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Water consumption of three ornamental species with the suction irrigation system

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ABSTRACT

Objective: To evaluate water consumption in ornamental plants (geranium, gazania and petunia) in two substrates with different particle sizes (fine and coarse) of tezontle and peat moss, through a suction irrigation system, which uses porous capsules as irrigation emitters.

Design/methodology/approach: The experimental design was in complete randomized blocks, with six treatments (three ornamental species and two substrates) with four repetitions (24 experimental units). The first mixture contains fine substrate (composed of tezontle with particle size less than 0.4 mm) and peat moss, in a 1:2 v/v ratio; the second mixture presents coarse substrate (composed of tezontle with particle size between 0.4-0.6 mm) and peat moss, 1:1 in v/v.

Results: In water consumption, there are significant differences by ornamental species and type of substrate, where the irrigation system has the ability to self-regulate. The highest water consumption was in petunia in the coarse substrate (which has a higher proportion of peat moss in its composition).

Limitations on study/implications: With use in protected agriculture, rural and urban orchards, gardens, walls and green roofs and research purposes.

Findings/Conclusions: The suction irrigation system through porous capsules has the capacity to continuously supply the water demanded by the plant-substrate-atmosphere system.

Keywords: Sustainable irrigation, irrigation, water efficiency.

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INTRODUCTION

Irrigation water is of best use when it is supplied to plants almost instantaneously (with constant moisture level in time) and in terms of amount, whatever is necessary (excess or deficiency have implications), which is associated with the form of water supply. There is a diversity of methods for water supply (irrigation) based on the agricultural system, intensive or extensive; for example, superficial gravity irrigation, pressurized irrigation, hydroponics and aeroponics. However, there is another irrigation option that works through suction,

Image by Onkel Ramirez at Pixabay

that is, by negative load. There is a close relationship between the amount of water used by a plant in normal growth conditions and the amount of plant material it produces (Lemaire *et al.*, 2005). Most of the studies on transpiration in plants are devoted to the study of crops (FAO, 2014) and there is scarce information about this topic in cutting flowers and potted plants (Montero *et al.*, 2001). For example, in "Freedom Red" poinsettia plants, their irrigation and Kc requirements were estimated by microlisimetric techniques in pots within a greenhouse, weekly. The consumption obtained in the first week was 0.24 $mm \cdot day^{-1}$ and increased until the tenth week to 0.9 $mm \cdot day^{-1}$ (Pacheco *et al.*, 2014). The use of ornamental plants in green spaces is very frequent, such as in parks, gardens, boulevards; in avenues, central reserves, roundabouts; cemeteries; even in green roofs and walls, among others (Salvador, 2003). The function of these green spaces, among other services, is to contribute to improve the air quality, regulate the environmental temperature, assimilate CO_2, generate oxygen, and prevent soil erosion; all of this, among other services, generates comfort and favors the spaces visually as ornamental components, and improves the quality of life (Rodríguez, 2002). In recent studies about climate change and particularly global warming with the increase in temperature, the increase in green areas in cities is an alternative to mitigate this process; from this the importance of ornamental plants (Herrera-Gómez *et al.*, 2017). With some exceptions, it is frequent for plant species planted in green areas not to prosper because of lack of knowledge about the species (adaptability to the weather) and of techniques for their management. In urban areas the problem of vegetation represents between 70 to 90% due to an inadequate selection of species (Lily, 1991; Fernández-Cañero *et al.*, 2014), and because of not having good management of irrigation water. The latter has greater relevance because it competes for this resource with the population, industry, agriculture and services, despite the advantages that green spaces offer. Presently, with the advances on the theme of evapotranspiration (ET) and on its calculation (FAO, 2014) to make a more efficient use of irrigation water, there is a need to improve in the estimation of the ET in zones with multiple microclimates (for example, green areas: gardens, parks, boulevards, etc.) where there is a diversity of plants and the measurement of ET is not representative when using traditional methods, which are inadequate (Snyder, 2014). Under this situation, estimating irrigation requirements (evapotranspiration estimation) in urban green landscapes is a challenge, especially in green walls (Pérez-Urrestarazu, 2018). Things to consider are biodiversity, size, geographic position of plants (which produce different microclimates), season of the year, different soils, water availability and even management of green spaces. Bainbridge (2002) suggested an alternative for irrigation for arid zones based on a bottle and intertwined nylon fabric that operates based on the absorption and liberation of water in the soil. A bottle (polyethylene terephthalate, PET) that is filled every time that it is emptied is necessary. Among the water supply systems for plants in a localized manner (at pressure) is drip irrigation, which is one of the most efficient, and is always operated adequately. The objective of this study was to evaluate the water consumption in three ornamental species that belong to the genera Geranium, Gazania and Petunia, through the suction irrigation system using porous capsules, in two substrates mixtures, under greenhouse conditions. Under the same management conditions and irrigation method in the ornamental species, two hypotheses have been suggested. *Ho*: there are no significant differences in water consumption between ornamental plants in the two types of substrate. *Ha*: there is at least one significant difference in water consumption in an ornamental plant for one of the substrates.

Emitters (capsules) for irrigation are spherical, made of ceramics, with constant wall thickness, pre-established surface-volume according to its size, and with a specific porosity (which depends on the manufacturing process). The ability to liberate or transfer water to the soil-plant-atmosphere system (SPAS) depends on the suction load, the hydraulic properties of the capsule, and the formulation and management of a nutritional solution applied in irrigation. It is considered that if there is an excess of water in the soil or low atmospheric demand, the irrigation system will not transfer water.

According to Filgueira *et al.* (2006), the infiltration process in the soil depends, among other factors, on the compacting, size and distribution of pores and the texture. There are several models that allow the simulation of the infiltration process (Philip, 1969, 1987 and Regalado, 2003).

$$I = S\sqrt{t} + Ct \tag{1}$$

Where: I, is the accumulated infiltration (mm); S, the capillary sorptivity (mm·h$^{-1/2}$); C, the coefficient related to the hydraulic conductivity at saturation (mm·h$^{-1/2}$); t, is time. The hydraulic conductivity represents the capacity of a porous medium to transmit water, where it is proportional to the soil moisture. If the pores are large, they are the first to lose water; one part of it is still retained in the pore walls, which results from a resistance to infiltration. Thus, two porous mediums with the same porosity can have different hydraulic conductivities, which depend on the distribution, size, continuity between pores, and characteristics of the liquid. In contrast, sorptivity represents the capacity or the speed of a porous material for absorption or desorption of liquids by capillarity, which is the function of the initial water content, uniformity and structure of the material, and the characteristics of the liquid (viscosity, density, superficial tension). Thus, for a surface (A) with a specific area, at a potential *ho*, where the capillarity force predominates:

$$\lim_{t \to 0}\left[\frac{Q(t)}{A}\right] = \frac{1}{2} S t^{-1/2} \tag{2}$$

Where: Q is the expenditure that happens in the area (A) in (mm^3·s^{-1}); t is time (s); A, contact surface (mm^2); S is the sorptivity that represents the water potential (mm·s$^{-1/2}$). When integrating the equation (2), there is:

$$I = S t^{-1/2} \tag{3}$$

Where I, is the infiltration accumulated (mm). In the initial infiltration process in the soils and dry, there is sorptivity, where the effects of gravity and lateral capillarity are small, which is why they are not considered.

MATERIALS AND METHODS

The experiment was established in the greenhouse at the Water Sciences meteorological station, which is located in the coordinates: latitude 19° 27' 37.18" N and longitude 98° 54' 12.12" W, with altitude of 2240 masl. Three ornamental genera were selected: Petunia (Pe), Gazania (Ga) and Geranium (Ge); all of they are common in Estado de México, whether to grow them in the soil or in pots, in landscape design in California, there is a classification system of 3,546 plants (species, cultivars and hybrids) with different selection criteria (Costello *et al.*, 2014).

The substrates that were used are fine substrate (FS) – sieved tezontle (size of the mesh under 0.4 mm) plus peat moss, in a ratio 1:2 in v/v, respectively; and coarse substrate (CS) – sieved coarse tezontle (size of the mesh of 0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v, respectively. From each substrate, the water liberation curves were elaborated based on the methodology by Boodt *et al.* (1974) for organic substrates, with the aim of evaluating easily available water (EAW), among other factors. According to Burés S. (1997), in the EAW substrates, it is "the percentage of volume liberated is between 10 and 50 cm of tension in the water column on the substrate".

The porous capsules of clay were handcrafted with the casting technique (in molds) and firing in a ceramics kiln. The physical characteristics of the porous capsules allow using them as irrigation emitters that operate by suction, that is, at negative load. They were classified based on their sorptivity, where 24 capsules were selected from a group of 106. Each experimental unit (EU) was made up of one pot (of 23 cm superior diameter, 16 cm inferior diameter, 15 cm height, and exposure area of 415.48 cm); substrate (tezontle plus peat moss); ornamental plant (obtained by transplanting); and irrigation system. The irrigation system was integrated by a porous capsule (emitter) and the source of water supply at a suction height of −10 cm, with regards to the center of emitter (Figure 1). The capsules are connected to the water source through a polyethylene hose of 5 mm diameter.

Figure 1. Experimental unit with pot, substrate, plant, and irrigation system.

The water source was a precipitate glass (with capacity of 200 mL), covered in its superior part with aluminum paper, and thus to avoid evaporation. Nutrition was supplied through the irrigation water (fertigation), with Steiner's universal nutritional solution (Table 2) described for its management in Baca *et al.* (2016), with industrial-grade salts, with the same management for all the experimental units.

The experimental design was completely randomized blocks (CRB) with six treatments and four repetitions, with 24 experimental units (Table 1), which were distributed randomly in two blocks (Figure 2). The response variable was water consumption of three ornamental species (Ge, Pe and Ga) in two substrates under the same conditions of fertigation management by suction, through porous capsules in pots, inside a greenhouse. The water consumption was measured and recorded by experimental unit (mL day^{-1}) and it was replaced every day to maintain the suction load of -10 cm.

RESULTS AND DISCUSSION

The experimental phase took place from September 12 to November 30, 2017, with duration of 80 days.

Capsules (*emitters*). The porous emitters (capsules) were classified and selected based on the sorptivity (Table 3). It was calculated based on the change in weight of the capsules, from a dry to a wet state, when the sphere was put into contact with the water surface, in a dampening time of 10 minutes. For each type of substrate, 12 capsules were selected. The porous capsules (emitters) are very similar, with differences under 1% in terms in sorptivity, which allowed evaluating with greater certainty the effect of the substrate mixture and the ornamental species, in the water consumption.

Substrates. Table 4 shows the values of water retained (v/v) of each of the substrates, in four levels of suction (0, 10, 50 and 100 cm of water column), where the water content

Table 2. Chemical composition of Steiner Nutritional Solution.

Salt	**Anions**			**Cations**		
	(mmol$_c$ L^{-1})					
	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	K^+	Ca^{2+}	Mg^{2+}
Potassium nitrate	3			3		
Calcium nitrate	9				9	
Monopotassium phosphate (MKP)		1		1		
Potassium sulfate			3	3		
Magnesium sulfate			4			4
∑	12.0	1.0	7.0	7.0	9.0	4.0
	∑A=20.0			∑C=20.0		
	mM					
	12.0	1.0	3.5	7.0	4.5	2.0
	PO=30*0.024=0.72 atm					

OP.-Osmotic Potential (atm.), Source: (Baca, Rodríguez, & Quevedo, 2016).

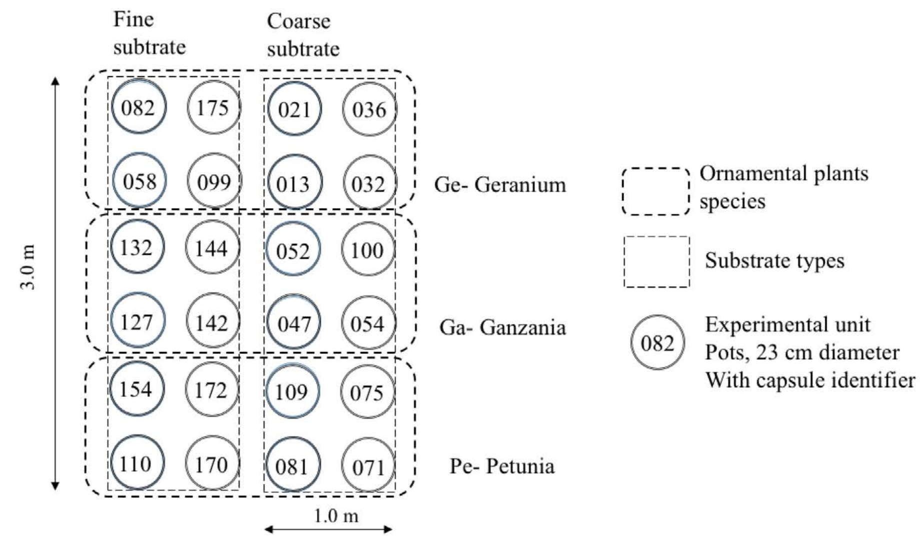

Figure 2. Distribution of experimental units in the greenhouse.

Table 1. Treatments to measure water consumption in three ornamental species (Geranium, Gazania and Petunia) in two substrates and irrigation system based on porous capsules in greenhouse.

Treatments	Substrate	Species	Notation
1	Fine Substrate	Geranium	SF-Ge
2	Coarse Substrate	Geranium	SG-Ge
3	Fine Substrate	Gazania	SF-Ga
4	Coarse Substrate	Gazania	SG-Ga
5	Fine Substrate	Petunia	SF-Pe
6	Coarse Substrate	Petunia	SG-Pe

* Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio 1:2 in v/v. Coarse Substrate (CS)=tezontle (0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v. Geranium (Ge), Gazania (Ga), Petunia (Pe).

Table 3. Statistics of sorptivity (mm $s^{-1/2}$) of the porous capsules for each substrate.

Estadistico	Fine Substrate	Coarse Substrate	Absolute difference
Maximum	0.524	0.569	0.045
Minimum	0.390	0.390	0.000
Media	0.444	0.474	0.030
Standard Deviation	0.038	0.049	0.011

that the substrates retain is different for each level. The coarse substrate presents a greater capacity for water retention at different forces of suction, despite having the largest particle size of tezontle (between 0.4-0.6 mm) due to the content of peat moss. When performing the water liberation curves of each substrate (Figure 3), a similar behavior is seen.

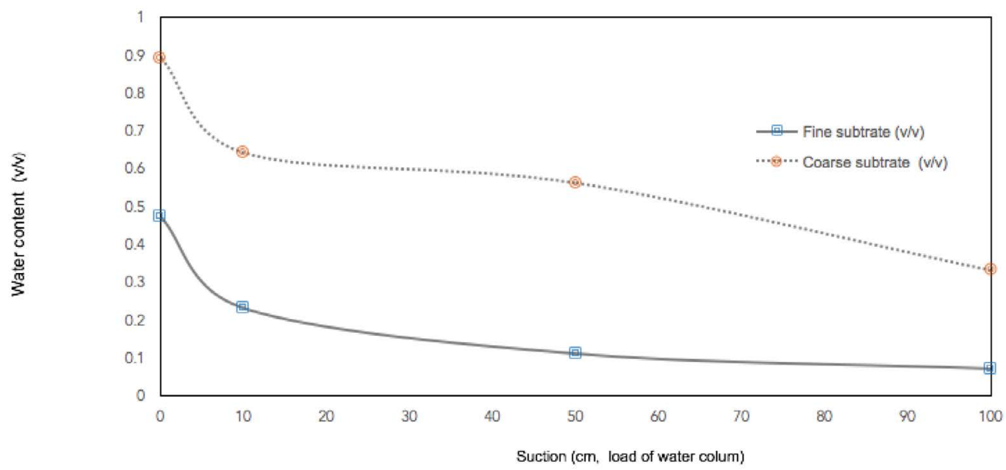

Figure 3. Curve of water retention of each of the substrates. *Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio 1:2 in v/v. Coarse Substrate (CS)=tezontle (0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v. Geranium (Ge), Gazania (Ga), Petunia (Pe).

Table 4. Volumetric water content at different tensions for each substrate.

Suction (cm) (c.c.a.*)	Fine Substrate **	Coarse Substrate ***
0	0.47	0.89
10	0.23	0.64
50	0.11	0.56
100	0.07	0.33

*c.c.a.- load of water column. **Ratio 1:2 v/v; Tezontle (<0.4 mm): peat moss). ***Ratio 1:1 v/v; Tezontle (0.4-0.6 mm): peat moss).

With the methodology by Boots *et al.* (1974), the results were evaluated and compared and interpreted based on these six variables (Table 5), given that it is a response in function of the type of material (organic, inorganic, synthetic, interaction between materials), size of the particles, and ratios of each mixture, which can even change the properties in time.

Table 5. Distribution of water, air and solids in substrates.

Variable	Fine Substrate (v/v)**	Coarse Substrate (v/v)**	Diferencia absoluta
Hardly available water (HAW)	0.07	0.33	0.26
Reserve Water(WR)	0.04	0.23	0.19
Easily available water (EAW)	0.12	0.08	0.04
Air capacity (AC)	0.24	0.25	0.01
Total pore spacel (TPE)	0.47	0.89	0.42
Solid Material (SM)	0.53	0.11	0.42

* Based on Boodt *et al.* (1974). ** v/v – Water content in v/v (volume of water /volume of substrate).

Fertigation. It is important to highlight the preparation of the nutritious solution, to avoid precipitations and with that, plugging of the internal surface of the capsules. It should be mentioned that the size of the pores in the capsules is measured in values of microns and ions at the level of angstrom.

Water consumption. For each experimental unit, the values are indicated in Table 6 (Fine Substrate) and Table 7 (Coarse Substrate), for each of the three ornamental species, where

Table 6. Water consumption by experimental unit of three ornamental species in Fine Substrate (FS) and irrigation system based on porous capsules, in greenhouse conditions.

EU*	Capsule Number	Irrigation sheet (cm)	Irrigation sheet (cm)	Irrigation sheet (cm)	Total (cm)
	Geranium				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12-Nov 21	-	-	
	DAS	1-80			
1	21	7.63	3.67	1.84	13.14
2	36	5.97	2.5	1.25	9.72
3	13	7.66	3.46	1.76	12.88
4	32	6.87	3.08	1.5	11.45
	Average	7.03	3.18	1.59	11.8
	S.D.	0.8	0.51	0.27	1.57
	Gazania				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12-Oct 30	Oct 31-Nov 20	Nov 21-Nov 30	
	DAS	1-50	51-70	71-80	
1	52	6.09	2.61	1.46	10.16
2	100	7.39	5.43	2.37	15.19
3	47	7.25	4.61	2.19	14.05
4	54	2.48	4.18	0.39	7.05
	Average.	5.8	4.21	1.6	11.61
	S.D.	2.29	1.18	0.9	3.73
	Petunia				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12- Oct 30	Oct 31-Nov 20	Nov 21-Nov 30	
	DAS	1-50	51-70	71-80	
1	109	7.91	3.34	1.8	13.05
2	75	5.89	1.88	1.03	8.8
3	81	8.21	5.41	2.64	16.26
4	71	10.57	6.03	3.22	19.82
	Average.	8.15	4.17	2.17	14.48
	S.D.	1.92	1.91	0.96	4.69

*E.U.-Experimental Unit. **DAS=Days after settling. ***S.D.-Standard Deviation. **** Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio of 1:2 in v/v.

the accumulated water consumption is indicated by phenological stage and the total. In terms of the total water consumption in the fine substrate, as it increased, it was 11.27, 14.23 and 18.23 mm for Geranium, Gazania and Petunia, respectively; similarly, for the coarse substrate, it was 11.61, 11.8 and 14.48 mm for Gazania, Geranium and Petunia, respectively.

Table 7. Water consumption in ornamental plants by experimental unit in Coarse Substrate (CS) and irrigation system based on porous capsules, in greenhouse conditions

EU*	Capsule Number	Irrigation sheet (cm)	Irrigation sheet (cm)	Irrigation sheet (cm)	Total (cm)
	Geranium				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12-Nov 21	-	-	
	DAS	1-80			
1	21	7.63	3.67	1.84	13.14
2	36	5.97	2.5	1.25	9.72
3	13	7.66	3.46	1.76	12.88
4	32	6.87	3.08	1.5	11.45
	Average.	7.03	3.18	1.59	11.8
	S.D.	0.8	0.51	0.27	1.57
	Gazania				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12-Oct 30	Oct 31-Nov 20	Nov 21-Nov 30	
	DAS	1-50	51-70	71-80	
1	52	6.09	2.61	1.46	10.16
2	100	7.39	5.43	2.37	15.19
3	47	7.25	4.61	2.19	14.05
4	54	2.48	4.18	0.39	7.05
	Prom.	5.8	4.21	1.6	11.61
	D.E.	2.29	1.18	0.9	3.73
	Petunia				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12- Oct 30	Oct 31-Nov 20	Nov 21-Nov 30	
	DAS	1-50	51-70	71-80	
1	109	7.91	3.34	1.8	13.05
2	75	5.89	1.88	1.03	8.8
3	81	8.21	5.41	2.64	16.26
4	71	10.57	6.03	3.22	19.82
	Average.	8.15	4.17	2.17	14.48
	S.D.	1.92	1.91	0.96	4.69

*E.U.-Experimental Unit. **DAS= Days after settling. ***S.D.-Standard Deviation. **** Coarse Substrate (CS)=tezontle (between 0.4-0.6 mm) and peat moss in a ratio of 1:1 in v/v, respectively.

To test the hypotheses, the statistical analysis of the experimental design was carried out with statistical package SAS 9.4, with regards to the water consumption as a response variable, in the three ornamental genera (Geranium, Gazania and Petunia) and the two substrates (fine and coarse). Based on the results from the ANOVA and Tukey's means analysis, it can be seen that there are no significant differences in water consumption between the treatments (Tables 8, 9). This implies that the irrigation system by porous capsules is capable of supplying water to ornamental plants, regardless of the species and within the substrates studied.

However, not all the hypothesis tests have a total certainty, which is why for the selection of a treatment with the mean improvements, it is frequent to use Tukey's and Duncan's test to make multiple comparisons between pairs of means in agricultural research. In a study, they tested the Tukey, Duncan and Dunnett tests (multiple means comparison with a control) in contrast with the specific means selection tests by Bechhofer and Hsu; they found that Dunnett's test was better, after Duncan's, given that Tukey's test is very conservative (García-Villalpando *et al.*, 2001). Similarly, Wong-González (2010) mentions that in order to conduct analysis of variance, it is necessary to understand the theoretical bases of the tests, and recommends that the most convenient test should be determined based on the objective. Therefore, Duncan's multiple means analysis was carried out, given that the errors of the experimental model are large. Based on Duncan's multiple range

Table 8. ANOVA of water consumption in ornament plants (Geranium, Gazania and Petunia) (alfa=0.05), established in two types of substrates (Fine and Coarse) and irrigation system based on porous capsules, in greenhouse.

Source	D.F*	Suma of squares	Mean Square	Value of F	Pr > F
Model	5	156.8330833	31.3666167	2.82	0.0476
Error	18	200.53265	11.1407028		
Corrected total	23	357.3657333			

* D.F. Degrees of freedom.

Table 9. Group of means with Tukey's test, of water consumption of three species of ornamental plants (Geranium, Gazania and Petunia), in two types of substrate (Fine and Coarse), and irrigation system based on porous capsules, in greenhouse.

Tukey groups	Mean	n	Treatments
A	18.643	4	SF-Pe
A	14.483	4	SG-Pe
A	14.228	4	SF-Ga
A	11.798	4	SG-Ge
A	11.613	4	SG-Ga
A	11.268	4	SF-Ge

*Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio 1:2 in v/v. Coarse Substrate (CS)=tezontle (0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v. Geranium (Ge), Gazania (Ga), Petunia (Pe).

**Means with the same letter are not significantly different.

means test, which controls the rate of the comparison error (Type I error) but not the experimental errors (Tables 10, 11).

The variation in water consumption is higher in fine and coarse substrates in Petunia, and it is similar in Gazania in the coarse substrate. Water consumption in Geranium was similar in both substrates and slightly higher in Gazania with fine substrate (Figure 4).

