC3 + b_6 ESC4 + b_7 EXP1 + b_8 EXP2 + b_9 EXP2 + b_{10} EXPI1 + \\ + b_{11} EXPI2 + b_{12} EXPI3 + b_{13} REN1 + b_{14} REN2 + b_{15} REN3 + b_{16} SUP1 + b_{17} SUP2 + b_{18} SUP3 + b_{19} SUP4 + e_i$$

Table 3. Variables used in the Probit model.

Original variable	Categorical variable	Categorical variable code
Producer’s age	1) Under 35 years (EDAD1)	Edad 1
	2) From 36 to 55 years old (EDAD1)	Edad 2
Scholarship	3) Elementary (ESCOL1)	Escol 1
	4) High school (ESCOL2)	Escol 2
	5) High school (ESCOL3)	Escol 3
	6) Bachelor and Postgraduate (ESCOL4)	Escol 4
Years of experience as a farmer	7) From 6 to 10 years (EXP1)	Exp A1
	8) From 11 to 20 years (EXP2)	Exp A2
	9) More than 20 years (EXP3)	Exp A3
Years of experience in greenhouse production	10) From 3 to 6 years (EXPI1)	Exp I1
	11) From 7 to 9 years (EXPI2)	Exp I2
	12) More than 10 years (EXPI3)	Exp I3
UPJ yield	13) From 101 to 150t ha^{-1} (REN1)	Rendim 1
	14) From 151 to 300 t ha^{-1} (REN2)	Rendim 2
	15) More than 300 t ha^{-1} (REN3)	Rendim 3
UPJ surface	16) 1 001 to 2 000 m^2 (SUP1)	Sup 1
	17) 2 001 to 3 000 m^2 (SUP2)	Sup 2
	18) 3 001 to 5 000 m^2 (SUP3)	Sup 3
	19) 5 000 m^2 or more (SUP4)	Sup 4

Surveys applied in July 2017.

The dependent variable is ITi, with three different categories IMT= 0; IMT= 1 (low); IMT= 2 (medium); IMT= 3 (high), the ranges were defined according to the results obtained in the creation of the index, β0 is the constant of the regression, the βi are the estimated coefficients of the regression.

Results and discussion

92% of tomato growers under greenhouse are men and 8% are women. This percentage of men is higher than that reported by Martínez *et al*. (2014). The average age was 42 years, similar to that reported by Vargas *et al*. (2015). The average schooling is 8.6 years, higher than the 6 years reported by Ortega *et al*. (2014) for tomato producers and close to Vargas *et al*. (2015) of 9.22 years. Greenhouse tomato production is the main source of income for 77% of producers, while 23% carry out a combination of agricultural and non-agricultural activities.

70% of the water used in cultivation comes from rivers and springs, similar data to that reported by Ortega *et al*. (2014). The other 30% of the water is obtained from wells. Multitunnel greenhouses with mobile and fixed overhead type ventilation represent the most frequent type of construction (94%), with an average surface area of 3 900 m^2, which is greater than that reported by Ortega *et al*. (2014); Vargas *et al*. (2015); Martínez *et al*. (2014). The materials used in the greenhouse structure are the galvanized rectangular tubular profile (PTR) and the plastic covers in 16 different variants. 100% of the constructions use polyethylene as a roofing material (Martínez *et al*., 2014; Ortega *et al*., 2014). Of the UPJ studied, 43% were established with their own resources, 30% with government support (Ortega *et al*., 2014) and 27% with credits. However, Martínez *et al*. (2014) reported that 77.6% of the greenhouses were established with federal or state investment and the remaining 22.4% with their own resources.

The operation of the greenhouses has an average of 7 years, a figure higher than that reported by Martínez *et al*. (2014); Ortega *et al*. (2014); Vargas *et al*. (2015). There are two planting cycles, January-July and September-February. The harvest takes place in May-July and October-December. The sowing is carried out by seed (66%) and cutting (34%). 23 different varieties used in the last two planting cycles were identified. The most used varieties are: reserve, El Cid, Pai-Pai, Saladette and Optimax with 65%. The remaining 35% is made up of 18 different varieties from those mentioned above. The average number of plants per m^2 was 3.1 (Martinez *et al*., 2014).

The average yield is 152 t ha^{-1}, 17 t below the state average and 22 less than the national average. These returns differ from that observed by Vargas *et al*. (2015) and Ortega *et al*. (2014). Sales were mostly made to intermediaries (74%) who collected the product directly from the UPJ. The rest were sales made to the central supply (23%) in Puebla, Mexico, Morelos and Toluca. Only 3% of sales were made to local markets. In this regard, Hernández-Ruiz *et al*. (2018) reported that marketing by small producers is carried out mainly in the regional and local market.