Based on the results, it is observed that there are two groups with statistically significant differences, which implies that the null hypothesis (*Ho*) is rejected. This is where group A is the Petunia treatments in both substrates and Gazania with fine substrate, which are the ones that presented the highest water consumptions (between 14.22 and 18.64 cm), with the Petunia treatment with fine substrate being the highest. Group B is integrated by the treatments of Gazania and Geranium (in the two types of substrates), in addition to

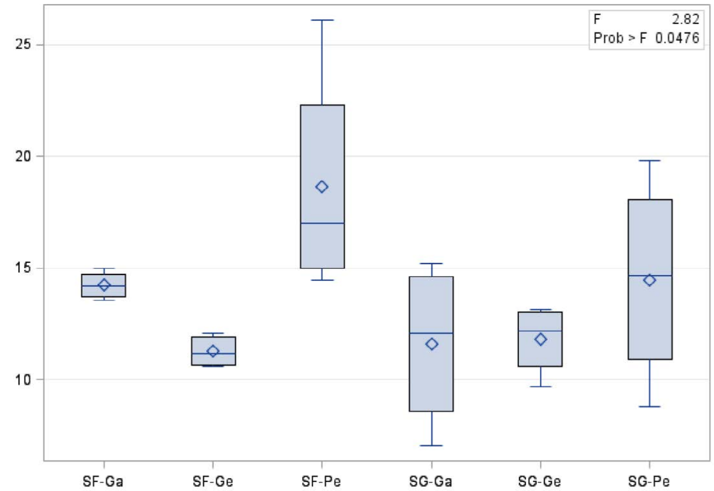

Figure 4. Box diagram of water consumption (cm) by treatment of three ornamental plant species (Geranium, Gazania and Petunia), in two types of substrate (Fine and Coarse) and an irrigation system based on porous capsules, in greenhouse.

Table 10. Groups of means (Duncan) of water consumption of three species of ornamental plants (Geranium, Gazania and Petunia), in two types of substrate (Fine and Coarse) and irrigation system based on porous capsules, in greenhouse.

Duncan Grouping		Mean	n	Treatments
	A	18.643	4	SF-Pe
B	A	14.483	4	SG-Pe
B	A	14.228	4	SF-Ga
B		11.798	4	SG-Ge
B		11.613	4	SG-Ga
B		11.268	4	SF-Ge

*Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio 1:2 in v/v. Coarse Substrate (CS)=tezontle (0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v. Geranium (Ge), Gazania (Ga), Petunia (Pe).

**Means with the same letter are not significantly different.

Table 11. Intervals of range for Duncan's means.

Number of Means	2	3	4	5	6
Critical Range	4.958	5.202	5.357	5.463	5.541

Petunia with coarse substrate, with water consumptions between 11.26 and 14.48 cm. The treatments that are in both groups are Petunia with coarse substrate and Gazania in fine substrate.

CONCLUSIONS

Significant differences in water consumption by ornamental plants and substrate type were present, where the irrigation system by porous capsules with suction have the capacity to supply continuously the water demand of the plant-substrate-atmosphere system of each of the species evaluated, based on the capacities for moisture retention of each substrate that was used.

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AGRO PRODUCTIVIDAD

Colegio de Postgraduados

Bioplastics: Environment-friendly materials and their production technologies

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ABSTRACT

Objective: To analyze the recent contributions of bioplastics in addressing environmental problems caused by plastic pollution.

Design/Methodology/Approach: A literature review was carried out on the definitions of plastics and bioplastics, the sources of raw materials, processing technologies and methods to assess biodegradation. Current practices for final disposal and/or reuse were also examined. Special emphasis was placed on polylactic acid (PLA), one of the most widely used biodegradable materials today.

Results: Over the years, there have been significant developments in the definitions of plastics and bioplastics, as well as in the sources of raw materials and processing technologies used to create final plastic products. By using bioplastics instead of conventional plastics, it is possible to reduce the dependence on petroleum and mitigate the pollution associated with plastic production and disposal. Furthermore, the enhanced biodegradability of bioplastics ensures that they break down more readily in natural environments, reducing the accumulation of plastic waste and its detrimental impact on ecosystems. The production of bioplastics using plant fibers, biological materials, and polymeric waste materials presents an opportunity for integration into the productive activities of the agro-industrial sector. This integration brings several benefits and synergies between agriculture and industry.

Study limitations/Implications: We provide a report based on the literature.

Findings/Conclusions: there is a notable current trend in the utilization of bioplastics as a viable substitute for conventional plastics. In order to assess the biodegradability and compostability of these materials, specific testing and certification standards have been established by reputable organizations. These standards serve as a reliable framework for evaluating the environmental impact and degradation characteristics of bioplastics. By adhering to these guidelines, manufacturers can ensure that their bioplastic products meet the necessary criteria for sustainable use.

Keywords: Bioplastics, Plant residues, Waste.

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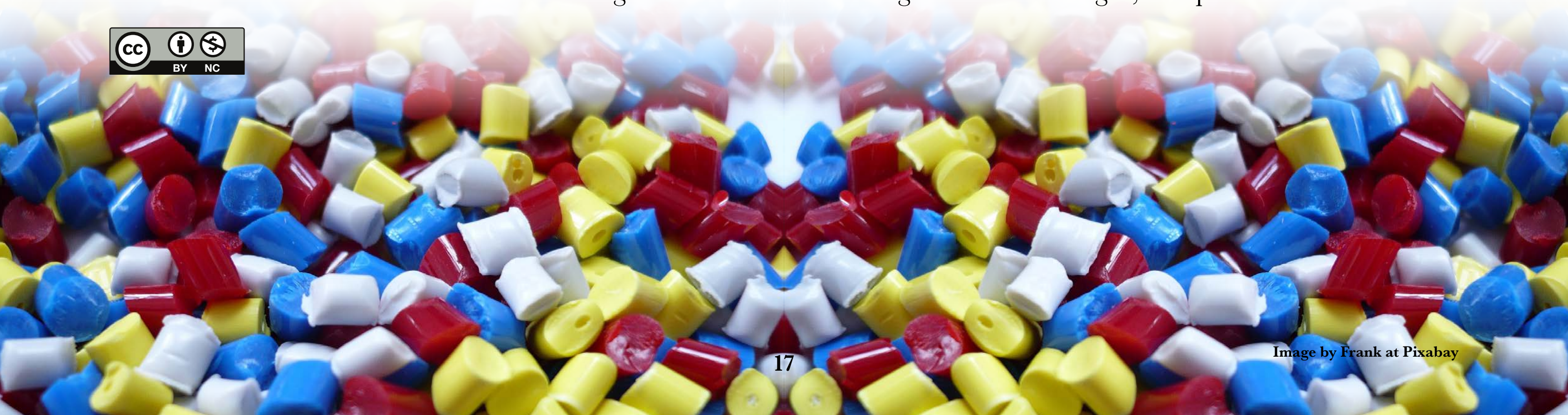
INTRODUCTION

The increasing levels of plastic pollution both in land and water degrade the environment (García and Robertson, 2017). Conventional plastics exhibit inherent resistance to degradation due to their high molecular weight, complex three-dimensional



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structure, minimal water content, and hydrophobic nature. These characteristics impede degradation processes caused by factors such as exposure to light, water, and the activities of living organisms or their enzymes (Kale *et al.*, 2015; Chamas *et al.*, 2020). When burned, plastics generate CO_2 and other toxic gases (Wu *et al.*, 2021), such as dioxins (Kale *et al.*, 2015). A significant amount of plastic waste ends up in landfills. While recycling technologies do exist for certain types of plastics, such as polyethylene terephthalate (PET) and polyethylene (PE), but effective recycling requires proper separation and collection of these materials (Song *et al.*, 2009). However, it is important to note that the costs of recycling can be high, and the quality of recycled plastic products may be lower compared to their virgin counterparts (García and Robertson, 2017).

One effective approach to minimize the reliance on traditional plastics is by substituting them with biodegradable (Ferreira *et al.*, 2019) and compostable (Sabapathy *et al.*, 2020) alternatives. These innovative materials can be broken down by microbial extracellular enzymes (Bano *et al.*, 2017; Sabapathy *et al.*, 2020) or through exposure to light, water, and oxygen (Siracusa, 2019). As a result, they generate carbon dioxide (CO_2), water (H_2O), methane (CH_4), and other light compounds (Siracusa, 2019), which have a reduced environmental impact compared to traditional plastics.

Definition of plastics

Plastics are polymers, which are large molecules composed of repeating subunits called monomers whose composition does not change when molded through heat and pressure (WWF, 2018). They are characterized by low density, low electrical conductivity, transparency, which allows their transformation into a variety of products. Polyethylene, polypropylene, and polyvinyl chloride are affordable, versatile, and extensively utilized plastics. They are commonly employed for short-term applications. Polycarbonates, polyether ether ketones, and polyimides are durable plastics that have a longer-term applications with a higher cost compared to other plastics (Feldman, 2008; Ramos, 2018). All these products come from the petrochemical industry and constitute over 80% of globally-used plastics (Urbanek *et al.*, 2018).

Classification of plastics by a degradability criteria. Plastics can be classified into recalcitrant and biodegradable. Recalcitrant plastics are derived from petroleum, transformed by synthesis into polymers with a high molecular weight, and do not degrade easily. Biodegradable plastics undergo degradation within a few months.

Bioplastics: definition and production

The International Union of Pure and Applied Chemistry (IUPAC) defines biodegradable polymers as materials that are susceptible to degradation by biological activity, with the degradation accompanied by a decrease in their molar mass (Haider *et al.*, 2019). According to the American Society for Testing and Materials (ASTM), biodegradable polymers can be distinguished from other plastics by their ability to decompose into carbon dioxide, water, inorganic compounds, and biomass at a similar rate to other recognized compostable materials. Additionally, it is crucial for these polymers not to leave any noticeable or harmful residues behind, ensuring their environmental compatibility (Food Packaging Forum, 2021). The determination of biodegradability and compostability of materials relies on specific testing and certification standards, such as those established by ASTM. These standards provide a systematic framework for evaluating and verifying the environmental characteristics of materials in order to ensure accurate assessment of their biodegradability and compostability. The European Bioplastics Organization defines bioplastics as those included in one of the following categories: a) of biological origin; b) biodegradable; or c) both. This categorization includes products containing raw materials derived from petroleum. Thus, some bioplastics, such as Bio-PET, are naturally occurring polymers combined with petroleum-derived polymers and are not biodegradable (Van Crevel, 2016). Some bioplastics are made of polymers of plant or animal origin, such as polysaccharides (cellulose, starch, chitin, and lignin); others contain proteins (gelatin, casein, gluten); and still others, lipids (Arikan and Ozsoy, 2015). Other biodegradable polymers are synthesized from precursors of microbial fermentation and subsequently polymerized through chemical and physical transformations (Arikan and Ozsoy, 2015). Most biodegradable polymers are aliphatic polyesters, like polylactic acids (PLA) and polyhydroxyalkanoate (PHA), manufactured from precursors of microbial origin that are biodegradable and compostable (Van Crevel, 2016; Sabapath *et al.*, 2020). Others are plant-based polymers such as thermoplastic starches (TPS) and polybutylene succinate (PBS) (Zhao *et al.*, 2020). Production of bioplastics is currently growing (Figure 1) (Verbeek and Uitto, 2017). In Mexico, the agricultural products —sugar cane, citrus fruits, and bananas (INEGI, 2019) (Figure 2)— generate waste that can be used in the production of bioplastics (Riera *et al.*, 2018; Rivera-Mackintosh and Nevárez-Moorillón, 2019).

Polylactic (PLA) production

PLA is a biodegradable aliphatic polyester known for its thermoplastic properties (Figure 3). It is derived through the polymerization process of lactic acid. Lactic acid, the precursor for PLA, can be obtained through either chemical synthesis or fermentation methods (Li *et al.*, 2020). Chemical synthesis primarily results in the production of DL-

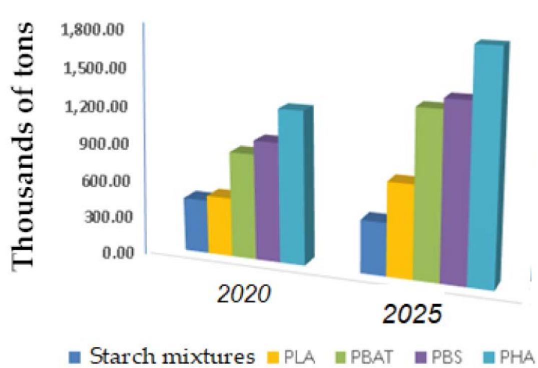

Figure 1. Comparative forecast for the production of biodegradable bioplastics from 2020 to 2025. Abbreviations: PLA, polylactic Acid; PBAT, polybutylene adipate; PBS, polybutylene succinate; PHA, polyhydroxyalkanoates (elaborated with data from the European Bioplastics Organization, https://www.european-bioplastics.org/bioplastics/materials/).

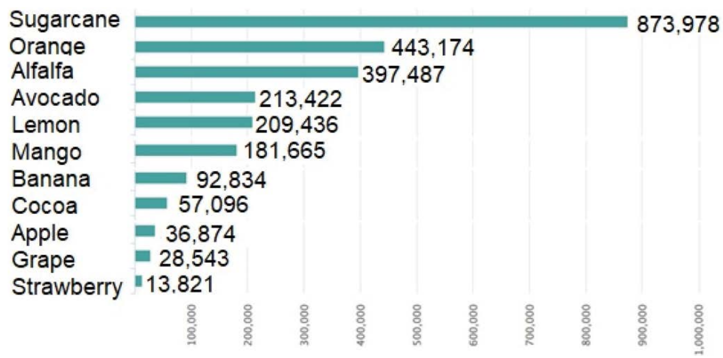

Figure 2. National agricultural survey. Source: INEGI, 2019.

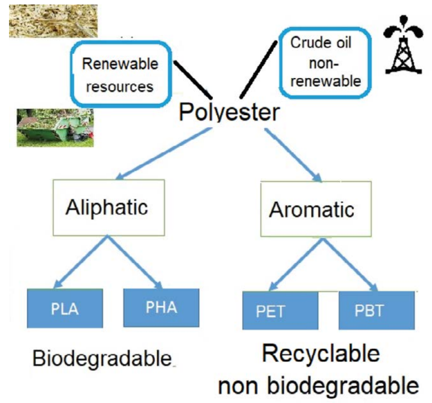

Figure 3. Bioplastics: biodegradable and from biological origin (renewable sources). PLA, polylactic acid; PHA, polyhidroxyalkanoates; ; PET, polyethylene terephthalate; PBT, polybutylene terephthalate.

lactic acid, whereas microbial fermentation can yield D- or L-lactic acid or a combination of isomers, depending on the bacterial species and the substrate employed. When PLA is derived from either the L-isomer or the D-isomer, the polymer exhibits a crystalline structure and greater stability compared to the amorphous polymer obtained from a racemic mixture. The choice of isomer in PLA production can influence its physical and chemical properties, making it important to consider the desired characteristics for specific applications (Calabia and Tokiwa, 2007). To produce lactic acid, whether it is the D or L isomer, maintaining pure bacterial cultures is essential to prevent contamination. Achieving aseptic conditions is crucial during this process. However, the sterilization of culture media can be an expensive step. In the production of polylactic acid, lactic acid is purified and subjected to condensation to form lactides. Lactides are cyclic dimers that undergo polymerization to form the desired polylactic acid. However, direct condensation is hindered by the presence of water and impurities. This can result in the production of polymers with low molecular weight and inferior mechanical properties.

To address this issue, chain extenders are utilized to facilitate longer chain polymerization, resulting in improved mechanical properties.

PLA properties. PLA has good transparency, gloss, crease retention, twist retention, heat sealability, flavor and aroma barrier properties, low heat sealing temperature, and a suitable surface for printing (Levytskyi *et al.*, 2021). It is insoluble in water and resistant to moisture and grease. Its mechanical properties depend on molecular weight and crystallinity. Current applications include transparent packaging films and food-grade disposable thermoformed articles. It can also be spun into fibers for fabrics and textiles. The recent production of biocomposites with a matrix of cellulose microfibers from sugar cane straw and polylactic acid (Figure 4) has led to renewed properties, such as a higher melting point and an increase in the elasticity modulus, which reduces the biocomposite's elongation index (López Velazquez *et al.*, 2020). PLA has properties similar to polyethylene terephthalate (PET) and is also used for packaging, but unlike PET, it is compostable. PLA is non-enzymatically degraded, the resulting monomers being degraded by microorganisms, and it is also compostable (Siracusa, 2019). Polylactide degradation occurs at >60 °C, in the presence of oxygen and moisture, by hydrolysis and photooxidation or thermal oxidation mechanisms (Chamas *et al.*, 2020) —although it also depends on pH, the polymer's molecular weight, and crystallinity (Levytskyi *et al.*, 2021).

Processing of bioplastics

The melting temperature of PLA falls within the range of 169-180 °C, which allows the processing of this polymer by the following methods: a) extrusion; b) blowing; c) thermoforming; and d) injection molding (Contreras *et al.* 2018; Levytskyi *et al.*, 2021). A) Extrusion: a die is used to melt the materials through friction forces (Figure 5), with a subsequent final cooling phase that allows the materials to harden. B) Blowing: this process follows the plastic's extrusion using a circular die with a hole in the center to blow the extruded material, which inflates like a balloon (Figure 5). The bubble of molten plastic cools with the external air and solidifies along the tube. This method is used to produce bottles. C) Thermoforming: this hot molding method includes variants based on thermoplastic heating (Figure 5). Molding can take place using vacuum, blowing, or mechanical means (vacuum, temperature, and pressure), and said methods can be combined. The machinery employed, besides being simple, is economical and compact, so that this method is widely used to manufacture large-sized and thin-walled molds of complex configurations (Figure 5). D) Injection: in this process, a thermoplastic is melted using heat. A machine injects

Figure 4. Biocomposite made of cellulose microfibers from sugarcane straw and polylactic acid.

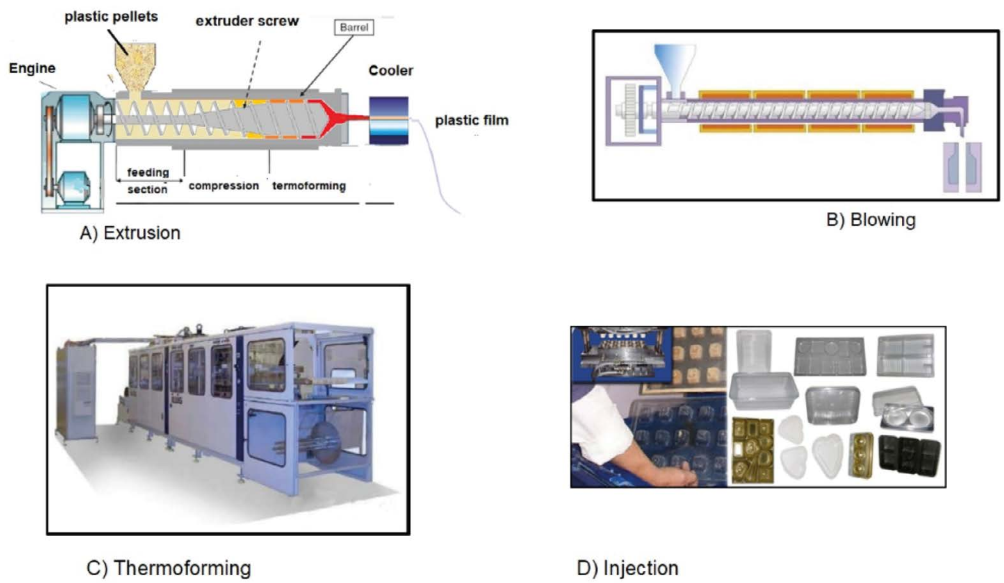

Figure 5. Technologies for the processing of bioplastics/biomaterials.

heat into the mold's cavities with an adequate pressure and temperature. Subsequently, the materials cool into a solid plastic shape with dimensions similar to those of the mold. To evaluate and define the optimal use of bioplastics, one must examine their physical, mechanical, and chemical properties.

Biodegradability

According to the ASTM, a compostable material should disappear within 12 weeks without leaving fragments, residues, heavy metals, or toxins that may affect plant growth. Tables 1 and 2 present the main differences between biodegradable and conventional plastics.

Table 1. Differences between biodegradable and conventional plastics.

Characteristics	Biodegradable plastics	Conventional plastics
Source of raw materials	Natural polymers such as starch, cellulose and chitin extracted from living organisms such as plants, animals or produced by microorganisms. Polymers synthesized from natural compounds	Petroleum derivatives
Examples	PLA, PHA, PBS, PBAT	PE, PP, PET
Uses	Food packaging, textiles,	Wide use
Decay time	$<$6 months	Up to 500 years
Type of pollution generated	Minimum	Wastes and microplastics in land, water and air
Type of treatment for degradation	Composting	burning

With data from: Intención del uso del plástico biodegradable en hogares y su incidencia en la contaminación ambiental, Arana and Miranda (2019), Emadian *et al*., 2017, and Goel *et al*., (2021).

Table 2. Biodegradability of bioplastics in different environments.

Bioplastic	Environment	Temperature/Relative humidity	Biodegradability (%)	Methods of assessment	Test period (days)
PLA	Compost	58 °C, 60% RH	13-84	CO_2	28-60
	Soil	25 °C, 30% −60% RH	10	Weigth loss	28-98
PHA	Soil/compost (90/10%)	25 °C, 65% RH	40–50	CO_2	15
	Soil	35 °C, 60% RH	35-48	Weigth loss, CO_2	60, 280
PHB	Compost	58 °C, 70% HR	80	CO_2	110
	Soil	30 °C, 80% HR	64-98	Weigth loss	180-300
	Sea water	25 °C	80-99	Weigth loss, CO_2	14-49
Starch based	Compost (termoplástic)	58 °C	73.1	CO_2	56
	soil (plastic made from starch)	20 °C, 60% HR	14.2	CO_2	110
	Marine environment	26 °C	100	Weigth loss	50
Celullose	Compost (celulose acetate)	53 °C	100	CO_2	18
	soil (celulose)	25 °C	100	Weigth loss	180

PLA, polylactic acid; PHA, polyhidroxyalkanoates; PHB, polyhydroxybutyrate. With data from: Intención del uso del plástico biodegradable en hogares y su incidencia en la contaminación ambiental, Arana and Miranda (2019), Emadian *et al.*, 2017, and Goel *et al.*, (2021).

It is crucial to assess the limitations and characteristics of bioplastics to understand their potential applications and performance. Testing the mechanical properties, resistance, and permeability of bioplastics to water and gases helps evaluate their suitability for specific uses. Bioplastics, derived from diverse sources, exhibit variations in their properties compared to traditional plastics. It is important to consider their origin, lifetime, and beneficial properties for the environment, and for the producers involved. In many cases, production costs need to be optimized.

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Colegio de Postgraduados

Descriptive analysis of wine tourism in Querétaro and Baja California, Mexico

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ABSTRACT

Objective: To present the characteristics of wine tourism that takes place in the states of Querétaro and Baja California, Mexico.

Design/methodology/approach: Descriptive analysis through primary sources of information where 228 questionnaires were applied to those who carried out wine tourism in the states of Querétaro and Baja California, or who in the last three years have carried out this activity in Mexico.

Results: The survey respondents reflect interest in the knowledge, production and culture of wine. In addition, they state that the wine routes in the study areas give them satisfaction in the price-quality ratio, wine tastings and gastronomy and that these are key to the development of viticulture in Mexico.

Limitations on study/implications: People feel that they do not have enough knowledge about wine tourism, which limited their participation when answering the questionnaire. However, this work is a first approximation to carry out a study that relates wine tourism and the competitiveness of the wine industry in Mexico, for which the answers are timely.

Findings/conclusions: Mexican wine is considered to have the potential to compete with foreign wines in factors such as quality, flavor and price. In addition, there is a preference for the consumption of Mexican wines, especially red, rose and white. Therefore, the wine production from states such as Chihuahua, Sonora, Coahuila and Durango, which have a large territorial extension, should be taken advantage of, and more commercial wine routes should be created to help promote this industry at the national level to improve society through greater offer, job creation and reduction of imports.

Keywords: wine tourism, viticulture competitiveness, regional economic growth.

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INTRODUCTION

According to the International Organization of Vine and Wine (OIV), in the year 2019, wine production in the world was distributed around the five continents, where Europe resulted in a total of 163,287 hectoliters (hl), that is, more than 63.4%; America

with 55,411 hl equivalent to 21.6%; for its part, Oceania had a production of 14,944 hl, which is 5.6%; Asia with 12,854 hl corresponding to 5%; and finally, Africa with a total of 11,197 hl equivalent to 4.4%. The resulting wine production in the world was 257,693 hl (OIV, 2019).

For the same year, regarding the trade and use of wine, nearly 237,485 hl were consumed in the world; that is, more than 92% of the total wine production, from which 107,335 hl (41.7%) were destined to exports from the main producing countries in the world, with Italy being the one of greatest renown, with a production of 47,533 hl (18.5%) of the wine in the world, followed by France with a production of 42,197 hl (16.4%), Spain with 33,676 hl (13%), the United States (USA) with 25,562 hl (10%), Argentina with 13,019 hl (5%); and finally, Mexico with a total of 406 hl (close to 1%) in the global production and exports of around 1hl with the destination of: USA, Europe, England, Spain, Italy, Norse countries, Canada and Japan (OIV, 2019).

When it comes to global imports, a figure of 106,728 hl was found; that is, 41.5% of the total production in countries such as the United Kingdom, which for the year 2020 was positioned as the main importer of this fermented beverage, followed by Germany, USA, France, China, Canada, Netherlands, Russia, Belgium and Portugal, which hold their positions thanks to the value market of offer and demand for wine (OIV, 2019).

Centering the information in Latin America, there are countries with broad recognition in wine culture, where Argentina stands out as the largest producer of global quality wine. These wines are produced mostly in Mendoza; in the second position, there is Valle de Guadalupe in Baja California, Mexico, better known as the empire of Mexican wine. Then follows Valle de Maipo in Chile, which stands out as the largest wine exporter; Canelones, Uruguay, which has perfect cellars for wine tourism; and finally, Rio Grande Do Sul in Brazil, which stands out for its sparkling wine (OIV, 2019).

Presently, wine production in the Mexican territory is considered one of the jobs with greatest demand [Secretaria de Agricultura y Desarrollo Rural (SADER, 2021)]. Wine production and vine cultivation in Mexico is carried out in large extensions of land; it is conducted primarily in 11 of the 32 states of the Mexican Republic, which are: Aguascalientes, Baja California, Chihuahua, Coahuila, Durango, Guanajuato, Nuevo León, Puebla, Querétaro, Sonora and Zacatecas. However, it is not enough to satisfy the current consumption in the country, so it is essential to import foreign wine in order to satisfy the demand. Because of this, more than 65% of the wine consumed in Mexico is imported from foreign countries like Spain, Chile, France, Italy and Argentina (Margall von Hegyeshalmy, 2000), thanks to which a total annual consumption of 1,166 hl was reached in 2019, equivalent to 1.2 liters *per capita* (OIV, 2019).

At the beginning of the 21st century, there was an increase in the quality and the ambition among the best wine producers in Mexico, and they increased their levels of production and improved the quality of their products; after this, foreign investment increased, causing for foreign wineries of great renown to invest in national wineries and to position their vineyards in the Mexican territory in order to generate sources of employment and implement wine tourism (Moss, 2017).

The tourism activity has been central for the development of wine routes in the states of Querétaro and Baja California, and with them, the locals have been forced to value their territory and think of wine tourism as the main vocation of the zone to make more dynamic the economy of the regions and to reassess their human capital when integrating natural and cultural resources. With this, the transformation of the wine industry took place, and it was achieved for it to become a great source of jobs and sustenance for Mexican families (Quiñonez *et al*., 2011).

Currently, although grape cultivation and wine production in Mexico have social, economic and religious importance for the country, the existing studies are related primarily with some type of productive comparison in two different locations, as well as its approach in research derived from the composition, market strategies, and profitability in terms of gastronomy and commercialization of wine.

This study is a first approach to determine the relationship between wine tourism and the competitiveness of the viticulture industry in Mexico. This first phase consists in presenting the characteristics of the wine tourism that is present in the states of Querétaro and Baja California, Mexico. It is expected to find that wine tourism in these regions has grown and the characteristics of tourists that are considered most relevant at the time of carrying out wine tourism have been identified. These regions have been selected, since they are where the viticulture industry is developed to a greater extent and have a similar tendency in terms of socioeconomic and economic-productive characteristics.

MATERIALS AND METHODS

This study has the objective of characterizing wine tourism in the regions of Valle de Guadalupe, Valle de Santo Tomás, and Ensenada in Baja California; and Peña de Bernal, Valle de Tequisquiapan, and Ezequiel Montes in the state of Queretaro.

To achieve this, primary sources of information were used which were obtained through field work. A questionnaire was elaborated made up of 15 questions with the objective of understanding the opinion of locals regarding wine tourism in the study zones and their wine consumption. The questions were applied exclusively to tourists and experts in wine tourism. The questionnaire was established by 35 questions divided into three sections: 1) survey respondent profile, 2) wine tourism, and 3) wine consumption.

The questionnaires were applied via Google Drive, where responses were obtained from 228 people who were carrying out wine tourism in the regions mentioned before, or else those who in the last three years have carried out the activity.

RESULTS AND DISCUSSION

From the 228 tourists surveyed, 54.5% were located in the following age ranges: from 25 to 30 years, 20.6%; followed by 35 to 40 years, 17.5%; and 40 to 45, 16.7%. The people who carry out wine tourism are 59.6% women and 37.3% men (the remaining 3.1% preferred not to reveal this information). In the case of marital status, 56.1% of the survey respondents are single, while 43.9% are married.

Regarding their place of residence, a differentiation was made between national or foreign, where 89.9% are national, from 17 of the 32 states in the Mexican Republic, as shown in Figure 1.

When it comes to foreigners, 90.0% are from the United States, primarily from California and Texas. The level of studies and current labor situation of the survey respondents indicate that 50.9% of them have undergraduate studies, followed by 17.1% with high school, and 14.9% with master's degree; they are followed by 7.5% with PhD studies and 3.9% with levels of primary and secondary education, while 1.8% equivalent to 4 survey respondents do not specify this information. The labor situation with highest percentage of responses was full time with 44.7% followed by independent workers, with 23.7%, and halftime employment with 9.2%; however, some survey respondents indicated they are students (4.8%), retired (3.1%), do not work (7.0%), are unemployed, halftime students and workers, or they are fulltime and independent workers (1.8%), while five survey respondents equivalent to 2.2% did not specify their labor situation.

When it comes to the second section of the survey on wine tourism, the survey respondents manifested that in a scale of 1 to 10 (1 is little and 10 is a lot), 13.6% are located in level five of knowledge about wine tourism, followed by 12.7% for level one, and 12.3% for level three. Regarding the willingness to pay for wine tourism, 19.3% are located in a range of 200 to 400 pesos per person, and this is followed by 17.5% with a range of 400 to 600 pesos, and then 17.1% from 800 to 1000 pesos. Within this willingness to pay, the most important activities to be conducted are: historical visits to the wineries and wine tastings. From the products and services offered during their trip and visit, the survey respondents manifest as very important the following: gastronomy, wine culture and tradition in the regions, and regarding their level of satisfaction from the services provided in the region, the ones that satisfy their needs most are: wine routes, wine tastings and gastronomy; and the ones that satisfy their needs the least are: transport (to reach the zone and inside the area), communication with people in the locality, and tours and tourism activities in the region. In a scale of 1 to 10 (where 1 is no satisfaction and 10 high satisfaction), in relation

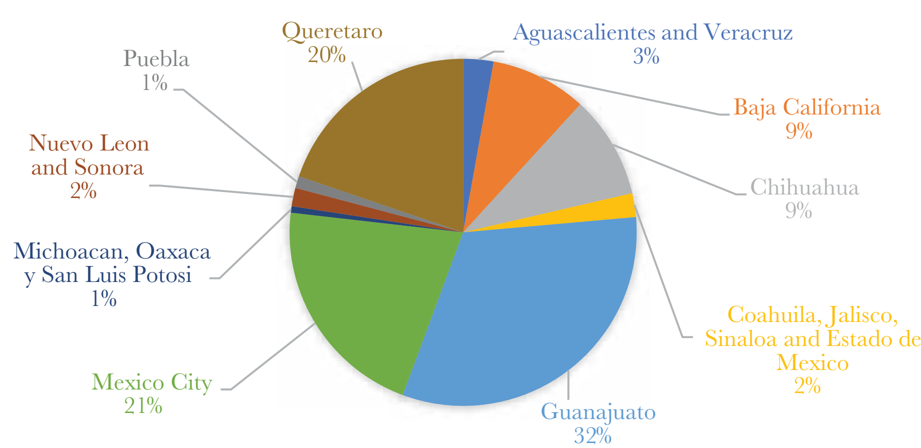

Figure 1. States where wine tourism has been carried out. Source: Prepared by the authors based on the surveys applied from January to June 2022.

to price and quality, 16.7% score this relationship with eight, followed by scores of nine and seven, with 12.7% and 11.8%, respectively. The rest are distributed in different scores, while 32.5% did not answer.

Of the people surveyed, 58.8% indicate that they have carried out wine tourism and they have done it primarily in the months of June, July and September (15.8% and 14%, respectively). The main wineries recognized by survey respondents, both in Queretaro and in Baja California, are presented in Figure 2.

In addition to these wineries, the survey respondents recognize other wineries such as La Cetto (3.5%), El Cielo (2.2%) and Decantos (1.8%), located in Valle de Guadalupe, Baja California. They also indicate that the means by which they learned about these wineries were 32.5% through social networks; 14% through an acquaintance; 12.7% did not specify; 2.2% by locals from the zone; and the remaining 7.9% researched on their own, found out from TV or radio advertising, or through travel agencies; 30.7% did not respond. They were asked in terms of viticulture competitiveness of the regions if they considered that the development of wine tourism activities in the wineries was important in a scale of 1 to 10 (where 1 is not important and 10 very important), 20.2% indicate that the scale is 10 in level of importance, followed by 8 with 18% and 9 for 14% of the survey respondents.

Regarding the third section on wine consumption, 71.1% indicated that they consume wine while the remaining 28.9% indicate that they do not mainly because they prefer to drink other types of beverages, do not consume alcohol, or because they think that the price is high. Of those who consume wine, 44.7% prefer national wine and 12.7% foreign wine, and the rest are indifferent to the origin. Among the most consumed wines by the survey respondents, there are those from the wineries: La Cetto, Casa Madero, La redonda, Finca las Moras, Feixenet and Castilla, and the preferred classifications are: reserve wine for 32.9% of the survey respondents; mature wine for 28.5%; grand reserve wine for 26.8%;

Figure 2. Main wineries visited by survey respondents. RLC * Rancho Llano Colorado (Ensenada, Baja California) VD** Valle de Guadalupe; Source: Prepared by the authors based on the surveys applied from January to June 2022.

and young wine for 25.9%. Within these responses, the survey respondents had the option of selecting vines from one classification. The preferred varieties are red wine, followed by rose wine, white wine and sparkling wine.

In terms of the potential that survey respondents consider for Mexican wine regarding six characteristics, the responses are presented in Figure 3.

These results show that currently there is a growing trend in national wine consumption, and they reflect the interest that people, especially single women between 25 and 30 years old, have to carry out activities related to wine tourism.

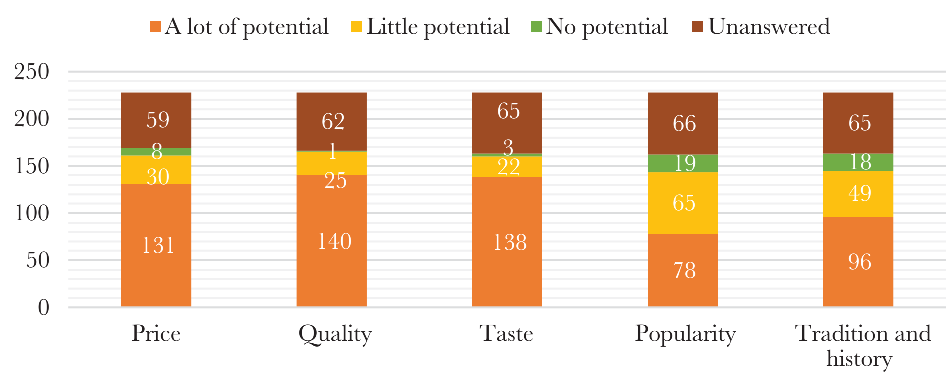

Figure 3. Potential factors that consumers identify in Mexican wine.
Source: Prepared by the authors based on the surveys applied from January to June, 2022.

CONCLUSIONS

The growth in wine consumption, in addition to the foreign investment in national wineries, can decrease wine imports in Mexico. However, the production of states such as Chihuahua, Sonora, Coahuila and Durango must be used, which have the advantage of their great territorial extension that is a factor of great relevance in viticulture industry. Something else that should not be ignored is that states such as Aguascalientes, Zacatecas, Nuevo Leon, Guanajuato and Puebla are key for the industry's growth, so it is important to develop wine tourism since this tourism activity has been key for the development of wine routes both in Querétaro and Baja California. In addition to this, actions must be taken that allow for more people from different states of the republic to visit the wineries, since generally wine tourism in the regions is carried out by people who live in nearby places.

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Colegio de Postgraduados

Strawberry (*Fragaria* × *ananassa* Duch.) production in a vertical hydroponic greenhouse system

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ABSTRACT

Objective: A vertical hydroponic greenhouse system (VHGS) was designed and built to evaluate two strawberry varieties (Festival and San Andreas), in two planting densities per pot (40 and 54 plants/m^2) and three elevation levels (high, medium, and low).

Design/Methodology/Approach: At 126 days after transplanting (dat), the Festival variety showed significant differences in the number of leaves and in the crown diameter.

Results: The vertical hydroponic greenhouse system had a high fruit yield (21 kg m^2): *i.e.*, this production system is up to 35% more efficient than the open field cultivation system or the multi-tunnel greenhouse system. There was a positive correlation between the number (r^2=0.89), diameter (r^2=0.54), and weight (r^2=0.40) of the fruits and the total yield. Planting density did not show a significant effect on plant growth, yield, and fruit quality. The vertical pot system did not show differences between elevation levels. This production system is a viable option for populations in places with a scarcity of water and to obtain fruits with guaranteed food safety.

Keywords: pot, substrate, soilless cultivation, intensive production, vegetables.

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INTRODUCTION

The current agricultural model —based on large, cultivated areas and the excessive use of water— will probably be threatened in the coming decades and will become unsustainable. Vertical farming can offer a solution to this problem (Despommier, 2010; Benke and Bruce, 2017). In view of the abovementioned situation, different architectural arrangements that use the hydroponic technique have been studied, including pyramidal systems, metal frames, and vertical bag arrangements (Resh, 2001) in which most horticultural crops can be produced, including lettuce, tomatoes, and strawberries (Frazier, 2017). The crop medium of this systems can consist of only water or different substrates —such as

minerals, wool, coconut fiber, or perlite—, with a nutrient solution that provides adequate nutrition (Kratky, 2005; Jones, 2016). In addition, Sánchez del Castillo (2014) indicates that hydroponic systems allow high crop densities, an adequate balance of nutrients, and water savings. For example, the density of strawberry plants grown in open field cultivation systems is 6.5 to 8 plants m^2, while the planting density in vertical hydroponic greenhouse system can be increased up to three times (Ozeker *et al.*, 1999). The strawberry plant can be produced in a vertical system, given its physio-morphological characteristics (Despommier, 2010). The fruit value of strawberry has increased the cultivation area and this phenomenon has made Mexico one of the most important producers worldwide (SIAP, 2017). In Mexico, the most commonly used strawberry varieties are Festival, Sweet Charlie, Galexia, Camino Real, Albión, Camarosa, Aromas, Ventana, and Diamante (SAGARPA, 2018). The San Andreas variety is new, and it has been used in the country only in recent years (Eurosemillas, 2018). Therefore, a vertical hydroponic greenhouse system that uses pots can be an option for strawberry production in a protected environment, increasing the plant density and consequently the production. The objective of this work is to evaluate two strawberry varieties, two planting densities per pot, and three elevation levels, in a vertical hydroponic greenhouse system without climate control.

MATERIALS AND METHODS

Description of the experimental site

The study was carried out in a 756-m^2 double tunnel greenhouse with passive ventilation, during March to October 2017, in the municipality of Salinas de Hidalgo, San Luis Potosí. The temperature and relative humidity conditions were recorded with a Hobo 2-channel datalogger; the data were arranged using the HOBOware software and finally exported to Microsoft® Excel.

Strawberry plant pretreatment

Bare root plants of the San Andreas and Festival varieties were subjected to cold treatment (3 °C for 60 days). Subsequently, the plants were disinfected with 1 ml/L of Ridomil Gold, the roots and damaged leaves were removed, and the vigorous plants of homogeneous size were selected. Finally, they were transplanted.

Hydroponic system

The plants were established in a vertical hydroponic greenhouse system with pots. This system was made of a supporting tube (fixed to the ground with concrete), where six 15-L round pots were placed one on top of the other. The pots were immobilized with two flat bars to avoid direct contact with the substratum placed immediately below. The supports were interconnected with a gutter system (made from a 10" tube) to drain excess irrigation water. Five kg of coconut fiber per pot were used as a substrate. The system had 48 columns with 5 pots per column, for a total of 240 pots. The columns were established 0.50 m apart from each other, with 1 m between rows (triangular plant spacing). The irrigation system consisted of a 2,500-L water tank (rainwater), a ¼ HP pump, a main distribution line (16 mm hose). Three 4-L h1 self-compensating drippers were placed in each column, with a

4-outlet drip irrigation manifold. Each one was connected to the micro tubing and finally to a dripper on stake. Each self-compensating dripper was connected to two pots; therefore, the micro tubings were cut into three different lengths: 0.25 m, 0.60 m, and 1.10 m.

Irrigation program and nutrient solution

For the first three days, the plants were irrigated only with rainwater. The initial nutrient solution was applied on a later date. The nutrient solution used was developed by Hewitt and Smith (1974) and Caruso *et al.* (2011). During the vegetative stage (*i.e.*, 1 to 140 days after transplanting (DAT)), the nutrient solution had a 6.0 (±0.3) pH and a 1.3 dS m^{-1} electrical conductivity. During the reproductive stage (*i.e.*, 141 to 210 DAT), the nutrient solution had a 1.5 dS m^{-1} electrical conductivity, which was applied to 100-400 mL $plant^{-1}$/day. The nutrient supply was managed with an open system. Volume, pH, and electrical conductivity were measured twice a week to avoid salinization of the coconut fiber (Depardieu *et al.*, 2016).

Plant behavior variables

Data on the number of leaves and crown diameter —considering the multiple crowns of the plant as one and measuring the widest part with a digital vernier— were recorded according to Cantliffe *et al.* (2007). The number of runners, flowers, and fruits, as well as the fresh and dry weight of the plant, were also measured. The variables were measured every 15 days. Fruit weight, fruit diameter, and fruit yield (g $plant^{-1}$ and kg m^2) were measured after the harvest. Soluble solids from strawberry juice were measured with an ATAGO optical refractometer (Brix 0.0-33.0%), according to the NMX-FF-062-SCFI-2002 standard. The fruits were harvested every week.

Experimental design

A randomized complete block design was used. It consisted of 12 treatments, 6 repetitions, and a factorial arrangement. The following factors were tested: a) two strawberry varieties ("Festival" and "San Andreas"); b) two planting densities per pot (three and four plants per pot; 54 plants m^2 and 40 plants m^2, respectively); and c) three elevation levels in the vertical system (high, medium, and low). Data were taken from one plant per experimental treatment. The statistical analysis of the results was carried out using a general linear model, a regression procedure, and a correlation analysis with Duncan's multiple range test (alfa=0.05) using the SAS 9.4 statistical software.

RESULTS AND DISCUSSION

Temperature and humidity in the greenhouse

From March to June, the temperature recorded a 35 °C average maximum and a 15 °C average minimum; from July to October, the temperature reached a 32 °C average maximum and a 14.5 °C average minimum. The relative humidity (RH) from July to October recorded a 91.1% average maximum and a 32.1% average minimum (Figure 1). The maximum temperatures during this period reached 38 °C, although this peak lasted less than 4 hours.

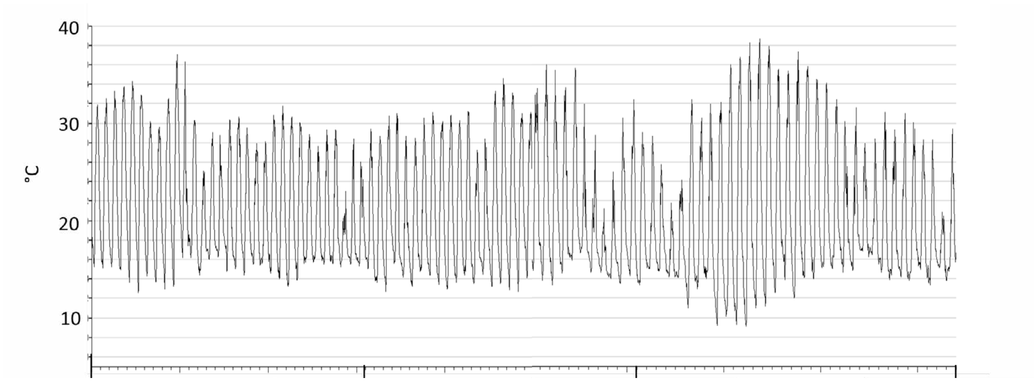

Figure 1. Distribution of the daily temperature inside the greenhouse, from July to October 2017.

As reported by Hidaka *et al.* (2017) and Radin *et al.* (2011), a minimum difference of three degrees in the average temperature leads to a lower production in the strawberry cultivar. However, Ledesma and Sugiyama (2005) reported that there are strawberry cultivars that have greater genetic tolerance to high temperature stress, such as the Nyoho variety.

Vegetative behavior of strawberry plants

The plants had good vegetative development during the first 45 days, but the flowering was delayed up to 98 days after transplanting (DAT). Hidaka *et al.* (2017) determined that flowering begins at 45 DAT. The delay may be attributed to photoperiod-related high temperatures, since low temperatures and short days induce differentiation of the floral bud (Miyoshi *et al.*, 2013). Temperatures below 2 °C and above 35 °C for prolonged periods cause weakened pollen, floral abortion, and fruit malformations (Bianchi, 1999). In addition, Ledesma and Kawbata (2016) reported that high temperature stress (temperatures greater than 32 °C for more than 4 hours) causes a decrease in fruit size and weight in strawberry varieties. The Festival and San Andreas varieties probably responded favorably to this stress.

In relation to growth, from 42 to 126 DAT, the plants showed significant differences in the number of leaves between strawberry variety (Figure 2). At 140 DAT, after a rejuvenation pruning, the plants were stimulated to develop leaves and flowers, homogenizing the number of leaves per plant (without differences between treatments). This result differs from the findings of Casierra-Posada *et al.* (2012), who reported an outstanding growth in the Chandler cultivar when more than 38% of the leaves were pruned. From 42 and 210 DAT, the Festival variety surpassed other varieties (Figure 3) in crown diameter (1.4-4.3 cm). Damaged leaves were eliminated every 15 days to control pests and that, when *Tetranychus urticae* appeared (May-August), abamectin was alternated with cypermethrin in doses of 1 ml L^{-1}. After one pruning (140 to 154 DAT), there was greater exposure to sunlight, producing more foliage in the upper part of the crop, matching the results obtained by Furlani and Junior (2007) with a vertical crop system.

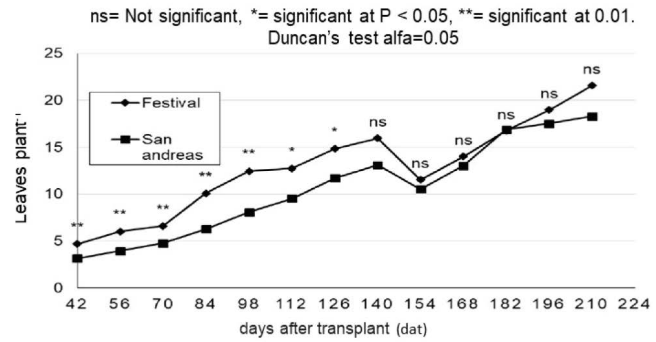

Figure 2. Number of leaves per plant of two strawberry varieties in a vertical hydroponic greenhouse system.