The labor used is family type in 70% of the UPJ, similar to that reported by Martínez *et al*. (2014). The rest of the UPJ hired at least 4 people to carry out daily activities in the greenhouse. Producers who have received training and technical assistance amount to 35%. Additionally, 13% of producers have been trained in marketing aspects. This aspect is of importance because the training of those who are in charge of the management and administration of the UPJ has a positive influence on their productivity (Moreno *et al*., 2011). Advice on marketing aspects has been provided (in order of importance) by the state government and higher-level educational institutions in the state of Puebla. This differs from that reported by Ortega *et al*. (2014), which highlights the null relationship of producers with a research center or university.

Technological management index (IMT)

According to the results found in the analysis of the 10 categorical variables that make up the technological components and cultural tasks (IMT), values ranging from 0.15 to 0.7 were obtained, allowing the determination of 3 different levels; less than 0.25= low; 0.26 to 0.5= medium and greater than 0.5= high. 60% of UPJ have a medium technological level, 26% low and 14% high.

Equipment Index (IEQ)

The IEQ of the greenhouses showed scores ranging from 0.06 to 0.76, allowing to determine 3 different levels: less than 0.25= low; 0.26 to 0.5= medium and greater than 0.5= high. The UPJ with low level represented 25%, with medium level 66% and with high level 9%. Table 4 shows the differences in performance according to the level in each of the indices.

Table 4. Number of producers and average yield in each index obtained.

Index obtained	Low		Medium		High	
	n	yield*	n	yield*	n	yield*
IMT	27	91.63	62	152.7	14	263.2
IEQ	40	128.7	57	156	6	264.5

*= average yield.

According to the previous results, it is deduced that the number of additional equipment and the activities applied in the cultivation allow to increase the yields. Similar results were reported by García *et al*. (2011) who, in a study on adoption of innovations in Tlaxcala found a positive relationship between level of equipment and yield.

Analysis of the technological index

IT represents the level of technology use of each production unit, which is related to the yield of the tomato; the difference of the low-medium, medium-high and low-high IT yield means are significant ($p \leq 0.05$) (Table 5).

Table 5. Difference in yield averages between IT categories.

IT level	Observations	Average yield	Dif. from the mean	Minimum	Maximum
Low	26	98.6	--	34	180
Medium	68	158.4	59.8*	24	340
High	9	255.0	96.6*	200	360
Total	103	151.7	--	24	360

*= the difference in means is significant ($p \leq 0.05$).

To explain the behavior of IT, a Probit regression model was estimated. Parameter estimates and model fit statistics are shown in Table 6. Seven variables in the model were significant ($p < 0.05$). These were schooling in the stratum made up of producers with a bachelor's and postgraduate degree (Águila and Padilla, 2010; Vargas *et al*., 2015), experience as a farmer in the stratum from 11 to 20 years old, experience with agriculture under greenhouse, the stratum of more than 10 years, and the surface of the greenhouse in strata 3 001 to 5 000 m^2 and more than 5 000 m^2. On this last variable, Hernández-Ruiz *et al*. (2018), in a study carried out in Oaxaca, identified a positive relationship between the technological level, yield and size of the greenhouse.

Table 6. Results of the IT Probit model.

Variable code	Variable	ß	Standard error	Value of t
Edad 1	Under 35 years	-0.32	0.75	-0.43
Edad 2	From 36 to 55 years	0.41	0.66	0.62
Escol 1	Elementary	1.36	0.89	1.53
Escol 2	High school	1.55	0.83	1.87*
Escol 3	High school	1.19	0.85	1.4
Escol 4	Bachelor and Postgraduate	4.89	1.46	3.35**
Exp A1	From 6 to 10 years	-0.88	0.58	-1.52
Exp A2	From 11 to 20 years	-0.75	0.31	-2.42**
Exp A3	More than 20 years	-0.78	0.6	-1.3
Exp I1	From 3 to 6 years	0.74	0.61	1.21
Exp I2	From 7 to 9 years	0.22	0.7	0.31
Exp I3	More than 10 years	0.73	0.2	3.65**
Rendim 1	From 101 to 150 t ha^{-1}	0.4	0.42	0.95
Rendim 2	From 151 to 300 t ha^{-1}	1.61	0.58	2.78**
Rendim 3	More than 300 t ha^{-1}	3.01	0.83	3.63**
Sup 1	From 1 001 to 2 000 m^2	0.19	0.59	0.32
Sup 2	From 2 001 to 3 000 m^2	-0.79	0.55	-1.44
Sup 3	From 3 001 to 5 000 m^2	0.68	0.22	3.09**
Sup 4	From 5 000 m^2 or more	0.35	0.11	3.18**
	Log likelihood		-45.333444	
	LR chi^2		112.88	
	Prob > chi2		0	
	Pseudo R2		0.581	