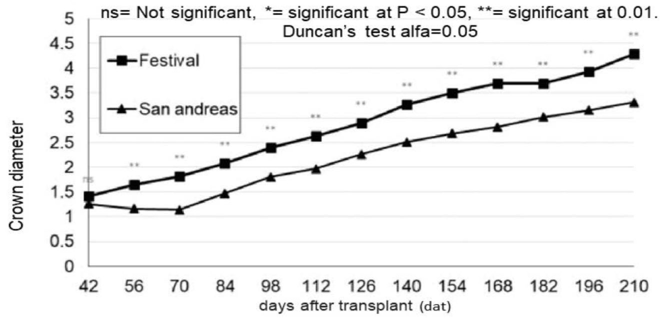

Figure 3. Crown diameter (cm) per plant of two strawberry varieties in a vertical hydroponic greenhouse system.

Strawberry plant yield

In this variable, no significant differences have been found between the varieties (Figure 4) and even the yield of the Festival variety tends to decrease at the end of the crop. The San Andreas variety showed a slight increase at the end of the plant cycle. Festival recorded its maximum production at 168 DAT (77.5 g plant^{-1}), before the production began to decline. San Andreas recorded its maximum production at 210 DAT (63.7 g plant^{-1}); at 140 DAT, a fall in production can be observed, which indicated that a pruning was required to stimulate flowering.

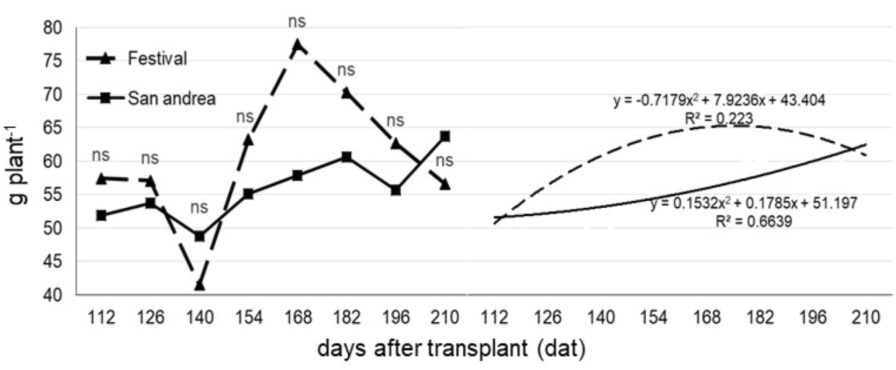

Figure 4. Fruit yield (g plant-1) of two strawberry varieties in a vertical hydroponic greenhouse system, through the analysis of: a) GLM and b) Linear Regression.

There were no significant differences in the tested levels of the density factor for any of the variables measured. The high elevation level showed a significant difference in the number of leaves at 112 DAT. This trend was observed at the end of the experiment (Figure 5), likely as a consequence of to the high radiation received at the most exposed level.

In regard to the cumulative yield of strawberry, the Festival variety stood out (Table 1), per variety, density, and elevation level. Fernandez *et al.* (2001) found no correlation between the yield of three strawberry varieties in North Carolina (USA) with the number of leaves per plant; their results match the findings of this work. The highest yield in this work was 492 g/plant, lower than the results reported by Menzel and Smith (2014) in an open field cultivation system in Australia, during 4.5 months of production (650-960 g plant^{-1} with the Festival variety). However, Karimi *et al.* (2013) found a lower yield (281.8 g plant^{-1}) in three production systems with the same variety (Festival).

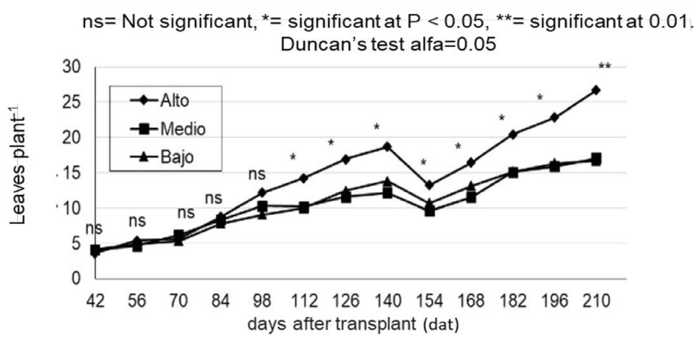

Figure 5. Number of leaves per strawberry plant at three elevation levels in a vertical hydroponic greenhouse system.

Table 1. Cumulative yield of strawberry in weight per plant and by effect of the three elevation levels, two strawberry varieties, and two planting densities per pot in a vertical hydroponic greenhouse system.

Factor/Level	**Yield (fruit)**	
	g plant^{-1}	**kg m^{-2}**
Varieties	ns	ns
Festival	486.04	22.8
San Andrea	447.26	21.0
Densities	ns	ns
3	482.02	22.6
4	454.70	21.3
Elevations	ns	ns
High	492.74	23.1
Middle	490.94	23.1
Low	425.33	20.0

ns=Not significant. Duncan's test alfa=0.05.

Correlation between foliage and yield variables

The Pearson correlation analysis determined a high correlation (r^2=0.898) between total yield and number of fruits, matching the findings of Grijalba (2015) regarding the Albión and Monterrey varieties (r^2=0.89 and r^2=0.93). On the one hand, a positive correlation (r^2=0.729) was found between fruit diameter and fruit weight, which was similar to the findings of Furlani and Junior (2007), since the larger the fruit diameter, the larger the size, and therefore a greater fruit weight is obtained. On the other hand, an average correlation (r^2=0.552) was found between the number of leaves against crown diameter; from these results, the influence of the crown diameter can be inferred. Finally, a medium correlation was found between the total yield and fruit diameter and fruit weight (Table 2).

Table 2. Pearson's correlation coefficient of the dependent variables by effect of the following factors: two strawberry varieties, two planting densities per pot, and three elevation levels, in a vertical hydroponic greenhouse system.

	nhoj	nflr	dcor	nest	nfru	dfru	Pfru	cfru	gbrx	Rtot
Nhoj	1.000	0.241	0.552	0.003	0.014	−0.104	−0.079	0.097	−0.125	−0.018
Nflr	0.241	1.000	0.215	0.022	0.335	−0.022	−0.011	0.032	−0.048	0.276
Dcor	0.552	0.215	1.000	0.060	0.133	−0.022	0.025	−0.041	−0.181	0.112
Nest	0.003	0.022	0.060	1.000	−0.261	0.060	0.002	0.128	0.044	−0.205
Nfru	0.014	0.335	0.133	−0.261	1.000	0.171	0.133	−0.146	−0.074	0.898
Dfru	−0.104	−0.022	−0.022	0.060	0.171	1.000	0.729	−0.446	0.132	0.545
Pfru	−0.079	−0.011	0.025	0.002	0.133	0.729	1.000	−0.381	0.103	0.405
Cfru	0.097	0.032	−0.041	0.128	−0.146	−0.446	−0.381	1.000	−0.214	−0.276
Gbrx	−0.125	−0.048	−0.181	0.044	−0.074	0.132	0.103	−0.214	1.000	−0.032
Rtot	−0.018	0.276	0.112	−0.205	0.898	0.545	0.405	−0.276	−0.032	1.000

nhoj=number of leaves, nflr=number of flowers, dcor=crown diameter, nest=number of runners, nfru=number of fruits, dfru=fruit diameter, pfru=fruit weight, cfru=fruit quality, gbrx=total soluble solids, rtot=fruit yield.

CONCLUSIONS

A vertical hydroponic greenhouse system (VHGS) was designed and built to evaluate two strawberry varieties (Festival and San Andreas. The vertical hydroponic greenhouse system had a high fruit yield (21 kg m^{-2}): *i.e.*, this production system is up to 35% more efficient than the open field cultivation system or the multi-tunnel greenhouse system. There was a positive correlation between the number (r^2=0.89), diameter (r^2=0.54), and weight (r^2=0.40) of the fruits and the total yield. This production system is a viable option for populations in places with a scarcity of water and to obtain fruits with guaranteed food safety.

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Colegio de Postgraduados

Evaluation of guajillo and chile de árbol peppers (*Capsicum annuum* L.) in a hydroponic greenhouse system

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ABSTRACT

Objective: To evaluate the yield of guajillo pepper (CHG) and chile de árbol pepper (CHA) grown in containers with coconut fiber substrate in a hydroponic greenhouse system.

Methodology: Four types of chili peppers were tested: two CHG and two CHA peppers. The CHG peppers with seeds were from two growing areas in the state of San Luis Potosí (SLP), located in the Altiplano Central (high plateau region) of Mexico: one from Las Colonias, Salinas, and the other from El Barril, Villa de Ramos. The CHA peppers were obtained in Yahualica, Jalisco: one in El Salto Verde (CHA-SaltoVerde) and the other in El Faro (CHA-Faro). The chili peppers were established in a hydroponic system with two types of containers (pots (SHM) and slabs (SHB)), in both of which coconut fiber (coir) was used as a substrate. The experimental design was completely randomized with three repetitions and the comparison of means was made with the Tukey test ($p<0.05$).

Results: Significant differences were observed between chile de árbol and guajillo peppers grown in SHM regarding the following variables: plant height and number of leaves, flowers, and peppers. Chile de árbol peppers recorded the highest values for the four variables. There were also significant differences between the chile de árbol and the guajillo peppers regarding the fresh weight and dry weight variables, but, in this case, the guajillo peppers had the highest values. The highest dry weight value (g plant-1) was obtained by CHG-Barril (1,094 g plant^{-1}), followed by CHG-Colonias (866 g plant^{-1}); meanwhile, the lowest values were recorded for CHA-Faro and CHA-SaltoVerde chile de árbol peppers (819 and 258 g plant^{-1}, respectively). The same pattern was observed in the SHB, with significant differences between the chile de árbol —which had the highest values— and guajillo peppers for the following variables: plant height, number of leaves, flowers, and peppers. There were also significant differences in terms of fresh weight between chile de árbol and guajillo peppers, with the latter recording higher values. Finally, CHG-Colonias and CHA-SaltoVerde showed the highest dry weight values with 633 and 595 g plant^{-1}, respectively. Although there were no significant differences between them, there were significant differences with respect to CHG-Barril and CHA-Faro (524 and 483 g plant^{-1}, respectively).

Study Limitations/Implications: The present study has no major limitations.

Conclusions: In general, a better dry yield of chili pepper was obtained with guajillo peppers produced in a pot system. Hydroponic systems in pots and slabs, using a coir substrate, are an alternative in protected agriculture for the production of guajillo and chile de árbol peppers.

INTRODUCTION

Chili pepper (*Capsicum* spp.) is one of the major crops consumed worldwide. The large amount of nutrients contained in its fruit make it a relevant food. Mexico is the center of origin of *Capsicum*. Chili pepper is an export crop, with great variety and tradition in

Image by Brett Hondow at Pixabay

the Mexican gastronomy. It is consumed fresh or dry and, for many years, it has been an essential and typical ingredient of Mexican dishes. It is also rich in vitamin A and a source of β-carotene (Shetty *et al.*, 2013; SAGARPA, 2017).

Mexico has a wide diversity of chili peppers, characterized by their color, smell, flavor, heat, and size. Dehydrated or dry chili peppers (mainly of the *C. Solanaceae*, *C. annuum*, *C. frutescents*, and *C. sinenses* types) are available throughout the year and they have very particular characteristics in each state (Inforural, 2010).

The level of technology used for the chili pepper production varies among the different regions in which it is grown. In the north and northeast region, high technology is used to produce fresh chili pepper, obtaining good yields and productivity. In the Bajío or central region, medium technology is used to produce dry chili pepper (*Capsicum annuum* Linnaeus cv. "Mulato" and "Ancho," *Capsicum annuum* L. var. *annuum* L. cv. "Pasilla", *Capsicum annuum* - "Puya", *Capsicum annuum* var. *annuum* L. "Guajillo") under irrigation. The fruits are harvested when they are completely dry; however, the traditional drying methods result in low dry yields and poor-quality products. This region includes the states of Aguascalientes, Guanajuato, Puebla, San Luis Potosí, Zacatecas and Querétaro. Meanwhile, in the south and southeast region, chili pepper is produced with low technology, resulting in low yields (Caro *et al.*, 2014; Inforural, 2012).

The chile de árbol pepper originated in tropical and subtropical regions of the Americas, but it can adapt to semi-arid and temperate environments with a clearly identifiable winter. It has an annual cycle. It develops from sea level up to 2,000 m.a.s.l. (Jaramillo, 2010). It responds to short days and neutral days (*i.e.*, less than 12 hours to 14 hours of light). It is a plant that requires a lot of light (Japón, 1980). It thrives at average temperatures of 24 °C (minimum 16 °C and maximum 30 °C), with at least 3 months of warm weather required for good crop development (Jaramillo, 2010). According to Martínez (2007), it tolerates temperatures from 10 °C to 32 °C. The optimum temperature ranges from 15 °C to 26 °C. It does not grow well under cold conditions, but temperatures above 32-34 °C can cause flower abscission and fertilization and fruit set problems. It grows well with 600 to 1,250 mm of rainfall per year and is favored by a range of 55 to 90% relative humidity (Jaramillo, 2010). A $\approx$75% relative humidity is favorable (Chávez, 2001). It requires 50 to 150 cm depth soils. It develops well in somewhat sandy to clayey soils; however, the production is higher in the former. It prefers soils with a clay-loam or sandy-loam texture, with good drainage (Japón, 1980). Soils with 6-6.5 pH are favorable for its development (Jaramillo, 2010).

Unlike other kinds of chili, fresh and dry chile de árbol peppers share the same name. They can be used regardless of their state (fresh or dry). This variety is the most used for making salsas, given its high heat. The main chili-producing states are: Jalisco, Nayarit, Aguascalientes, Zacatecas, Chihuahua, and Guanajuato (Aguirre and Muñoz, 2015).

Given its production volume, guajillo pepper is included among the four most important chili peppers in the country. From 2000 to 2009, the apparent consumption averaged 1,584,000 tonnes; however, in 2008 and 2009, it was below the average. In 2000, one out of every ten tonnes was exported, but currently only four tonnes are exported. The harvested area registered an average annual growth rate of -0.4 % in the 2000-2009 period; therefore, it decreased from 145,674 ha in 2000 to 140,424 ha in 2009 (COFUPRO, 2010).

The production of dry guajillo pepper has three main destinations: direct consumption, the production of mole and salsas, and the production of dyes. Almost 50% of the guajillo pepper produced is destined for direct consumption and the preparation of mole. They include first and second quality peppers, while the remaining 50% (poor-quality peppers) is destined for industrial consumption (production of salsas and mole) (COFUPRO, 2010).

The guajillo pepper has a particular flavor, resulting from its aroma and fleshiness, and is used to prepare mole, adobo, and salsa (SIAP, 2022).

The guajillo pepper has a heat of 2,500 to 5,000 Scoville units, while the chile de árbol pepper reaches 15,000 to 30,000 units (SIAP, 2017).

One of the main horticultural crops in the Altiplano Potosino is the guajillo or mirasol pepper. The area sown in that region reaches 5,000 ha and a 1.2 t ha^{-1} yield is produced with 80 days of work per ha, providing approximately \$36 million MXN for the state. Its production requires the extraction of subsoil water, which is increasingly scarce. Likewise, a more efficient application of fertilizer will allow producers to obtain better yields that enable them to pay production costs and use water more efficiently. Ferti-irrigation is an alternative to improve the use of water and fertilizers in the cultivation of mirasol pepper. Ferti-irrigation can increase the production of dry chili pepper by more than 100%, speed up the harvest by 15 to 20 days, and pay the investment in the drip irrigation and ferti-irrigation systems with the first year's production (INIFAP, 2002).

In the Altiplano Potosino, 2-4 dry tonne yields are obtained per cycle, when guajillo or mirasol pepper is grown in the traditional way —mainly an open-air sowing for a period of 4 to 5 months after transplanting, combined with weeding and rolling or drip irrigation (INIFAP, 2002).

According to Reyes *et al.* (2006), a larger cultivated property generally means a greater use of technology and higher yield. Therefore, the levels of technology have a direct influence on the production volume. They also consider that the profitability and income of producers may increase as a result of the improved chances and conditions that they have to adopt technology. In short, as the size of the property and the application of technology increase, the yield per hectare will be higher and profitability levels will increase.

The use of medium and low technology is a common denominator in the cultivation of chili pepper in the whole country and some of its regions (*e.g.*, the north central region). This situation causes low yields of guajillo pepper and poor-quality fruits and seeds. Given the need to innovate the production systems, the hydroponic greenhouse production system can be an alternative to increase the yield potential and the quality of fruits and seeds.

MATERIALS AND METHODS

The experiment was carried out in a double tunnel greenhouse located in the "La Huerta" Experimental Unit, of the San Luis Potosí Campus (22° 62' N and 101° 71' W). Four types of chili peppers were tested: two from CHA, Salto Verde (CHA-SaltoVerde) and El Faro (CHA-Faro); and two from CHG, Las Colonias (CHG-Colonias) and El Barril (CHG-Barril). The seeds came from different places in the Altiplano Central of

Mexico: the chile de árbol peppers came from Yahualica, Jalisco; and the guajillo peppers came from Las Colonias, Salinas, SLP, and from El Barril, Villa de Ramos, SLP. The experiment was established in a hydroponic system with two types of containers: pots (SHM) and slabs (SHB). Both containers included coconut fiber as substrate, and they were irrigated with drippers on stake. Each type of container was evaluated independently. The experimental design was completely randomized with three repetitions. Before the experiment was established, the chili peppers with the best characteristics (size and seed weight) were selected. To determine which was the best seed to sow, 1,000 seeds were weighted with 5 repetitions, according to the following procedure: the seeds of 10 chili peppers were counted and weighed with 5 repetitions; the peel was also weighed; and the length, tip, and end of all the collected chili peppers were measured.

Sowing the seeds. Two seeds were sown per cavity at a 1-cm depth, in seedbeds with a peat moss substrate.

Irrigation system. It was installed in order to uniformize the pressure in both systems (slabs and pots). A 2,500-L water tank was installed to store the irrigation water with nutrient solution (NS); another 450-L water tank was used for the application of fungicides, pesticides, or rooting products. The water tanks were connected to a one-inch PVC tube and a ¼ HP pump. In order to control the water flow, a 16 mm hose was connected to the main line and a stopcock was placed at each of the hose's water outlets that irrigate the pots and slabs. In each line, 4 L h^{-1} drippers were installed, making a small hole in the hose. To avoid spilling water and consequently to distribute the irrigation evenly in each pot and slab, each dripper was assembled using a 5-outlet drip irrigation manifold with a micro tubing and 4 drippers on stake. Finally, a stopcock was installed at the outlet of each line to allow drainage and, therefore, to prevent the blockage of the drippers.

Placement and preparation of pots and slabs. A sketch with accurate measures was prepared in order to evenly distribute the pots and slabs. These containers were filled with commercial coconut fiber substrate (Germinaza) and perforated to place the plants. Both pots and slabs were placed in parallel lines and moistened for two days and two nights before the transplanting (February 26, 2018).

The transplanting was carried out 50 days after germination, once the substrate of pots and slabs was completely humid.

Nutrient solutions. The nutrient solution recommended by Hewit and Smith and modified by Gómez-González *et al.* (2019) was used. Two solutions (an initial and a final) with the exact requirements for the chili pepper crop was applied to 1,000 L of water and adjusted to 2,500 L.

Irrigation frequency. For one week after the transplanting, a flood-like irrigation was applied to avoid dehydration stress. For the initial phenological stage of the crop seven 5-min irrigations were programmed using a timer. Subsequently, eight irrigations (three 5-min and five 8-min irrigations) were scheduled for a more advanced phenological stage, in order to keep the plants well hydrated and with good drainage. The amount of water applied per plant was determined with ***control drippers***. The percentage of solution that was actually applied to each pot was observed in the ***drainage trays***, which were emptied daily.

Plant tutoring. The plants were attached to a steel cable using raffia. A hook, a clamp, and a plastic ring were used to fix a point of the stem and the base of the plant, in order to prevent them from falling. The raffia was as taut as possible.

Pests and diseases were controlled with the irrigation and spraying of various fungicides and insecticides. A 15-L sprayer was used to apply 1 mm of the product per 1 L of water. The "Muralla" insecticide was applied to control aphids, while the "Raley" fungicide was used to control downy mildew.

For **the harvest**, only ripe chili peppers or those that had signs of maturation were cut, counted, and weighed individually. Afterwards, they were stored in paper bags and dried. Two cuts were made (July 9 and 27, 2018).

Fruit drying. The samples were put in paper bags. The first cut of chili peppers was dried in ovens at a temperature of 60 °C. One part of the second cut was dried in an oven and the other in a greenhouse dryer.

Study variables

The following variables were measured: steam diameter, number of leaves, flowers, and fruits, plant height, and dry weight. The ***stem diameter*** was measured with a vernier, from the beginning of the crop until the end of the experiment. The ***leaves, flowers, and fruits*** were counted individually as they appeared on the plant, throughout the experiment, in order to determine their ***number***. ***Plant height*** was measured with a measuring tape, from the base of the stem to the tip, taking the highest leaf as reference. Each freshly cut fruit was weighed to determine the ***fresh weight***, considering only the fruits of the sampled plants. The ***dry weight*** was determined when the plants reached a constant weight during drying, in order to find the average weight of the sample.

Statistical analysis

The measured variables were subjected to an analysis of variance for a completely randomized model with three repetitions. The comparison of means was performed using Tukey's test ($p<0.05$).

RESULTS AND DISCUSSION

The analysis of variance for the types of chili peppers produced in the hydroponics system (with both containers) showed significant differences between the treatments (the four types of peppers evaluated). The comparison of means also showed significant differences between the evaluated variables.

In the case of the ***hydroponic system with pots***, the statistical analysis of the means test shows the results detailed below for the studied variables.

Regarding the plant height, number of leaves, and number of flowers variables, Table 1 shows that there were no significant differences ($p<0.05$), neither between one chile de árbol pepper and the other (CHA-SaltoVerde and CHA-Faro), nor between one guajillo pepper and the other (CHG-Colonies and CHG-Barril). However, significant differences were observed between chile de árbol peppers (CHA) and guajillo peppers (CHG). The

CHA recorded the highest values for plant height, number of leaves, and number of flowers. The CHG had a much lower value in these three variables.

Like the previous variables, the average number of chili peppers in the last sampling does not show significant differences (Table 2), neither between chile de árbol peppers (CHA-SaltoVerde and CHA-Faro), nor between guajillo peppers (CHG- Colonias and CHG-Barril). However, there are significant differences between the means of both types of peppers (CHA and CHG). Meanwhile, there are significant differences between the fresh weight of chile de árbol peppers (CHA) and guajillo peppers (CHG). However, guajillo peppers: CHG-Colonias (5,435 g plant^{-1}) and CHG-Barril (5,147 g plant^{-1}) had similar fresh weight, while there were significant differences between CHA-SaltoVerde (428 g plant^{-1}) and CHA-Faro (954 g plant^{-1}).

Regarding the average dry weight (g plant^{-1}) yields, differences were recorded between the means of each type of chili pepper and in the comparison of CHG with CHA. For example, CHG-Barril and CHG-Colonias had a yield of 1,094 and 866, respectively. For their part, CHA peppers had major differences: the CHA-Faro had the highest weight (819), while CHA-SaltoVerde recorded the lowest yield (258). Due to the type of fruit produced by each type of chili pepper, the CHG —which has a lower number of fruits than CHA— achieves a greater weight per plant in production.

Through the management systems, the dry weight of the fruit tended to have an inverse relationship with the number of fruits per plant —*i.e.*, a greater number of fruits observed represented a lower dry weight of the fruit. Although this was not the case for the CHA, the CHG did show this behavior. Differences between the types of chili peppers are also shown. The same response was observed by Olutolaj and Makine (1994) in chili peppers of

Table 1. Average height, number of leaves, and number of flowers, in the pot system.

Chili types	Height (cm)	Leaves (number)	Flowers (number)
CHA-Salto Verde	252.25 a	452.00 a	315.06 a
CHA-Faro	251.93 a	452.71 a	313.34 a
CHG-Colonias	175.56 b	331.43 b	110.25 b
CHG-Barril	174.31 b	330.15 b	107.03 b

CHA=chile de árbol pepper; CHG=guajillo pepper; Values with different letters between columns have a significant difference, Tukey (α=0.05).

Table 2. Average number of chili peppers, fresh weight, and dry weight, in the pot system.

Chili types	Fruit (number)	Fresh weight (g planta^{-1})	Dry weight (g planta^{-1})
CHA-Salto Verde	113.96 a	428.27 c	257.84 c
CHA-Faro	116.96 a	953.78 b	819.09 b
CHG-Colonias	60.40 b	5,435.07 a	865.81 b
CHG-Barril	60.40 b	5,146.96 a	1,094.02 a

CHA=chile de árbol pepper; CHG=guajillo pepper; Values with different letters between columns have a significant difference, Tukey (α=0.05).

the *C. annuum* and *C. frutescens* species, which indicates that it is a species-specific response. As observed in this study, some types of chili peppers experience a gradual increase in the number of flowers, number of fruits, and fruit weight, followed by a decrease in the reproductive organs. Nevertheless, in this study, the decrease occurred alternately according to the reproductive attribute and not in the same way that was reported by Olutolaj and Makine (1994).

Regarding the hydroponic system with slabs, the comparison of means shows that there were no significant differences in the plant height and number of flowers between chile de árbol peppers (CHA-SaltoVerde and CHA-Faro). However, there were significant differences between the number of leaves (Table 3). The number of leaves per plant was significantly higher for CHA-SaltoVerde than for CHA-Faro. On the contrary, none of the three variables of the CHG —which have very similar mean values— show significant differences. The means of the CHA have significant differences with respect to the CHG, since the former has higher height, number of leaves, and number of flowers.

The average number of chili peppers per plant in the last sampling was 122.68 (CHA-SaltoVerde) and 120.75 (CHA-Faro); meanwhile the CHG recorded averages of 66.21 (CHA-Colonias) and 65.71 (CHA-Barril) (Table 4). There are no significant differences in means, neither between chile de árbol peppers (CHA-SaltoVerde and CHA-Faro), nor between guajillo peppers (CHG-Colonias and CHG-Barril). On the contrary, there were significant differences between chile de árbol peppers (CHA) and guajillo peppers (CHG).

Table 4 shows that, regarding the fresh weight yield, significant differences were found between the guajillo peppers: CHG-Colonias recorded an average of 5,396 g plant^{-1}, while CHG-Barril registered 2,415 g plant^{-1}. On the contrary, there were no significant differences between both chile de árbol peppers: CHA-SaltoVerde obtained an average of

Table 3. Average height, number of leaves, and number of flowers, in the slab system.

Chili type	Height (cm)	Leaves (number)	Flowers (number)
CHA-Salto Verde	239.25 a	452.65 a	343.65 a
CHA-Faro	238.12 a	436.62 b	338.81 a
CHG-Colonias	181.81 b	334.75 c	116.00 b
CHG-Barril	181.06 b	333.53 c	115.00 b

CHA=chile de árbol pepper; CHG=guajillo pepper; Values with different letters between columns have a significant difference, Tukey (α=0.05).

Table 4. Average number of chili peppers and fresh and dry weight, in the slab system.

Chili types	Fruit (number)	Fresh weight (g planta^{-1})	Dry weight (g planta^{-1})
CHA-SaltoVerde	122.68 a	732.99 c	594.69 a
CHA-Faro	120.75 a	853.76 c	483.02 b
CHG-Colonias	66.21 b	5,396.49 a	632.60 a
CHG-Barril	65.71 b	2,414.72 b	523.60 b

CHA=chile de árbol pepper; CHG=guajillo pepper; Values with different letters between columns have a significant difference, Tukey (α=0.05).

733 g plant^{-1}, while CHA-Barril recorded 854 g plant^{-1}. As proven by their averages, the differences between CHAs and CHGs are significant.

Significant differences were recorded for the dry weight of chile de árbol peppers (Table 4): CHA-SaltoVerde had an average of 595 g plant^{-1}, while CHA-Faro had 483 g plant^{-1}. Likewise, the differences between the guajillo peppers were significant: the average for CHG-Colonias and for CHG-Barril was 633 g plant^{-1} and 524 g plant^{-1}, respectively. Chile de árbol and guajillo peppers show no clear difference regarding this variable, since CHA-SaltoVerde was significantly higher than CHG-Barril, while CHG-Colonias was significantly higher than CHA-Faro.

The maximum number of flowers and the final number of established or set fruits of guajillo pepper recorded in this study matched the results of Marcelis and Baan (1997) and Guardiola (1997) —given that the number of flowers is usually greater than the number of fruits, although the difference between these two attributes in guajillo pepper was not so excessive. An important fact in this study is the percentage of fruit set —*i.e.*, the number of ripe fruits in relation to the maximum number of flowers—, which had a 38-100% fluctuation in the management systems. For their part, Dahal *et al.* (2006) reported that up to 19% of chili pepper fruits had set.

The initial decrease in the number of flowers match the gradual increase in the number of fruits as a result of the diversion of photoassimilates towards the formation of fruits (Azofeifa and Moreira, 2004). However, a continuously low production of buds and flowers due to the lower accumulation of carbohydrates suggests the existence of a competition for assimilates between all vegetative and reproductive organs, including leaves (Aloni *et al.*, 1996) and seeds, whose growth also demands a high amount of carbohydrates (Marcelis and Baan, 1997). Regarding the behavior of the evaluated variables in relation to the type of production system (pots and slabs), there is a very similar behavior in both systems in terms of the following variables: plant height, number of flowers, number of leaves, and number of fruits (Figure 1). With regard to the fresh weight and dry weight of the fruits, the

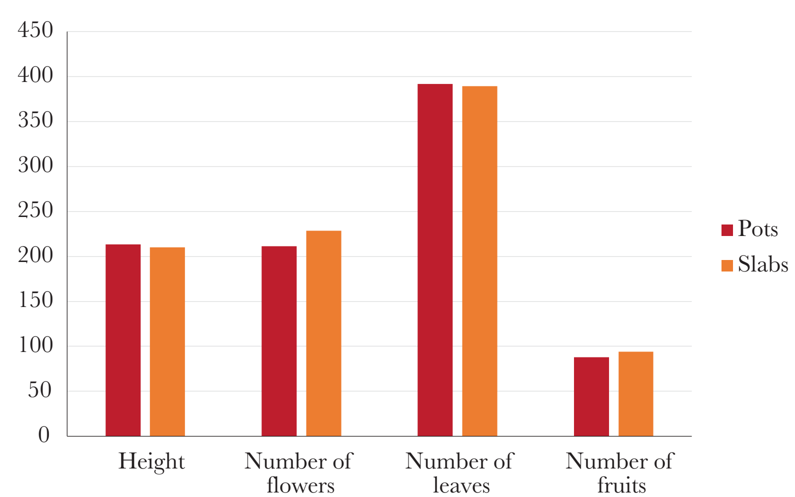

Figure 1. Response of the plant height (cm), number of flowers, number of leaves, and number of fruits variables to the production systems (pots and slabs).

potted system showed a superiority in both variables in relation to the system with slabs (Figure 2).

Additionally, a simple calculation of the value of dry chili pepper production that would be obtained per greenhouse ha was carried out, estimating the yields from the average dry weight (g plant^{-1}) of the different types of chili pepper (Table 5). The calculation was based on the density of 3 plants m^{-2} and a cost of \$150,000 MXN per tonne of dry guajillo pepper and \$180,000 MXN per tonne of chile de árbol pepper.

Given that the estimated yields of dry chili pepper (except for the CHA-SaltoVerde) were higher under the production system in pots, the highest production values were obtained under this production system. The highest production value of chili pepper was obtained with CHG-Barril, whose estimated dry yield was 32.82 t ha^{-1} which had a value

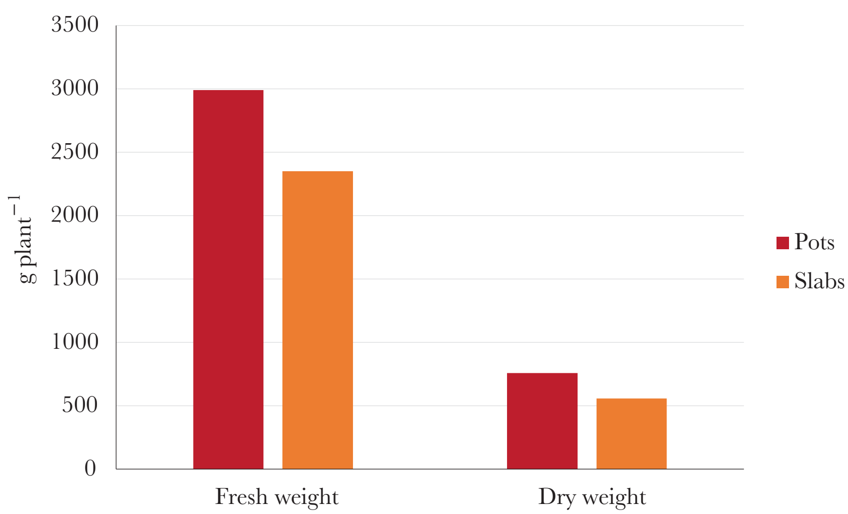

Figure 2. Response of the fresh weight and dry weight variables to the production systems (pots and slabs).

Table 5. Value of the estimated yields (per ha) based on the dry weight of the different types of chili pepper.

Chili type	**Dry yield (g planta^{-1})**	**Yield* (kg m^{-2})**	**Yield (t ha^{-1})**	**Value per ha** ($)**
	Potted production system			
CHG-Barril	1094.02	3,282.06	32.82	4'923,000
CHG-Colonias	865.81	2,597.43	25.97	3'895,500
CHA-Faro	819.09	2,457.27	24.57	4'422,600
CHA-SaltoVerde	257.84	773.52	7.73	1'391,400
	Pen production system			
CHG-Barril	523.60	1,570.80	15.71	2'356,500
CHG-Colonias	632.60	1,897.80	18.98	2'847,000
CHA-Faro	483.02	1,449.06	14.96	2'692,800
CHA-SaltoVerde	594.69	1,784.07	17.84	3'211,200

* With a density of 3 plants m^{-2}. ** Considering a price of \$150,000 MXN (USD\$ 7,500.00) per ton for guajillo pepper and \$180,000 MXN (USD\$ 9,000.00) per ton of chile de árbol pepper.

of $4,923,000 MXN (USD$246,150) (considering a price of USD$7,500 ton). In second place, CHA-Faro recorded an estimated dry yield of 24.57 t ha^{-1}, which amounts to $4,422,600 MXN (USD$221,130) (considering a price of USD$9,000 ton).

CONCLUSIONS

Except for chile de árbol pepper from Salto Verde (CHA-SaltoVerde), the production of dry chili peppers showed a better response in the production system with pots. Under that production system, the guajillo pepper from El Barril (CHG-Barril) obtained the highest dry weight yield and is therefore the chili pepper from which the greatest profitability would be obtained. The hydroponic greenhouse production of guajillo and chile de árbol peppers (using pots and slabs) is a good alternative for protected agriculture.

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Colegio de Postgraduados

Analysis of national and international tomato trade routes through the simplex method

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ABSTRACT

Objective: To find the optimal national and international tomato trade routes through the simplex method to maximize profit.

Design/methodology/approach: The apparent national consumption was determined from the production, the volume of exports, the imports, and the population of each state in the Mexican republic; based on this, the points of origin and destinations were established, to later optimize the routes through the simplex method taking into account two scenarios, a closed market economy and an open market economy.

Results: Of the total offer, 21% is destined to the national market, where only 64% of the offerors supply tomato to national consumers. On the other hand, in the open economy it is evident that only 45% of the destinations through which tomato can be exported to North American territory are optimal, and it is also clear that 79% of national surpluses are destined to trade in a foreign market.

Limitations on study/implications: The model was designed with data from 2020, considering all the tomato variants produced and exported in Mexico contained in the tariff classification 070200; the independent variable was the distance between offerors and destinations.

Findings/conclusions: In conditions of closed market there is surplus production of tomato in 19 states that allows supplying the states with negative balance. Estado de México, Mexico City, and Veracruz concentrate the greatest demand due to their large population density. The two states with greatest surplus, Sinaloa and San Luis Potosí, destined the total of their offer to the foreign market, primarily because of their proximity to border customs.

Keywords: simplex method, optimization of agricultural routes, tomato, open and closed economy.

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INTRODUCTION

Presently, tomato (*Solanum lycopersicum*) is considered one of the strategic products for the development of the agricultural sector in Mexico (Bustamante *et al.*, 2022), since it occupies the 9th place among vegetables with highest production in the country (SIAP, 2021); in addition, it is a basic ingredient in Mexican cuisine that has managed to earn a prominent place in other parts of the world (Gobierno de México, 2022). According to the *Revista Industrial del Campo* (2020), among its characteristics those that stand out are that it is an important source of vitamins (A, B1, B2 and C), minerals (calcium, phosphorus, potassium, sodium), and antioxidants.

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Because of its nature and characteristics, tomato has medicinal properties among which the following functions stand out: antiseptic, alkalizing, depurative, diuretic, digestive, laxative, anti-inflammatory, and remineralizing (Revista Industrial del Campo, 2020); likewise, it represents a role of utmost importance within the Mexican economy since it acts as a balm for society to generate sources of employment and income (Velasco *et al.*, 2011).

Mexico is considered as the main place where this vegetable was domesticated, with the state of Sinaloa being the principal one, followed by Querétaro, Coahuila, Nuevo León and Puebla; these regions stand out because they present better yields attributed to their investment in irrigation systems and technologies that protect the crop (USDA, 2022).

Within these techniques of crop protection, there are greenhouses, since there are environmental factors that reduce the life cycle of tomato, so that production through greenhouses is gaining territory (Mundo *et al.*, 2019), the main reason being the optimization of production sustained with the use of technology, which helps to save water and to reduce the level of pesticides used (Sánchez, 1999; Galbraith, 1969).

Global integration allows for actors such as producers, distributors, and consumers of the merchandise to remain in the same tenor by establishing a supply chain, where the international division of labor is established based on the capacities of a certain region (Gereffi and Korzeniewicz, 1994). Mexico is identified as one of the 10 main tomato suppliers due to its favorable climatological conditions, making it the third most exported product (Infografo, 2019).

Tomato is considered the vegetable of highest economic value since at the national level it is the one that is destined the most to exports. Evidence of this is that the amount exported denoted 18% of the total production of the country (SIAP, 2021), and according to FAOSTAT (2020) the country occupies the first place at the global level in exports of the product. In addition, it is due to the number of direct and indirect jobs generated by its cultivation and the currencies that enter the country as a result of its trade (Secretaría del campo, 2022).

Because of the surface destined to its cultivation (open air and greenhouse) and the production value, tomato is one of the most important crops. According to FAOSTAT (2020), tomato production in Mexico represents 1.64% of the 251 million tons produced in the world, placing it in the tenth place, and also from the total Mexican exports, those for this vegetable represent 23.2%, equivalent to 2,538,501 thousand dollars, positioning it as a leading territory (TradeMap, 2022).

Given the economic and commercial importance of tomato in Mexico, this study has the objective of finding the optimal routes to trade the vegetable in the national and international market through the simplex method, with which a reduction in costs and an increase in profits will be determined.

MATERIALS AND METHODS

Because of the commercial importance of this vegetable for Mexico, this study suggests the optimization of a transport model for the tomato variants contemplated in tariff fraction 070200 (SIAVI, 2021), using the simplex method, which is considered a functional tool in the resolution of linear programming problems, evaluating the objective function (Ayllón *et al.*, 2015); it is practical to solve questions about transport optimization (Díaz and Cruz, 2006), an example of which is the one used in the hydrocarbons sector (García, 2014).

Among other applications, there are some related to perishable foods, an example of which is presented by Ayllón *et al.* (2015) for fresh prickly pears when its production exceeds the national demand, where the model for closed and open economy was used. Ramírez (2013) made a similar application for the transport model of onion in Mexico, and Toxqui (2013) did it for white corn.

In their presence, a model is suggested that allows minimization of transport costs from the offering to the demanding zones, both in closed economy and in open economy so that the distribution is efficient, making use of the simplex method, proposed by Dantzig in the 1940s (Gass, 2002), an algorithm that solves problems when they are of linear programming (Dantzig, 1990). That is, a procedure to optimize an objective function subject to restrictions of equality (=) and/or inequality (≤, ≥), so that the maximum profits or the minimum costs are determined (Moncayo and Muñoz, 2018).

The resolution of the linear programming will be through the LINGO 19.0 software, designed for the optimization of linear functions. For this purpose, the variables and the restrictions of offer and demand were determined, which are expressed in the following way: origins (m) and destination (n), amount of the offer in the origin (i) is Em and the demand in the destination (j) is Dn, the existing distance between origin (i) and destination (j) is Cij, and finally Xij is the amount transported from origin to destination.

The point of origin is the objective function, and it is represented in the following way:

$$Y = \sum_{i}^{m} \sum_{j}^{n} C_{ij} X_{ij}$$

Where i=1, 2,... m (producing regions); j=1, 2,... n (consuming regions), thus building the minimization function:

$$Min Y = C_{11}X_{11} + C_{12}X_{12} + \dots\dots\dots\dots C_{mn}X_{mn}$$

Where C_{11} represents the distance from origin 1 to destination 1; C_{12} represents the distance from origin 1 to destination 2, and thus successively, until finishing with the origins and the destinations; these distances were obtained from the Digital Map (INEGI, 2022). The codes with letter X (X_{11}, $X_{12}\ldots$) will be the unknown variable to be solved with the application of the model so they will always be represented with letters. Then, the restrictions that condition the objective function are formed, denoting the amount available from each offeror and the amount needed by each consumer.

Offer

$$X_{11} + X_{12} + X_{13} \dots\dots\dots\dots + X_{1n} = E_1$$

$$X_{21} + X_{22} + X_{23} \dots\dots\dots\dots + X_{2n} = E_2$$

$$\dots\dots$$

$$\ldots\ldots$$

$$X_{m1} + X_{m2} + X_{m3} \ldots\ldots\ldots\ldots\ldots\ldots + X_{mn} = E_m$$

These restrictions show that the production from each center exceeds its demand, sending to consuming centers an equal amount as their offer.

Demand

$$X_{11} + X_{21} + X_{31} + \ldots\ldots\ldots\ldots\ldots\ldots + X_{m1} = D_1$$

$$X_{12} + X_{22} + X_{32} + \ldots\ldots\ldots\ldots\ldots\ldots + X_{m2} = D_2$$

$$\ldots\ldots$$

$$\ldots\ldots$$

$$X_{1n} + X_{2n} + X_{3n} + \ldots\ldots\ldots\ldots\ldots\ldots + X_{mn} = D_n$$

These restrictions indicate that the amounts sent from different producing centers should agree with the demand from each consumer center.

To apply the model in closed economy it was necessary to determine the deficit or surplus in the production, and therefore the national production from 2020 was taken up again, considering the 31 states and Mexico City, information that was obtained from the agricultural close; the population by state was consulted in the current population and housing census 2020 (INEGI).

The National Apparent Consumption (NAC) is the starting point that expresses the availability in the country of a specific consumption product in a certain period of time (Ramírez, 2016); it is obtained from the sum of national production and imports, minus exports. For the *per capita* consumption, the NAC is divided by the total population in Mexico, and then, this figure is multiplied by the number of inhabitants in each state, resulting in the apparent consumption by state, necessary for the determination of offerors and consumers.

Finally, the tomato consumption by state is subtracted from its production to identify whether the state is capable of satisfying its demand. If the result is positive after the operation, it will be an offeror, and in the contrary case it will be a consumer; 13 demanding states and 19 offerors were obtained with the calculation, and therefore, the codes for the restrictions of offer and demand have the following sequence:

Offer

$$X_{11} + X_{12} + X_{13} + \ldots\ldots\ldots\ldots\ldots\ldots + X_{113} = E_1;$$

$$X_{21} + X_{22} + X_{23} + \ldots\ldots\ldots\ldots\ldots\ldots + X_{213} = E_2;$$

$$\ldots\ldots$$

$$\ldots\ldots$$

$$X_{191} + X_{192} + X_{193} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + X_{1913} = E_{19};$$

Demand

$$X_{11} + X_{21} + X_{31} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + X_{191} = D_1;$$

$$X_{12} + X_{22} + X_{32} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + X_{192} = D_2;$$

$$\ldots\ldots$$

$$X_{113} + X_{213} + X_{313} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + X_{1913} = D_{13};$$

The aforementioned applies to a closed economy, although the intention of this article is for the model to be applicable also to an open economy where part of a country's production is offered in the national territory and another is exported (Icomena, 2020).

For this purpose, it is necessary to add new destinations for offerors to send the tomato, and these new destinations are all the land customs offices that are located in the northern border, of which 19 in total are the ones that fulfill these characteristics resulting in 32 destinations in total.

The structure of the code for the tomato demand is presented in the following way:

$$X114 + X214 + \ldots + X1914 > 0;$$

$$X115 + X215 + \ldots + X1915 > 0;$$

$$\ldots$$

$$X131 + X231 + \ldots + X1931 > 0;$$

$$X132 + X232 + \ldots + X1932 > 0;$$

This code represents that the amount to send from the 19 offerors to the consumers in the open market (from 14 to 32) should be higher than 0, and a specific amount cannot be used because the demand is unknown.

On the other hand, the offer is represented in the following way:

$$X114 + X115 + \ldots + X132 = Em;$$

$$X214 + X215 + \ldots + X232 = Em;$$

$$\ldots$$

$$X1814 + X1815 + \ldots + X1832 = Em;$$

$$X1914 + X1915 + \ldots + X1932 = Em;$$

The same logic as in the closed market is applied, where the offer is the same as the surpluses once its territorial demand is covered.

RESULTS AND DISCUSSION

Tomato production in 2020 was 3,370,827 tons, exceeding by 46% the national apparent consumption estimated for the same year (1,544,366.65 tons), so there was a surplus, ideal situation to achieve exports of the product, as mentioned in the transport model for the distribution of guava in Mexico, where, once the national demand was covered there was a surplus for exports or transformation in the industry (Quintero *et al.*, 2016). The NAC divided by the total population in Mexico, which was 1,26,014,024 inhabitants in 2020, originated *per capita* consumption of 0.012255514 tons, equivalent to 12.25 kilograms.

Closed economy

The self-sufficient states, capable of covering their internal demand, were denominated origins, and instead the ones that had a deficit were called destinations, forming with them the restrictions both of offer and of demand. With this, 19 states were obtained with the ability to offer their surpluses to the rest, among them Sinaloa, San Luis Potosí, Zacatecas, Michoacán, Baja California Sur, Morelos, Querétaro, Sonora, Coahuila, Puebla, Oaxaca, Baja California, Durango, Aguascalientes, Guanajuato, Hidalgo, Chiapas, and Colima, since their total offer was 2,315,692 tons, even allowing them to export.

The rest of the states, that is, 13, did not manage to cover their internal demand, among them: Nayarit, Campeche, Tlaxcala, Guerrero, Quintana Roo, Yucatán, Tabasco, Tamaulipas, Chihuahua, Nuevo León, Veracruz, Estado de México and Mexico City, with a total demand of 489,232 tons.

According to the results obtained, the optimal solution represents the amount of tons that should be distributed from each origin (i) to each destination (j), which minimizes the distances between the offerors and the consumers both for the closed market and for the open market represented in Table 1.

Table 1. Optimal distribution in closed market

Origin (i)	Destination (j)
Zacatecas	Monterrey
Michoacán	Tamaulipas, México y Ciudad de México
Baja California Sur	Chihuahua
Morelos	Tlaxcala, Guerrero, Quintana Roo, Yucatán, Veracruz, Ciudad de México
Jalisco	Nayarit
Puebla	Veracruz
Oaxaca	Campeche, Yucatán, Tabasco
Durango	Chihuahua
Aguascalientes	Monterrey
Guanajuato	Tamaulipas
Hidalgo	Veracruz
Chiapas	Yucatán

Own elaboration with data from FAOSTAT, SIAP, INEGI and TradeMap 2020.

The results from the analysis showed that 21% of the total offer is destined to the national market, where only 64% of the offerors supply tomato to the national consumers, with Morelos together with Michoacán being the states that supply 55% of the total demand, having the capacity to distribute to 8 states in deficit. As with the transport model for avocado, where, although they are not the states that cover the most demand, they are the best located to supply the largest guava consumer centers: Estado de México and Mexico City (Avendaño, 2019).

On the other hand, Oaxaca, Durango, Aguascalientes, Guanajuato and Puebla supply 7 states that represent 37% of the total demand, and finally, Zacatecas, Baja California Sur, Guadalajara, Hidalgo and Chiapas cover the remaining 8%, represented in Figure 1.

Open economy

The results show that only 45% of the destinations to which tomato can be exported in North America are optimal; the rest, due to the distance from producing states, are no longer optimal because they imply higher transport costs. It is also exposed that 79% of the national surpluses are destined to trade in foreign markets, and they are summarized in Table 2.