** = significant variables (p< 0.05).

In the Probit model, the model coefficients are interpreted as the logarithm of the odds ratio. For each one-unit increase in the explanatory variable, the response variable (IT) changes in one of its categories, in the magnitude of the coefficient (Greene, 2008). To make the model coefficients more informative, the marginal effect that defines the impact of a change in an explanatory variable on the predicted probabilities of IT was calculated. For an explanatory variable, a change of one unit impacts increasing or decreasing probabilities. Predicted, in the magnitude of the marginal effect (Greene, 2008). Table 7 presents the marginal effects of the explanatory variables of the model, for each of the IT levels.

Table 7. Marginal effects in the IT model.

Variable code	Variable	IT=1 (low)	IT=2 (medium)	IT=3 (high)
Edad 1	Under 35 years	0.014	0.016	-0.03
Edad 2	From 36 to 55 years	-0.018	-0.02	0.041
Escol 1	Elementary	-0.06	-0.07	-0.134
Escol 2	High school	-0.073	-0.081	0.055
Escol 3	High school	-0.051	-0.062	0.114
Escol 4	Bachelor and Postgraduate	-0.231	-0.269	0.499
Exp A1	From 6 to 10 years	0.035	0.045	-0.089
Exp A2	From 11 to 20 years	0.053	0.062	-0.118
Exp A3	More than 20 years	0.042	0.045	-0.088
Exp I1	From 3 to 6 years	-0.037	-0.045	0.085
Exp I2	From 7 to 9 years	-0.013	-0.015	0.125
Exp I3	More than 10 years	-0.062	-0.071	0.13
Rendim 1	From 101 to 150 t ha^{-1}	-0.136	0.135	0.002
Rendim 2	From 151 to 300 t ha^{-1}	-0.349	0.305	0.539
Rendim 3	More than 300 t ha^{-1}	-0.371	-0.579	0.945
Sup 1	From 1 001 to 2 000 m^2	-0.005	-0.015	-0.018
Sup 2	From 2 001 to 3 000 m^2	0.071	-0.025	-0.045
Sup 3	From 3 001 to 5 000 m^2	-0.002	-0.003	0.113
Sup 4	From 5 000 m^2 or more	-0.008	-0.016	0.129

Schooling is directly related to higher IT, having elementary school decreases the probability of having high IT while having high school increases the probability of having high IT by 11%. On the other hand, having a bachelor's degree or higher, increases the probability of having high IT by 49.9%. This means that having trained human capital, represented by the level of schooling, facilitates the assimilation of technologies in the company (Águila and Padilla, 2010). In addition, school level can be a determining factor in the performance of the technologies used in protected agriculture (Vargas *et al*., 2015). Having experience in greenhouse production is also related to a higher level of IT, especially over seven years, which increases the probability of high IT by 12.5%. Beyond 10 years of experience in this regard, it does not increase the probability of high IT significantly. The surface shows that less than 3 000 m^2 reduces the probability of having a high IT while, from this greenhouse surface, the probability increases significantly.

Conclusions

Tomato cultivation shows a permanent productive activity in the last seven years of having established greenhouses. Government support was not an important factor in the establishment and operation of the greenhouses. The UPJ in the state of Puebla mainly have low and medium technological levels, with IT being a determining factor in the yield obtained by the greenhouse, given that the UPJs with a High IT have a higher average yield.

The most important sociodemographic and economic variables that explain the technological level, and also those that are directly related to a high IT are the level of schooling, the experience in greenhouse production, high yield and the area cultivated under this modality. These results can be used to generate strategies aimed at improving the adoption of technology, which allow maintaining high yield.

The productivity of the UPJ lies in the experience of crop management and the way in which the activities and technological components applied to the tomato are carried out, as well as the equipment in each of them. The above factors are decisive in improving performance. For this reason, it is necessary to strengthen the link between the research and government centers at their different levels with tomato producers in the context of ongoing advice and training.

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