The percentage of surpluses in the total production of each state also stands out, which is destined to customs offices that are presented as optimal destinations, with the states of Sinaloa, Baja California Sur and Sonora being the ones that offer between 98% and 99% of the surplus of their production to the customs office in Nogales, Sonora. On the other hand, Zacatecas and Coahuila offer between 96% and 99% to the customs office in Ciudad Miguel Alemán, Tamaulipas; Baja California and Colima destine nearly 100% to the customs office in Mexicali, Baja California.

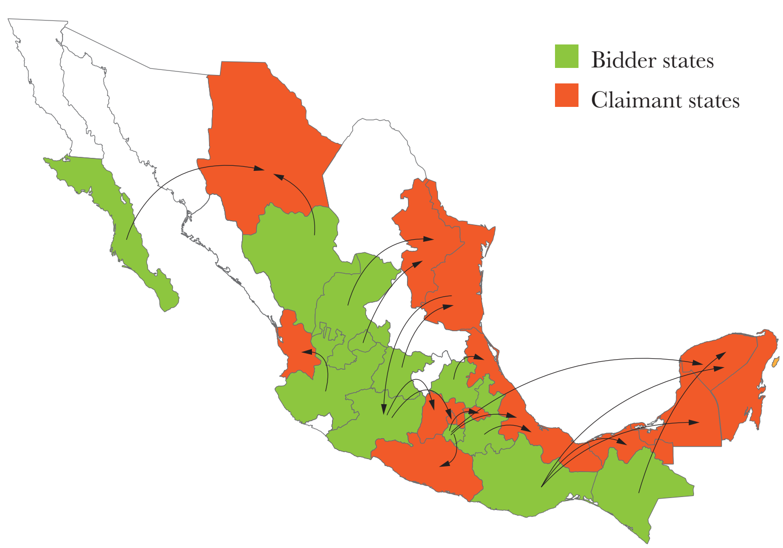

Figure 1. Optimal distribution in a closed economy. Own elaboration with data from FAOSTAT, SIAP, INEGI and TradeMap (2020).

Table 2. Optimal distribution in open market.

Origin (i)	Destination (j)
Sinaloa	Nogales
San Luis Potosí	Matamoros
Zacatecas	Ciudad Miguel Alemán
Michoacán	Matamoros
Baja California Sur	Nogales
Querétaro	Matamoros
Sonora	Nogales
Coahuila	Ciudad Miguel Alemán
Baja California	Mexicali
Colima	Mexicali
Guadalajara	Ciudad Reynosa

Own elaboration with data from FAOSTAT, SIAP, INEGI and TradeMap (2020).

There is a particular case for the offering state of Michoacán, since it only transports 31% of its surplus to the customs office in Matamoros, Tamaulipas; this is because the largest part of it is destined to national trade, although this destination is also supplied by San Luis Potosí and Querétaro. Finally, Guadalajara offers 98% of its surpluses of tomato just to the customs office in Ciudad Reynosa, Tamaulipas. The optimal transport routes for the open economy are illustrated in Figure 2.

Figure 2. Optimal distribution in the open market
Own elaboration with data from FAOSTAT, SIAP, INEGI and TradeMap (2020).

CONCLUSIONS

In closed market conditions, the model seeks an efficient distribution for the country to cover its domestic demand, ensuring food security in its territory. Estado de México, Mexico City and Veracruz concentrate the highest demand due to their great population density.

On the other hand, in the open market, it is necessary for the producing states to present surpluses once their internal demand is covered and this way they may have the possibility of offering in foreign territory, optimizing their costs and obtaining greater profit. This is the case of Sinaloa and San Luis Potosí, which found it optimal to destine their total offer to the foreign market. Without a doubt, the presence of products from some states of the Mexican Republic in the foreign market depends, to a certain degree, on their geographic location.

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Technological proposal for a greater irrigated corn (*Zea mays* L.) production

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ABSTRACT

Objective: To validate the experimental results of corn (*Zea mays* L.) production under irrigation during the 2019-2022 autumn-winter cycles.

Design/Methodology/Approach: Six validation plots were established, three in the Cuxtepeques irrigation district and three in irrigation systems in Chiapas, Mexico.

Results: Corn grain production is 64% higher with the INIFAP technology than the traditional methods; however, the average yield obtained in the validation phase (11.5 t ha^{-1}) was lower than the yield of the experimental phase (15.9 t ha^{-1}).

Study Limitations/Implications: None.

Findings/Conclusions: Production requires machinery for sowing and precision fertilization, efficient irrigation infrastructure, access to credit, and permanent technical assistance to achieve yields similar to those obtained in the experiment.

Keywords: Corn; Irrigation; Frailesca, Chiapas.

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INTRODUCTION

Although corn (*Zea mays* L.) is native to Mexico, the country is unable to meet the needs of its population. Several production systems have potential in Mexico, including rainfed agriculture and irrigation on flat soils or hillsides (slopes). The highest productivity should be recorded in the latter system, decreasing the dependence on imports. Irrigated areas in Mexico are crucial to increase corn production, since they are not impacted by uncontrollable agricultural factors (*e.g.*, shortage or excess of rain, winds, etc.), during the spring-summer (SS) cycle. For their part, rainfed agriculture areas face greater risks.

Corn contributes 31.5% of the agricultural production value in Chiapas, occupying 690,653 hectares (SIAP, 2021), out of which 58,129 are distributed in four irrigation districts. The Cuxtepeques irrigation district is located in the region of La Frailesca, Chiapas, considered the main corn-producing area. This district is being under used for corn production; since only 40% of the 12,500-hectare land is irrigated, and the water is usually used to irrigate pastures (forages). Additionally, 10,000 hectares from irrigation systems (IS) are classified as fluvisols and are located on river banks. These IS use water in different forms and from different sources, such as direct intakes from rivers by gravity, pumping, water diverter structures, and artesian wells. Only 50% of the area is used to produce corn.

Although Chiapas has vast soil and water resources and a favorable climate for production, the average yield of irrigated corn is 4.0 t ha^{-1}, which is lower than the 8.0 t ha^{-1} national average.

Producers grow little irrigated corn as a consequence of low profitability. Therefore, based on a diagnosis of the irrigated areas, our results detect the lack of technology and technical assistance focused on driving greater productivity as the main causes, along with poor infrastructure conditions resulting from the lack of maintenance (Camas, 2017; Camas, 2020).

Therefore, during the 2017-2018 and 2018-2019 autumn-winter (AW) cycles the corn production model was evaluated under irrigation conditions with the purpose of helping to increase the productivity of the crop in La Frailesca, Chiapas, Mexico.

MATERIALS AND METHODS

A sub-split plot design with two replicates was established. The large plots (LP) were assigned to four treatments resulting from the combination of two sowing dates and two irrigation contributions (with and without limitation). The split plots (SP) were assigned to 26 treatments of a double hypercube design (central composite rotatable), divided into one third of a plot, in three incomplete lots, and two repetitions of the center (Cochran and Cox, 1957; Martínez and Martínez, 1996; Volke *et al.*, 2005). Hyperspace was explored using five equally spaced levels with four factors; $(80<N<240$ kg $ha^{-1})\times(0<P_2O_5<160$ kg $ha^{-1})\times(0<K_2O<160$ kg $ha^{-1})\times(50$ thousand $<D<90{,}000$ plants $ha^{-1})$. The split plots (SP) were assigned to six hybrids. Each experiment had 1,248 sub-split plots where information on the best sowing date was generated and the optimal management of fertilizers, population density and hybrids were calculated.

The following agronomic recommendations were the result of the two-year experimentation in the Cuxtepeques irrigation district and the IS of Villaflores and Villa Corzo municipalities: sowing date from December 15th to January 15th; 90,000 seeds at sowing; 190N-160P-160K and 240N-160P-60K fertilization for the Cuxtepeques irrigation district and the irrigation systems, respectively. Taking into account that the regional diagnoses showed that all the soils have B deficiencies and that eight out of ten soils have Zn deficiencies, 2 kg ha^{-1} of B and 20 kg ha^{-1} of Zn were mixed with the first N-P-K fertilization (Camas *et al.* 2019). In this study, the validation was performed with cooperating producers as final users of technology. The main results are presented below.

Three plots were established in the Benito Juarez ejido, located on La Concordia municipality, Cuxtepeques District. Each plot belonged to each of the AW cycles (2019-2020, 2020-2021, and 2021-2022). In the IS of Villa Corzo, three plots were established in the 2019-2020 AW cycle. Loam soils and moderate organic matter stand out in the plots, except at El Limón. The 1.2 gr $cm^{3\ -1}$ apparent density corresponds to fine-textured soils. These physical characteristics favor soil tillage and the development of the corn crop.

El Cedral is a highly important locality where the pH is strongly acidic, exchangeable aluminum is found at a toxic level, and the percentage of aluminum saturation is close to 20%, which is considered the critical level for corn (Tasistro *et al*., 2022). The rest of the localities do not record significant pH and exchangeable aluminum problems. Limiting B values and low to moderately low Ca values were detected (DOF, 2002). This result is of great importance to solve these limiting levels using amendments (Table 1).

Treatment distribution

Plots of 1.5 to 2.0 hectares were subdivided into 3,000-4,000 m^2 strips (one per hybrid). The INIFAP technology was established in two thirds of each strip, while the control or the producer's traditional management method was established in the remaining third.

Assessed treatments

Traditional management of the producer	INIFAP Technology
Medium to low yield genetic materials. Sowing: December 1 to 15 Planting density 70,000 seeds ha^{-1} Fertilization: Nitrogen with 180 to 240 units	INIFAP hybrids and transnational commercials with yield potential and adaptation to the region. Sowing: December 1 to January 25 Planting density 90,000 seeds ha^{-1}. Fertilization: with 190-160-160 for La Concordia and 240-160-60 in the Villa Corzo irrigation units for nitrogen, phosphorus, and potassium, respectively. Correction of micronutrients with militant levels in the soil.

Table 1. Soil chemical characteristics of the study locations.

Region	Location	pH water 1:2	MO %	P Bray	K	Ca	Mg	Na	Fe	Zn	Mn	Cu	B	S	N-NO_3	Al	CIC	Sat Al
				Mg kg^{-1}												meq/100 g		%
La Concordia	La Vega	5.9	2.2	27	77	10.3	203	27	68	2	25	1.1	0.1	2	4	0.02	7.2	0.3
Villa Corzo	San Lorenzo	5.0	1.7	102	132	934	160	17	108	3	30	0.7	0.1	47	31	0.40	6.9	6.0
	El Limón	5.5	1.3	61	88	810	208	21	119	4	14	0.8	0.1	20	10	0.24	6.3	3.8
	El Cedral	4.8	1.6	34	74	756	147	34	83	1	22	0.6	0.1	44	21	1.43	7.5	19.1

Loc=locality; pH 1:2 in water; OM (MO)=organic matter; P=phosphorus; K=potassium; Ca=calcium; Mg=magnesium; Na=sodium; Fe=iron; Zn=zinc; Mg=manganese; Cu=copper; B=boron; S=sulfur; N-NO_3=nitrates; Al=aluminum; CEC (CIC)=Cation Exchange Capacity; and Al Sat (Sat Al)=aluminum saturation.

Assessed variables

Yield was estimated with three sub-samplings per strip (hybrid) for the two management treatments. The following items were quantified: number of plants at harvest, earless plants, total and diseased corncobs, poor pollination, shelling factor, 1,000-grain weight, harvest index, and economic indicators.

RESULTS AND DISCUSSION

In the experimental plots where the validated technology was generated, an average yield of 14.8 t ha^{-1} and 17 t ha^{-1} were recorded, for the localities of the Cuxtepeques irrigation district, municipality of La Concordia, and the IS San Pedro Buenavista, municipality of Villa Corzo, respectively.

These results exceed the 12 t ha^{-1} recorded by Turrent *et al.* (2004), in the Granos del Sur project during the 1997-1998 and 1998-1999 AW cycles, at the IS of Villaflores. The 70,000 seeds ha^{-1} density and base dose of 200N-100P-60K kg ha^{-1} fertilization of that study is lower than the 90,000 seeds density and the 240N-160P-60K kg ha^{-1} fertilization determined in the experimental phase of the 2017-2018 and 2018- 2019 AW cycles of this study. In addition, micronutrient limitation problems were not solved; therefore, the experimental results of the aforementioned cycles suggest an important technological difference. In the 2019-2020 AW cycle, the experimentally generated technology was validated in plots managed by the cooperating producer. In the four localities, all the hybrids had higher grain yield with the INIFAP technology, but with lower readings than those obtained in the experimental phase.

Traditional management (control) was exceeded by 52% with the use of the INIFAP technology and, at the local level, the increase was 57% in Benito Juárez, municipality of La Concordia (Table 2). The average yield obtained using INIFAP technology was 10.4 t ha^{-1}. This figure was higher than the 7.1 t ha^{-1} obtained during the technology validation of the Granos del Sur project during the 1997-1998 and 1998-1999 WA cycles.

The highest yield (12.3 t ha^{-1}) was obtained in the San Lorenzo locality using INIFAP technology. This result was related to the use of drip irrigation, which improved the efficiency of water use, unlike gravity irrigation, which has a <50% application efficiency at the plot level (Chávez *et al.*, 2010). The water used was obtained from an artesian well whose water table recorded a decrease in April. The producer chose to make his well deeper; nevertheless, irrigation provided with the appropriate irrigation lamina was limited when the temperature in the area reached 40 °C.

The greatest photosynthetic capacity in corn occurs in the flowering season; therefore, the assimilable matter available in this period is a critical factor that determines the yield of the grain and the lower carbon and nitrogen flow towards the developing grains, which is important since these determine their size (Lafitte, 2001). Cheikh and Jones (1994) mention that a temperature higher than 35 °C and a low relative humidity cause desiccation of the stigmas in corn, and that temperatures higher than 38 °C reduce the viability of pollen. Some estimates suggest that, for each degree centigrade (°C) above the optimum environmental temperature (25 °C) grain yield is reduced between 3 and 4% (Rincón *et al.*, 2006).

Table 2. Corn grain yield of commercial hybrids in four localities in La Frailesca, Chiapas, Mexico, 2019-2020 AW cycle.

Hybrid	Irrigation units of the municipality Villacorzo						Irrigation district Cuxtepeques municipality of la Concordia		Average	
	Villacorzo		San Pedro Buenavista				Benito Juárez			
	San Lorenzo		El Cedral		El Limón		La Vega			
	INIFAP	Witness	INIFAP	Witness	INIFAP	Witness	INIFAP	Witness	INIFAP	Witness
Impact	11143 d	5312 f	6911 d	4506 fg	10662 cb	6559 d	11450 b	4384 e	10042	5190
P4279W	13833 a	6565 e	8245 b	5423 e	11949 a	5628 de	12433 a	5222 d	11615	5710
H-386	11715 c	6675 e	6994 d	4158 h	11474 ab	5403 e	10809 c	4903 d	10248	5285
H-568	12757 b	6522 e	7762 c	4221 hg	11683 ab	5549 de	11452 b	4930 d	10914	5306
H-377	11866 c	5256 f	8017 bc	4761 f	10256 c	5941 de	10873 c	4889 d	10253	5212
B3993			9256 a	5642 e					9256	5642
Average	12263	6066	7864	4785	11205	5816	11403	4866	10388	5391
% Increase	51		39		48		57		52	
DMS	475		343		1072		439			
CV	5		6		7		6			

The lowest yield in El Cedral (7.8 t ha^{-1}) was attributed to a high level of exchangeable aluminum with 19% aluminum saturation. Although this result did not exceed the critical level for corn (20%), it can influence the availability of other elements, such as phosphorus, potassium, and magnesium (Tasistro *et al.*, 2022). This suggests that, to obtain the maximum benefits of the nutritional recommendation of the proposed technology, it would be advisable to apply moderate amounts of dolomitic lime that help reduce aluminum and provide calcium and magnesium. Additionally, a higher harvest index (HI) was obtained in El Limón (Villa Corzo) using the proposed technology, which suggests a more efficient accumulation of dry matter in the grain (Escalante *et al.*, 2015). The shelling factor and the 100-grain weight had desirable values for all the assessed hybrids (Table 3).

Table 3. Harvest index (HI/IC), shelling factor (SF/FD), and 1,000-grain weight in five hybrids under irrigation. Locality of El Limón, San Pedro Buenavista ejido, municipality of Villa Corzo, Chiapas, Mexico, 2021 AW cycle.

Hybrid	IC		FD (%)		weight 1000 grains (g)	
	Technology		Technology		Technology	
	INIFAP	Witness	INIFAP	Witness	INIFAP	Witness
Syngenta	0.45	0.40	85	82	312	288
H-386A	0.43	0.39	85	79	366	315
H-568	0.46	0.41	84	81	312	298
H-377	0.43	0.40	85	83	302	285
P-4072W	0.44	0.41	85	81	356	328
Average	0.44	0.40	85	81	330	303

In the 2020-2021 and 2021-2022 AW cycles, one of the cooperating producers oversaw two plots. This producer had been trained during previous cycles, when he participated in the validation plots using the proposed technology. The increase regarding control was greater than the yield for the 2019 and 2020 cycles, whose average readings of 9.4 and 11.5 t ha^{-1} represented an increase of 57% and 64%, respectively (Table 4). This result suggests that, with adequate training for the correct application of the components of the proposed technology, an increase in yield is feasible compared with the traditional management used by the producer.

Financial analysis in commercial validation plots

Excluding the yields of El Cedral —due to the aluminum problem that could not be solved in a timely manner—, the financial analysis (August 2022) indicates that the INIFAP technology obtained higher net benefit and benefit-cost than the traditional management in the Cuxtepeques irrigation district and in the irrigation systems. The net benefit and benefit-cost were higher when using INIFAP seeds, which are approximately 50% less expensive than commercial seeds, possibly because they are the result of a research carried out with public resources (Table 5).

Table 4. Hybrid corn grain yield in two localities of the municipality of La Concordia, Chiapas, 2020-2021 and 2021-2022 AW cycles.

Hybrid	Technology	Locality and cycle	
		El Alto OI 2020-2021	El Alto OI 2021-2022
		Yield[1] (t ha^{-1})	
SKW-505	INIFAP*	7.8[1]	
	Producer	4.5	
P4279W	INIFAP	9.3	10.1
	Producer	4.9	4.1
P4028W	INIFAP	10.3	
	Producer	6.1	
P3966W	INIFAP		11.5
	Producer		4.2
NB-830	INIFAP	10.1	
	Producer	6.2	
B3937	INIFAP		13.6
	Producer		4.2
B3916	INIFAP		10.7
	Producer		4.3
H-377	INIFAP		11.6
	Producer		3.9
Average Yield	INIFAP	9.4	11.5
	Producer	5.4	4.1
Increase in yield		57%	64%

[1] Real yield; *INIFAP technology applied by a cooperating producer.

Table 5. Financial analysis of corn production using INIFAP and traditional technology in the Cuxtepeques irrigation district and the Villaflores and Villa Corzo irrigation systems, La Frailesca, Chiapas, Mexico.

	Locality							
	Irrigation district Cuxtepeques, La Concordia				**Irrigation units of Villa Corzo and Villaflores**			
	Technology INIFAP		**Technology Testigo**		**Technology INIFAP**		**Technology Witness**	
	Seed		**Seed**		**Seed**		**Seed**	
	INIFAP	**Company**	**INIFAP**	**Company**	**INIFAP**	**Company**	**INIFAP**	**Company**
Total cost ($)	44985	47080	26463	28591	45324	47879	28405	29945
Yield (t ha^{-1})	11322	11184	4403	4807	11625	11897	5891	6016
Gross profit ($)	72891	72002	28346	30947	74680	76593	37926	38731
Net profit ($)	27906	24923	1883	2357	29357	28714	9522	8786
B/C	1.6	1.5	1.1	1.1	1.7	1.6	1.3	1.3

*Average yield of validation in the 2019-2020, 2020-2021, and 2021-2022 AW cycles.

These results suggest that —in the event of the reactivation of the 12,500 hectares of the Cuxtepeques irrigation district and the approximately 10,000 hectares in the irrigation systems— 259,000 tons of white and yellow corn could be produced in the AW cycle, using the INIFAP technology, which would represent a net profit of 62 million pesos (García *et al.*, 2000).

CONCLUSIONS

The technology proposed by INIFAP increases the production and profitability of irrigated corn by more than 50% with respect to the traditional management of producers in La Frailesca, Chiapas. Once the irrigation infrastructure, equipment, and input problems are solved, larger increases could be obtained.

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Variations of the agroecological potential of *Moringa oleifera* Lam., in the presence of climate change scenarios in Veracruz, Mexico

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ABSTRACT

Objective: This research aimed to identify variations in areas with agroecological potential for *Moringa oleifera* Lam. (Moringa) cultivation, derived from the effects of climate change to the near horizon of 2039 in the state of Veracruz, Mexico.

Design/methodology/approach: The future scenario considered the current agroecological potential in the State and the general circulation model (GCM) HADGEM2-ES for the RCP8.5 scenario projected to the near future, 2039, with five categories: Very High, High, Medium, Low, and Very Low potential.

Results: An area with a Very High category of 1,057,415 hectares (ha) was identified, which corresponds to an expansion of 4.9% with respect to the current size. It was determined that climate change favors the cultivation of Moringa in three areas of the state. The most significant variation with an increase in the Very High category (115.58%) was identified in southern Veracruz, followed by the central area (110.17%). The greatest decrease (−4.53%) occurred in the north of the state.

Limitations on study/implications: Only the regions with Very High potential were identified, without considering those with High, Medium, Low, and Very Low agroecological potential.

Findings/conclusions: The projections under climate change conditions to the horizon of 2039 highlight the expansion of regions with Very High potential for cultivating the species in 19% of the Veracruz territory.

Keywords: Resilient crops, general circulation models, very high potential.

INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change (CC) as a variation in climate caused, directly or indirectly, by human activity that modifies the composition of the global atmosphere (Naciones Unidas, 1992).

Image by rsk585823 at Pixabay

Therefore, the current agricultural practices should adapt to the environmental and CC dynamics, with resilient species as potential resources for food production and financial income in tropical regions. Within this context, *Moringa oleifera* Lam. (Moringa) stands out due to its adaptability to rough conditions and fluctuations in temperature and rainfall (Holguín *et al.*, 2018). Nevertheless, assessments of the future behavior of any crop require studies for the construction of CC scenarios, where different contexts of greenhouse gas (GHG) emissions are used to evaluate global concentrations and radiative forcing; and, thus, to obtain models of the temperature increments in different time horizons (Manzanilla *et al.*, 2018).

The resource available to study climate is the set of General Circulation Models (GCM), which are the basis for constructing scenarios and future projections of CC. In regional studies, the information from the GCM is considered and complemented with regional and local climate factors (Conde and Gay, 2008).

Within this framework, the state of Veracruz presently stands out due to its high potential for Moringa cultivation (Carrión-Delgado *et al.*, 2022). However, it is necessary to know the impact that CC would have on the current potential of the crop according to climate change scenarios from the Intergovernmental Panel on Climate Change (IPCC).

Therefore, this study aimed to identify the changes in the areas with agroecological potential for the cultivation of *Moringa oleifera*, derived from the effects of climate change to the near horizon of 2039 in the state of Veracruz, Mexico.

MATERIALS AND METHODS

The data were collected from two sources: 1) The studies carried out by Carrión-Delgado *et al.* (2021 and 2022) (Table 1), which show georeferentiation and soil samples collected which served as a basis for the elaboration of climate layers and current environmental factors. 2) The Climate Atlas of Mexico (*Atlas Climático de México*, ACDM).

The scenarios elaborated by the IPCC (2000) to determine the future behavior of climate are A1, B1, A2, and B2, where A1 and B1 assume development at the global level while scenarios A2 and B2 are at the local level. Thus, the cartography to evaluate the distribution under CC change conditions was supported by scenario A2. Likewise, the local scenario A2 (Very High), the most extreme, was used under the assumption of a lack of actions for

Table 1. Agroclimatic characteristics from georeferenced data, interviews with producers, and soil sample collected in municipalities where Moringa is cultivated in Veracruz, Mexico.

Variable	Emiliano Zapata	Soledad de Doblado	Cosamaloapan
Temperature intervals (C°)	19-30	19-32	22-32
Altitude (masl)	827	103	10
Accumulated annual precipitation (mm)	894	887	1307
Types of soil	Phaeozem	Phaeozem	Vertisol
Soil pH	6.15-6.83	7.63-7.99	6.6-6.9
Soil texture	Clay-loam	Clay-loam	Clay

Carrión-Delgado *et al.*, 2022.

adaptation and mitigation in the presence of the effects of CC. The definition of climate layers and future environmental factors was carried out with precipitation and temperature data from the ACDM (Centro de Ciencias de la Atmósfera, 2018), contained in the Daily Climatological Base (DCB) from 1902 to 2011 with a spatial resolution of 1 km×1 km (Fernández *et al.*, 2014). The CC scenarios for the state of Veracruz were structured using a GCM based on the most favorable results obtained from the performance and spatial resolution for the region of Mexico (Conde & Gay, 2008), and the HADGEM2-ES model (Met Office Hadley) was chosen, with a spatial resolution of 1 km×1 km and the scenario with the highest level of GHG emissions (RCP8.5) to the near horizon of 2039. The climate layers of average monthly temperature (°C) and accumulated precipitation (mm) were downloaded from the GCM HADGEM2-ES, with a high spatial resolution of 1 km×1 km, sampled at a spatial scale of 30 m×pixel and with its corresponding topographic effect (UNIATMOS, 2021).

As suggested by Carrión-Delgado *et al.* (2022), the source maps were obtained with the ArcGis® Version: 10.7.1 tools; the values with the most significant adjustments in the raster images were interpolated, the values were classified for the variables, and the shape files were generated for the minimum and maximum annual temperature, the minimum and maximum annual rainfall in the adequate interval for the cultivation of Moringa in the state of Veracruz. The criteria established by Carrión-Delgado *et al.* (2022) were considered again for the future scenarios, with five categories: Very High, High, Medium, Low, and Very Low. The classification of each category was based on the evaluation of five variables: soil type, annual accumulated rainfall, agriculture and livestock land use, altitude, and minimum and maximum temperature. The areas categorized as Very High were those that passed the requirement of the five variables; those with High passed four; and those in the category Very Low were the ones that passed only one variable (Table 2).

The Very High category was the most important in this study. Because of this, the potential of Moringa for the scenario described was obtained as a result of the difference between the reference climate period and the future climate scenario (Fernández *et al.*, 2015); that is, from the subtraction of the layers of the current territorial potential minus the future one from MGC HADGEM2-ES. This analysis reflected the impact of CC on the modeled system, and the cartographic representation allowed identifying the variations

Table 2. Categories for the identification of areas with agroecological potential for the cultivation of *Moringa oleifera* Lam.

Number of variables	Category				
	Very low	Low	Medium	High	Very high
1	X	X	X	X	X
2	X	X	X	X	X
3		X	X	X	X
4			X	X	X
5				X	X
Total	1	2	3	4	5

Carrión-Delgado *et al.*, 2022.

of the areas with increment or decrement of agroecological potential to the time horizon 2039 for scenarios RCP8.5 (Fernández *et al.*, 2015; Trejo, 2016).

RESULTS AND DISCUSSION

Figure 1 shows the current distribution of the potential cultivation of Moringa in the state of Veracruz.

Table 3 shows the assessment of the current agroecological potential and the future projection. Table 3 (a) exposes the values of the current agroecological potential for the cultivation of Moringa in the territory of Veracruz (Carrión-Delgado *et al.*, 2022), while 3(b) shows the agroecological potential projected to 2039 under the non-conservationist scenario of RCP8.5 (A2).

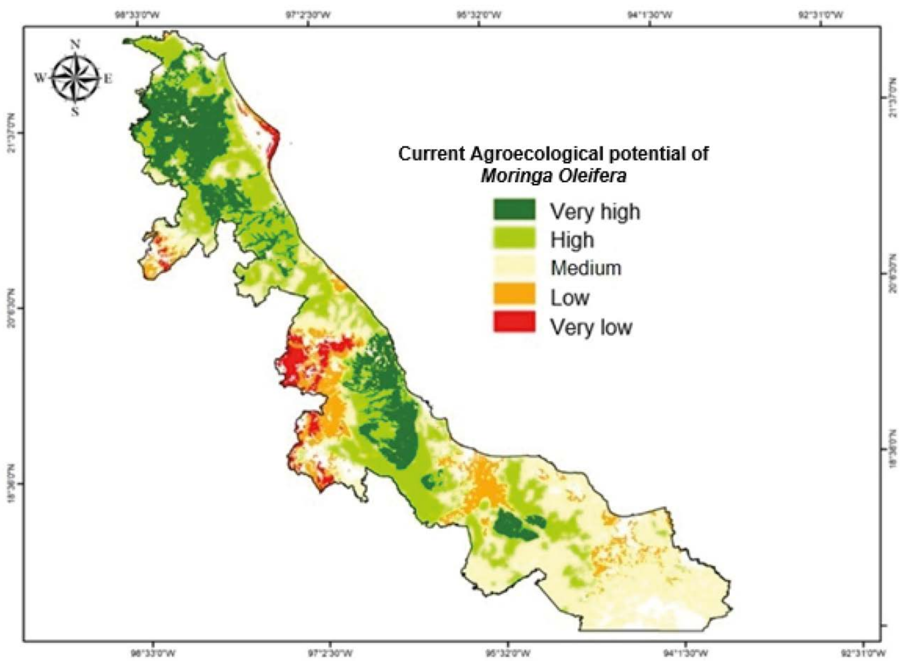

Figure 1. Current agroecological potential of Moringa in the state of Veracruz, Mexico (Carrión-Delgado *et al.*, 2022).

Table 3. Surface with agroecological potential for the cultivation of Moringa in the state of Veracruz: a) current and b) projected under scenario RCP8.5 to 2039.

Category	Current surface (ha)†	%	Projected surface (ha)	%
Very low	1,008,119	18.4	1,057,415	19.3
Low	1,602,381	29.3	1,600,814	29.3
Medium	2,049,887	37.5	2,000,107	36.6
High	639,212	11.7	648,081	11.8
Very high	170,551	3.1	165,157	3.0
TOTAL	5,470,148	100	5,471,575	100

†Carrión-Delgado *et al.* (2022).

The results obtained with the HADGEM2-ES Model under CC scenarios evidenced a significant variation: a territorial incrment in the agroecological potential for Moringa cultivation. The variations in agroclimatic conditions impacted the spatial dimensions (number of ha). Similarly, they will affect both the growth of the crop and biomass production, as mentioned by Meza-Carranco *et al.* (2016).

On the other hand, when contrasting the distribution of the current agroecological potential with the scenario RCP8.5 projected to the horizon of 2039, the findings show that the most significant increment was found in the category Very High (2.4%) and, to a lower proportion, in the Low (0.7%). The Very Low (−1.6%) was the most significant decrement, followed by the Medium (−1.2%).

Figure 2 indicates the spatial distribution of Moringa in its different categories, with MGC HADGEM2-ES under scenario RCP8.5 (A2), projected to horizon 2039. Three areas of larger spatial dimension were obtained regarding the Very High category. The first is located to the south (Los Tuxtlas, Olmeca, and Papaloapan), between the state of Oaxaca and the Gulf of Mexico (Table 4), with an extension of 92,782 ha and 115.58% of expansion compared to the current potential. The second is located in the center (Sotavento, Capital, Nautla, and Altas Montañas), in the central part of the state, neighboring the Gulf of Mexico and with a projected area of 347,026 ha, presenting 110.17% of expansion compared to the current state. Finally, the third is located to the north (Totonaca, Huasteca Alta, Huasteca baja) of the state, neighboring the states of San Luis Potosí, Hidalgo, and Puebla, with a projected extension of 617,492 ha that presented a decrease of −4.53% compared to the current status. These results agree with Rueda-Magaña and Gay-García

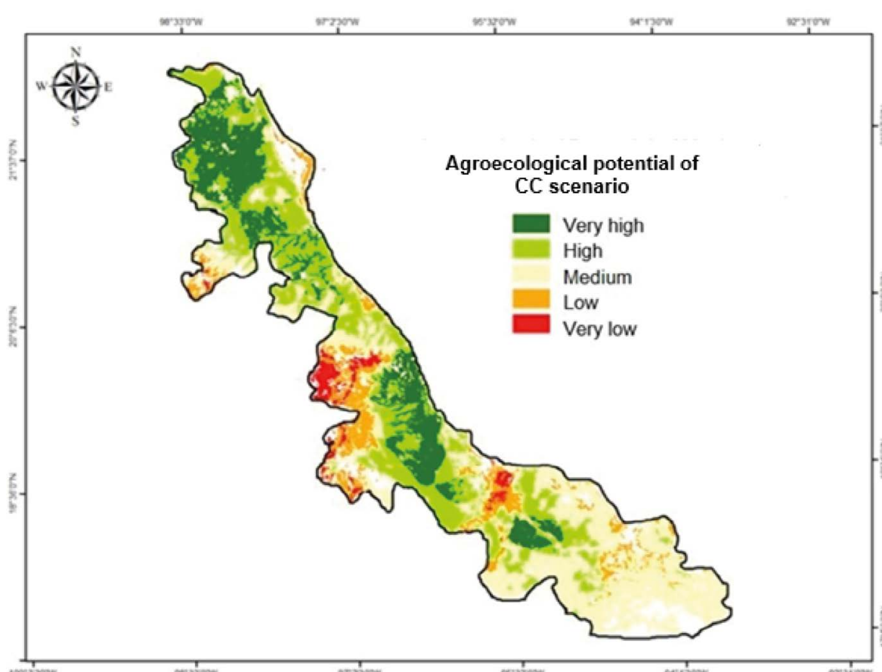

Figure 2. Agroecological potential of Moringa with MGC HADGESM2-ES, to the future horizon 2039 for the RCP8.5 scenario, in the state of Veracruz, Mexico.
Source: Prepared by de la Rosa-Portilla (2021).

Table 4. Estimated potential surface for the plantation of *Moringa oleífera* Lam. projected under scenario RCP8.5 to 2039 in the state of Veracruz.

Region	Municipalities	Surface (ha)	†%
Totonaca	Cazones de Herrera, Coatzintla+, Gutiérrez Zamora+, Papantla, Poza Rica de Hidalgo, Tecolutla+, Tihuatlán.	39,870	3.77
Huasteca Alta	Chalma, El Higo, Ozuluama de Mascareñas, Pánuco, Platón Sánchez, Pueblo Viejo, Tamalín+, Tamiahua+, Tampico Alto, Tantima, Tantoyuca, Tempoal.	471,486	44.59
Papaloapan	Ignacio de la Llave+, Isla, José Azueta, Juan Rodríguez Clara, Tres Valles+, Tierra Blanca.	66,893	6.33
Huasteca Baja	Álamo Temapache, Chicontepec, Cerro Azul, Chontla, Citlaltépetl, Ixcatepec, Ixhuatlán de Madero, Tepetzintla, Tuxpan.	106,136	10.04
Sotavento	Cotaxtla+, Jamapa+, La Antigua, Manlio Fabio Altamirano, Medellín de Bravo, Paso de Ovejas, Puente Nacional+, Soledad de Doblado, Tlalixcoyan, Úrsulo Galván, Veracruz	222,544	21.05
Nautla	Juchique de Ferrer, Martínez de la Torre+.	499	0.05
Capital	Actopan, Alto Lucero de Gutiérrez Barrios, Apazapan, Coatepec, Emiliano Zapata, Jalcomulco, Naolinco, Tepetlán+, Xalapa.	88,806	8.40
Olmeca	Acayucan, San Juan Evangelista+.	4,598	0.44
Las Altas Montañas	Camarón de Tejeda, Carrillo Puerto, Comapa, Cuitláhuac, Paso del Macho, Tenampa+, Tlaltetela, Zentla.	35,177	3.33
Los Tuxtlas	Hueyapan de Ocampo, San Andrés Tuxtla+, Santiago Tuxtla+.	21,407	2.02
	Total	1,057,415	100

†=Statewide percentage of the Very High category, + municipalities added to 2039.

(2002), who obtained more significant temperature changes in southeastern Mexico, with an increment no higher than 2.8 °C and a slight decrease in precipitation no higher than 10%. These climatologic variables will impact the agroecological potential, development, and production levels (Meza-Carranco *et al.*, 2016), favoring resilient crops like Moringa (Egea *et al.*, 2015).

Under the RCP8.5 scenario, the state of Veracruz presents a trend towards increasing temperature and decreasing rainfall in the south. These results agree with the GCM models obtained by Magaña *et al.* (1997), which showed an increase in temperature for the Gulf of Mexico zone at the end of the 21st century. Similarly, this agrees with Trejo (2016) regarding the expansion of the dry forest foreseen on the coast of the Gulf of Mexico due to the increments in temperatures and the decrements in rainfall in the south of the state.

CONCLUSIONS

The variations of areas with agroecological potential for the cultivation of *Moringa oleifera* under conditions of climate change to the near horizon of 2039 and scenario A2 (RCP8.5) tend to present higher agroecological potential towards the category of Very High in the state of Veracruz.

As a resilient species, Moringa can adapt and recover after disturbances under severe drought conditions, which could increase in broader regions of Veracruz. Therefore, its cultivation represents a great opportunity area as a source of income under the effects of climate change in the state of Veracruz.

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Lyophilized biopolymeric beads of chitosan-xanthan with edible fungus *Laccaria laccata* (Scop.) Cooke as forest ectomycorrhizal biofertilizers

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ABSTRACT

Objective: To evaluate whether or not the spores of the edible fungus *Laccaria laccata* (Scop.) Cooke encapsulated in a lyophilized biopolymeric matrix of chitosan-xanthan can cause ectomycorrhization in *Pinus greggii* Englem. trees under greenhouse conditions.

Methodology: Spores of the edible ectomycorrhizal fungus *L. laccata* were encapsulated in beads made with the chitosan-xanthan biopolymer. The embedded spores were analyzed using scanning electron microscopy to evaluate possible structural damage. Next, these beads were used as biofertilizers in a greenhouse bioassay using *Pinus greggii* plants to evaluate their ability to be ectomycorrhized. The bioassay lasted 270 days. Subsequently, stereoscopic and bright field microscopy was used to determine if the roots of the pines had been subjected to an ectomycorrhizal colonization. Additionally, the growth of inoculated plants was evaluated compared to non-inoculated plants, 180 and 270 days after sowing.

Results: The spores of *L. laccata* encapsulated in the biopolymeric matrix formed ectomycorrhizae in the roots of *P. greggii*. The percentages of ectomycorrhizal colonization in the plants ranged from 80 to 90%, demonstrating that the production of chitosan-xanthan biopolymeric beads can maintain the viability of the spores of the ectomycorrhizal fungus evaluated and extensively colonize the roots of *Pinus greggii*.

Study Limitations/Implications: The biopolymeric matrix beads that contain spores of the fungus *L. laccata* can induce ectomycorrhization in trees of forest importance.

Conclusions: The spores of an edible ectomycorrhizal fungus encapsulated in the chitosan-xanthan biopolymer have potential as a forest biofertilizer, which opens the opportunity to scale its use up to an industrial level.

Keywords: Edible ectomycorrhizal fungi, biofertilizers, forest production, Mexican pines.

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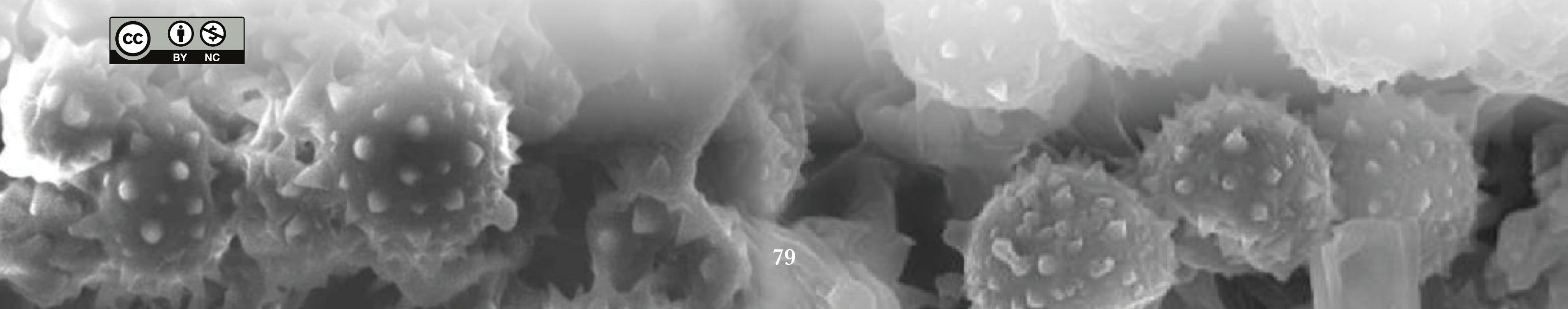
INTRODUCTION

Some fungi found in the soil form mycorrhizae, which provides many benefits to the plant (Jamiołkowska *et al.*, 2021; Rigueiro-Messa and Rodrigues-Savioli, 2021; Nairet *et al.*, 2022; Milton *et al.*, 2021). The technological challenge is to inoculate mycorrhizal fungi



in order to produce ectomycorrhized plants; therefore, the spores of the said fungi have been used on different commercial substrates. However, one limitation is the development of techniques that prolong the shelf life of mycorrhizal inoculants (Salomon *et al.*, 2022).

There are different types of mycorrhizae, including ectomycorrhizal, which is a mutualism established between plant species, mainly trees (angiosperms and gymnosperms) and fungi, mainly Basidiomycetes and Ascomycetes (Smith and Read, 2008; Hall *et al.*, 2003). Ectomycorrhizal fungi can improve the nutritional conditions associated with the poor environments —especially nitrogen- and phosphorus-deficient ecosystems— in which their host plants grow. This property has been used in reforestation to promote the growth of plants in the field. Currently, one of the selection criteria of the fungi to be used to inoculate trees is their edibility. Mexico ranks second in the world with the greatest biodiversity of edible wild fungi —500 species which include around 200 ectomycorrhizal species (HSCE). These fungi are sold in local markets and some of them have a high value in international markets (Villarreal and Pérez-Moreno, 1989; Gómez-Vázquez *et al.*, 2019). The survival of trees in the field depends, to a large extent, on the formation of ectomycorrhizae, which can be evaluated in greenhouse-inoculated plants (Tateishi *et al.*, 2003; Bernaola-Paucar *et al.*, 2022; Salcido-Ruiz *et al.*, 2021).

Due to their low cost and relative ease of handling, the use of spores from fungal species involved in ectomycorrhizal symbiosis has enormous biotechnological potential for the production of forest inoculants. Currently, the production of ectomycorrhizal fungi-based inoculants has gained enormous importance in countries with a forest tradition (Pérez-Moreno *et al.*, 2008). However, no ectomycorrhizal fungi-based commercial inoculant made from native species is available in Mexico. Consequently, the objective was to encapsulate spores of the fungus *Laccaria laccata* (an HSCE) in a chitosan-xanthan biopolymeric matrix, in order to maintain its viability and verify their capacity to generate ectomycorrhization in *Pinus greggii* Englem plants under greenhouse conditions.

MATERIALS AND METHODS

Location

The research was carried out in the Microbiology greenhouse of the Edaphology Program, at the Colegio de Posgraduados, Campus Montecillo, Mexico-Texcoco Highway, Km 36.5, Montecillo, Texcoco, State of Mexico.

Establishment of the greenhouse

The seeds of *P. greggii* used in this work were collected at the natural forest of Chignahuapan, in the municipality of Puebla, State of Puebla, Mexico. During the pre-germination treatment, the seeds were soaked in running water for 24 h and were subsequently disinfected with hydrogen peroxide (H_2O_2) at 30% v/v in water for 20 min. Finally, the seeds were rinsed twice with sterile distilled water, the excess water was removed, and the seeds were sown.

The sowing was carried out on September 22, 2020. Three seeds were placed in every140-cm^3 black plastic forestry tube with internal root guides at a 2-cm depth. The tubes were placed in tube-stock trays with 48 cavities. The substrate used consisted of a 2:2:1 mixture of river sand, pine bark, and forest soil. The substrate was previously subjected to steam sterilization, at a pressure of 1.3 kg/cm^2 and a temperature of 125 °C for 5 h. It was left to rest for two days and then sterilized again for 5 h.

To avoid cross contamination, the tube-stock trays were placed in a wooden container, covered with a plastic film. This container was located inside the greenhouse, which has a metal structure and side windows. A 2-mm black shade net was placed over the metal structure.

The seeds sown were irrigated every third day with bottled water for 90 days. Subsequently, the seeds sown were irrigated with running water. The amount of water in each irrigation reached field capacity.

The Captan 50 WP (Captan: N-trichloromethylthio-4-cyclohexene-1,2-dicarboximide) fungicide was used to prevent damage from damping off fungi. The seedlings were watered with a 2-g/L solution of this fungicide, up to three months after sowing.

Synthesis and characterization of encapsulated spores

The fungal material used was acquired in the Ozumba market, State of Mexico, located at 18° 15' 00" N and 98° 46' 30" W. The said material had been collected in the surrounding pine forests. The inoculum was obtained from fresh *L. laccata* sporocarp, separating the pileus from the stipe. The pileus was dehydrated at 35 °C for 48 h in a Jersa® fruit dehydrator. Subsequently, these pilei were ground and sieved with a 1.19-mm mesh, in order to homogenize the particle size. The spores were counted using a Neubauer chamber (Marienfeld, Lauda-Königshofen, Germany) to determine their concentration.

The *L. laccata* inoculum was encapsulated in a bead-shaped chitosan-xanthan biopolymeric matrix for its application on *P. greggii* seeds. High-density, industrial grade, America Alimentos® chitosan (Q) from lot K1202029 and Sigma® xanthan (X) from lot G1253-500G were used for this matrix.

The chitosan-xanthan beads (Q-X beads) were synthesized following the procedure described below. Two g of Q were dissolved in 100 mL of 0.4 M acetic acid, 24 h after the Q had been placed on the acid solution for its hydration. Subsequently, 0.6 g of X were added. An Ultra-Turrax® homogenizer (IKA) was used to homogenize the suspension, at 25 °C and 7,000 rpm for 30 min. Afterwards, 80 g of *L. laccata* inoculum were added and the mixture was homogenized again for another 30 min. It was then sonicated in an ultrasonic bath (Branson 2510MT Ultrasonic Cleaner). Once its pH was determined, the mixture was dripped at a 3-mL/min flow, in a 1 M sodium hydroxide solution at 25 °C, using a Masterflex® L/S peristaltic pump (Cole Parmer, model 7523 80) with a 2-mm internal diameter nozzle. The resulting Q-X beads with inoculum were left to mature for 2 h. Finally, they were washed once with distilled water (DW) and dehydrated using a FreeZone Plus® 2.5-L lyophilizer (Labconco, Cascade Benchtop Freeze Dry System), before they were stored at room temperature awaiting their characterization and subsequent use.

After the beads were lyophilized and covered with a gold bath for 30 s, they were characterized through a morphological analysis, using a JSM-6610LV scanning electron microscope (JEOL).

Experimental design and treatments

A completely randomized experimental design was used to evaluate the potential ectomycorrhization of the beads of chitosan-xanthan containing the spores of the fungus *L. laccata*. There were two treatments: the control and the plants inoculated with Q-X beads with the fungus *L. laccata*. Each treatment consisted of 22 plants; therefore, 44 experimental units were established, each consisting of one plant. For the inoculation of the plants, the seeds were covered with 10 g of substrate; the 0.15-g Q-X beads were placed on top of the substrate and they were covered with approximately 1 cm of substrate. In total, each plant was inoculated with 10^7 to 10^8 spores of *L. laccata* embedded in the biopolymeric matrix.

Evaluation

Two morphometric evaluations were performed at 180 and 270 days after sowing (das). The height was measured from the base of the stem to the apical bud with a graduated ruler, while the diameter was measured at the base of the stem of each plant, with a Mitutoyo digital vernier caliper.

The percentage of mycorrhizal colonization (PMC) was evaluated in three plants per treatment. The said evaluation took 4 to 5 days per plant. The plants were randomly selected at 270 das. The root balls of the plants were extracted from the forestry tubes and the root part was washed under a low-pressure water jet, using three Duvesa and FIICSA sieves (1.19-, 0.180-, and 0.0850-mm opening diameters), to avoid the loss of short roots. The number of mycorrhized apices was determined by direct observation with a EZ4 HD stereoscopic microscope (Leica, Switzerland) and the PMC was calculated.

$$PMC = \left(\frac{mycorrhized\ apices}{mycorrhized\ apices + non - mycorrhized\ apices} \right) 100 \quad (1)$$

To verify the existence of colonized or ectomycorrhizal roots, cross sections and preparations for anatomical characterization were made, in order to find the ectomycorrhizal structures (mantle, Hartig net, and external mycelium).

RESULTS AND DISCUSSION

The spores were satisfactorily encapsulated in the chitosan-xanthan biopolymeric matrix, generating brown beads with a robust consistency to the touch and handling (Figure 1b). These beads were lyophilized prior to their use (Figure 1c). Figures 1 d and e show the images obtained by the scanning electron microscopy (SEM) of the spores of *L. laccata*, both in the inoculum and in the beads where they were encapsulated. The said spores remained turgid, did not show ruptures, or evident morphological modifications after the encapsulation and lyophilization processes.

Table 1 shows the results of the morphometric evaluation of the treatments at 180 and 270 das. The average height is higher in the treatment inoculated with Q-X beads,

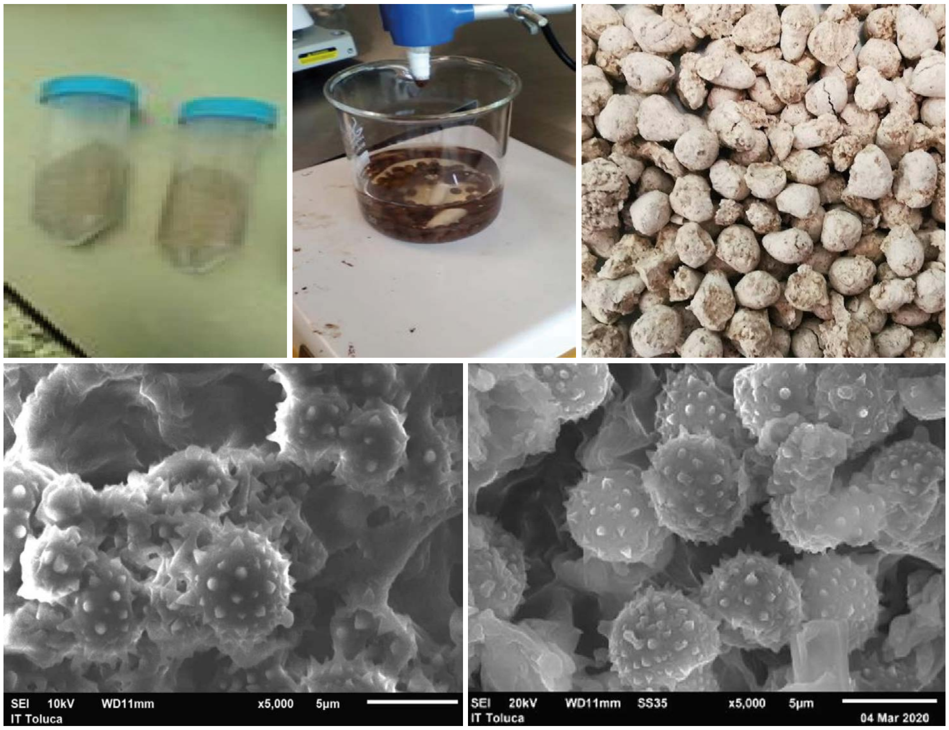


Figure 1. a) *L. laccata* inoculum; b) Q-X beads with encapsulated spores; c) lyophilized beads; d) Micrograph of spores in the inoculum; e) Micrograph of the spores encapsulated in the chitosan-xanthan biopolymeric matrix (Q-X beads).

both at 180 and 270 das. Likewise, the average diameter was also greater in the treatment inoculated with Q-X beads, both at 180 and at 270 das. This shows that the inoculation was favorable for mycorrhization, and therefore that the encapsulated spores remained viables. The high PMC recorded at 270 das also accounts for the viability of the spores encapsulated in the beads of the chitosan-xanthan biopolymeric matrix.

A high percentage of mycorrhization (mantle, Hartig net, and external mycelium) was observed in the inoculated plants and ranged from 80 to 90% in the roots of the ectomycorrhized plants. The results of the anatomical characterization are shown in Figure 2. The presence of the mycorrhization can be clearly seen in the treatment inoculated with Q-X beads (images a, b, and c). Figure 2d clearly shows the effect of mycorrhization on the height of the treatment where it was inoculated.

Table 1. Results of the morphometric and PMC evaluation in the experimental design.

Parameter	180 das		270 das	
	Control	Q-X	Control	Q-X
Height (cm)	7.830±1.119	7.865±1.166	18.890±2.750	21.800±3.430
Diameter (mm)	0.954±0.074	1.060±0.127	1.440±0.100	1.600±0.155
PMC	-	-	0.00	83.01±12.48

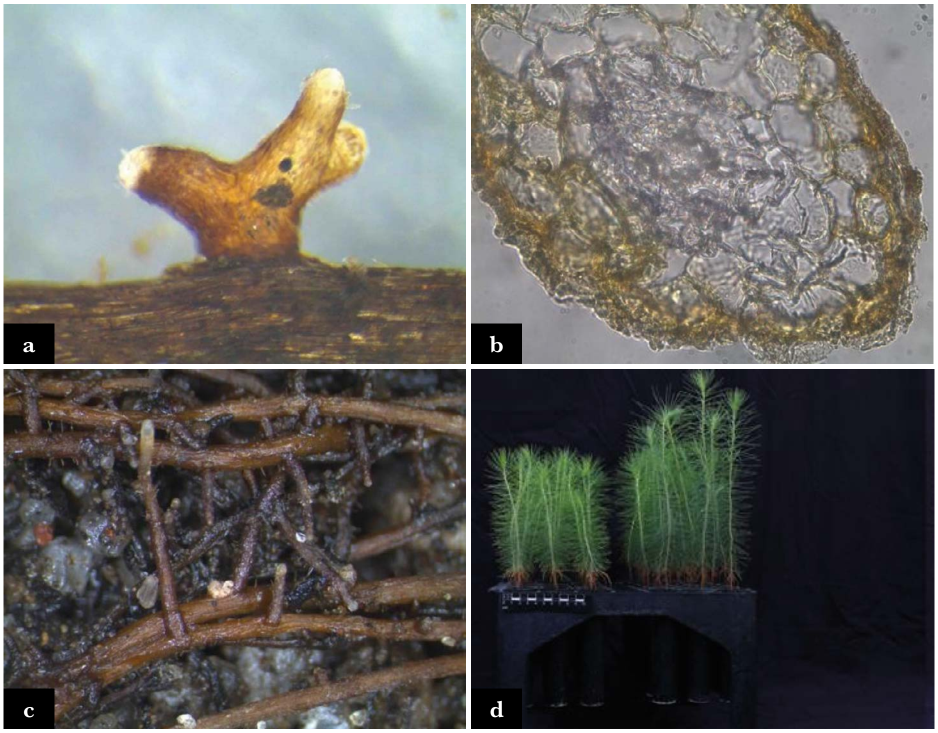


Figure 2. Images obtained from the treatment inoculated with Q-X beads. a) Tetrapod-shaped mycorrhized root; b) Cross section in which the fungal mantle, Hartig net, and external mycelium can be observed; c) Root ball; d) Differences in the growth of both treatments: control (left) and the treatments inoculated with Q-X beads (right).

CONCLUSIONS

Scanning electron microscopy showed that the spores of *L. laccata* did not suffer harmful structural modifications when they were encapsulated in the chitosan-xanthan biopolymeric matrix. The spores of *L. laccata* encapsulated in the biopolymeric matrix under study caused high mycorrhizations (80-90%) in *P. greggii* plants inoculated under greenhouse conditions after 270 das. In contrast, non-inoculated plants lacked mycorrhization. This research shows that the spores of the ectomycorrhizal fungus *L. laccata* encapsulated in chitosan-xanthan biopolymeric beads can be used to produce a biofertilizer for inoculation purposes in plants of forest interest. Consequently, this research proves that there is potential both for increasing the shelf life of the ectomycorrhizal inoculum and for scaling it up to an industrial level.

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Colegio de Postgraduados

Effect of THI, NDF and rumination in milk production in Holstein cows

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ABSTRACT
Objective: The aim of the present study was to evaluate the effect of the temperature-humidity index (THI), the content of neutral detergent fiber (NDF), and rumination rate (RR) on milk production in Holstein cows in a dairy farm located in Bajío de San José, Jalisco, Mexico.
Design/methodology/approach: The THI is an indicator of the effect of the environmental climate can have on milk production, and likewise the nutritional content of forage is affected by weather conditions, such as the NDF is related with rumination activity of cows; increasing THI has shown a direct effect on milk production in cows. The HealthyCow 24® CSR remote equipment was used (SCR Engineers Ltd., Netanya, Israel), to monitor rumination, from a total registry of 284 cows with 2, 3, and 4 lactations distributed between August and December 2020 period, analyzing the NDF content from total mixed portion and monitoring the THI.
Results: The results showed there was no effect of THI on milk production ($p>0.05$), despite having reached a THI score of 76, while NDF ($p<0.05$) and RR ($p<0.001$) affected milk production; an effect of THI on RR ($p>0.05$) was not found, and the NDF only had a trend ($p<0.1$).
Limitations on study/implications: There were no limitations for the study.
Findings/conclusions: According to the results obtained, the THI threshold should be reconsidered according to the resistance of the productively active cattle on dairy farms.

Keywords: Climate adaptation, degradability, heat stress.

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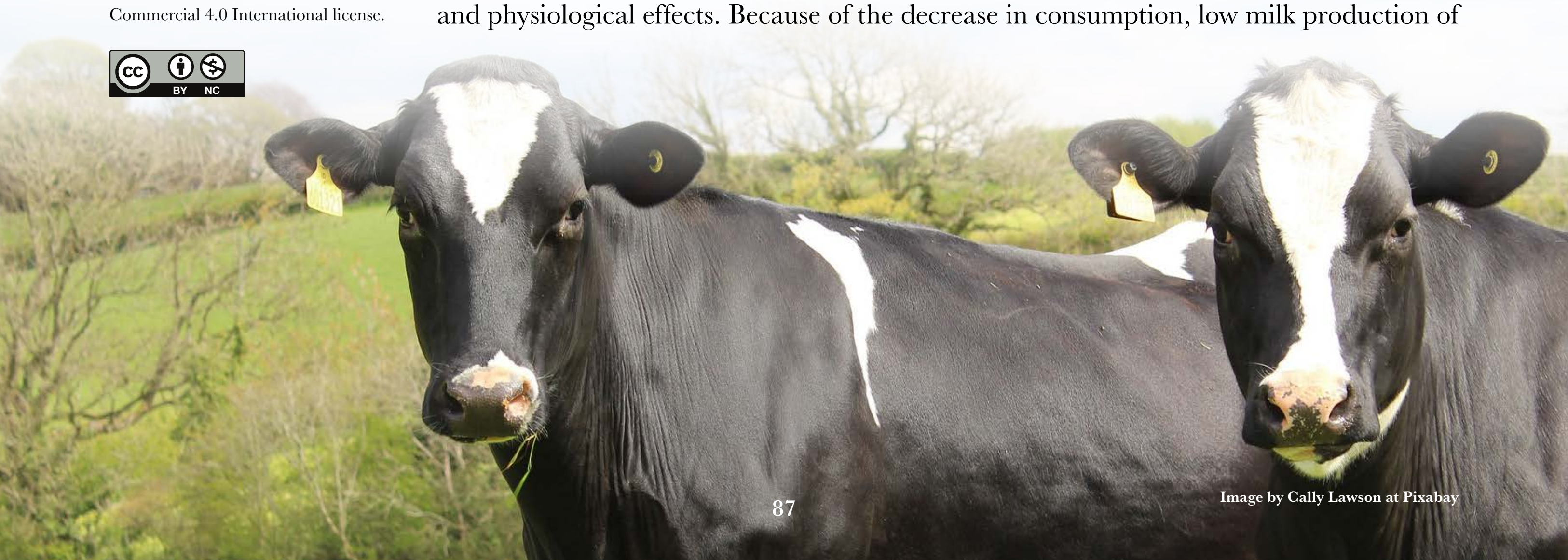
INTRODUCTION

The temperature-humidity index (THI) is an indicator of the effect that the environmental climate can have on milk production. Cowley *et al.* (2015) mention that the impact of the heat stress (CS) has two causes: reduction of consumption and metabolic and physiological effects. Because of the decrease in consumption, low milk production of



between 25-40% has been seen (Tao *et al.*, 2018). Collier *et al.* (2012) indicated that the THI threshold should be reconsidered, because of multiple results where thresholds of CS have been found at a lower scale than a THI of 72.

Increasing the Neutral Detergent Fiber (NDF) has been seen to improve the digestion of some nutrients such as starch. Dann *et al.* (2015) found similar milk productions (51.6 *vs* 50.5 kg of milk) when increasing the NDF from non-forage sources (34.7 *vs* 38.0%), similar to what is reported by Ranathunga *et al.* (2018) who increased non-forage NDF and did not have an increase in milk production (+2.1%). Naderi *et al.* (2016) reported that by substituting 12% of the sources of non-fodder fiber in place of the corn silage there were higher milk productions even under conditions of CS (+6.27%). The physically effective NDF is the fraction of fiber that stimulates chewing and contributes to the floating bed of long particles in the rumen (White *et al.*, 2017). Milk production has been associated with the rumination time, which has been associated with cows of higher milk production having a higher consumption and therefore needing more rumination time (Stone *et al.*, 2017). Salfer *et al.* (2018) mention that, in general, consumption, rumination and ruminal pH follow a daily pattern that was minimally modified by the type of fiber and carbohydrates. The cows use more time in rumination throughout the entire day when there is a higher concentration of NDF. Byskov *et al.* (2015) found an increase of 22 min of rumination time for every kg of NDF of forage consumed.

The CSR Heatime® HR system, in addition to being commonly used for reproductive programs (Burnett *et al.*, 2017; LeRoy *et al.*, 2018), has proven to have high sensitivity to detect changes in the activity and the rumination before the evident clinical signs of a disease such as displacement of abomasum, as well as metabolic and digestive disorders; this results in the early identification of it (Stangaferro *et al.*, 2016). Due to the variability of response of milk production in the presence of changes in THI, NDF and rumination that have been found, the objective of this study was to evaluate the effect of THI, NDF and the rumination rate (RR) on milk production, as well as evaluating the effect of THI and NDF on the RR in Holstein cows in a stable located in Bajío de San José, Jalisco.

MATERIALS AND METHODS

Study area

The study was developed in a stable of the locality of Bajío de San Jose, municipality of Encarnación de Díaz, Jalisco, Mexico.

Distribution of cows for the study

To record the information, there were cows of second, third and fourth lactation that had normal births, and in addition the cows had to be in a range between 21 and 306 days in milking (DIM), in each period of reading. The DairyComp305® system (DC305; Valley Ag Software, Tulare, CA) was used to identify the number of lactation and the days in milking (DIM) of the animals in each registry date of milk production when it was done. Monitoring was carried out during the period from the month of August to the month of December, 2020, adjusting the milk records based on the activities of the ranch to avoid interfering with the management, obtaining a total of 284 records of milk weighing distributed in the dates: August 06 and 28, September 16, October 06 and 21, November 13, and December 18 of the year 2020.

Monitoring of the Temperature-Humidity Index

To estimate the THI, first the temperature and the humidity were measured manually within the farmyards, with a digital thermometer with relative humidity sensor brand Radioshack®, model 80904, with electrical characteristics of the temperature sensor: 10 K (−2%) Ohms, 3435 K. The readings were carried out at 15:00 hours (Cerqueira *et al.*, 2016) in the same dates when the records of milk production were obtained. The equation of the Temperature and Humidity Index equation by Dikmen and Hansen (2009) was used.

$$THI = (1.8 * T + 32) - [(0.55 - 0.0055 * RH) * (1.8 * T - 26)]$$

Where T is the temperature expressed in Celsius degrees and RH is the Relative Humidity expressed in percentage; these records were noted in a database with an Excel ® spreadsheet.

Rumination activity

To monitor the rumination activity, the remote equipment HealthyCow 24® CSR (SCR Engineers Ltd., Netanya, Israel) was used. The SCR Company programmed the software of the HC24 system to automatically download a back-up in Excel® format of the rumination monitoring each day. Every day throughout the monitoring period, considering the rumination reading that closes at 23:00 hours, it was used as the rumination rate in 24 hours (RR) for the purpose of mathematical analysis (Stangaferro *et al.* 2016).

Milk production

The milk production for each cow was recorded manually and individually with the SCR Milking Control System (SCR Engineers Ltd., Netanya, Israel) in each of the dates mentioned before.

Sampling of total mixed portions

Samples were collected from the total mixed portions in the day of the record of milk production directly from the manger; five portions of approximately 500 g were taken along the manger in equidistant form from the recently served manger, and then, mixing the five portions and from there taking a single sample of 1 kg.

Bromatological analysis

The dry matter, protein, ethereal extract and ashes were determined according to the AOAC (1990) method; the neutral detergent fiber was determined with the technique by Van Soest *et al.* (1991).

Statistical analysis

For the analysis of the effects of the variables THI, rumination and NDF on milk production, a multiple linear regression model was used, where the dependent variable Y=milk production and the three independent variables, X_1=THI, X_2=NDF and X_3=Rumination, were considered under model 1:

Model 1: $Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon_i$

Where, "β" 0=Factor of initial adjustment, "β" 1=Coefficient of the THI effect, "β" 2=Coefficient of the NDF effect, "β" 3=Coefficient of the Rumination effect.

The assumptions of the model were tested making adjustments to the dependency of errors through the Cochrane-Orcutt method.

For the analysis of the effects of the variables THI and NDF on the Rumination, a multiple linear regression model was used, where the dependent variable Y=Rumination and the two independent variables, X_1=THI and X_2=NDF were considered, under model 2:

Model 2: $Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon_i$

Where, "β" 0=Factor of initial adjustment, "β" 1=Coefficient of the THI effect, "β" 2=Coefficient of the NDF effect.

An adjustment to model 2 was conducted through the transformation of the dependent variable by the Box-Cox technique, with a transformation factor 2.476736, to fulfill the assumption of normality of residuals.

All the statistical analyses were carried out with the R-Studio version 2022.03.3 system.

RESULTS AND DISCUSSION

Temperature and Humidity Index

During the monitoring period, fluctuating values of THI were found between 68 and 76 (Figure 1). The average milk production found when the THI was 76 that was recorded twice under an average of 3.1 Kg milk/day compared to the average that was obtained when the THI was 68 in the date of August; although within the August period the average milk production decreased by 6.21%, by the months of September and October the productions were maintained compared to the end of August, without altering them, although the THI decreased to 72 and then increased again to 76 at the end of October ($p>0.05$).

Neutral Detergent Fiber

The percentage ranges of NDF in total mixed portions were between 25.2% and 35.6% (Figure 2), where a significant negative effect of the NDF content on milk production was found of up to −19.5% ($p<0.05$); the drastic increase of the NDF recorded in the month of November was because of an imbalance of ingredients found per week.

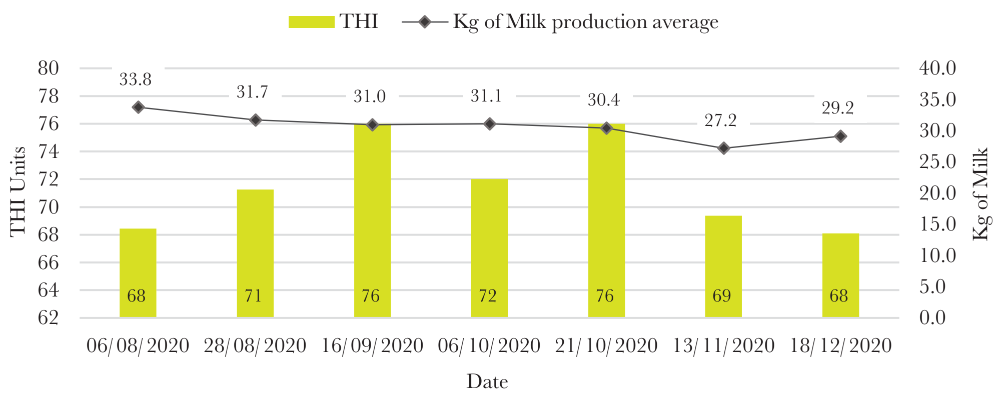


Figure 1. Variations of the Temperature and Humidity Index (THI) by date and average milk production (Kg), of cows with 2, 3 and 4 lactations, from August to December 2020, Bajío de San José, Jalisco.

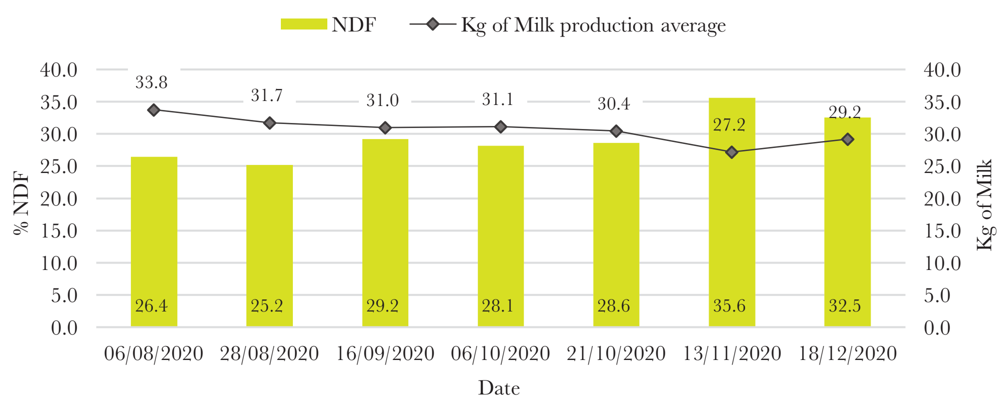


Figure 2. Variations of the content of Neutral Detergent Fiber (NDF) in the total mixed portions by date and average milk production (Kg) of cows with 2, 3 and 4 lactations, from August to December 2020, Bajío de San José, Jalisco.

Ruminant activity

The average RR of animals for each period had a range between 511 and 582/24 hr (Figure 3); the RR had a highly significant positive effect on milk production ($p<0.001$), although the RR was affected with lower significance due to the NDF ($p<0.10$) content, and the THI did not have a significant effect on the RR ($p>0.05$).

Temperature and Humidity Index

Results from this study indicate that milk production was maintained despite reaching THI of 76, compared to what was found by Cerqueira *et al.* (2016) and Perano *et al.* (2015) where production decreased when reaching a THI of 78 and 80.7, respectively, which in the case of Perano *et al.* (2015) found a decrease of milk production in heifers of up to 11.2% when reaching a THI of 80.7 if management to attenuate CS was not given. On the one hand, it is possible that the increase in THI in this study is due to an increase of food efficiency as mentioned by Hill and Wall (2017) when cows went through a medium CS, although Gao *et al.* (2017) reported that even if the apparent digestibility of

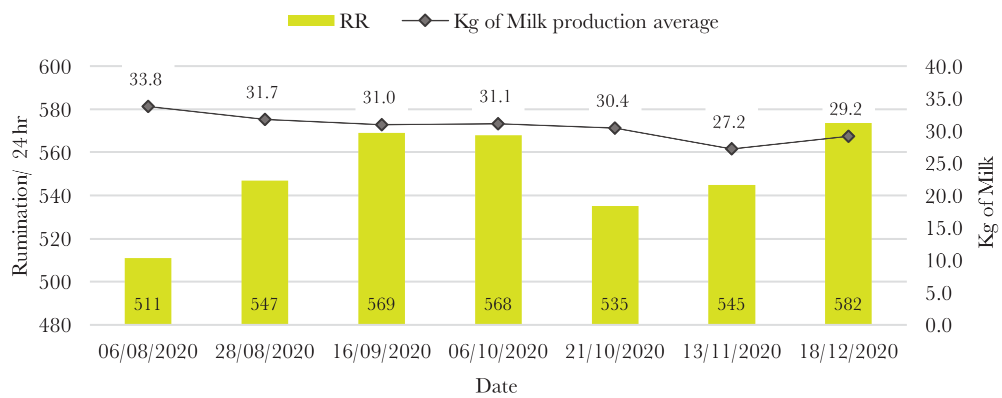


Figure 3. Variations of the average Ruminant Rate (RR) and the average milk production (Kg) of cows with 2, 3 and 4 lactations, from August to December 2020, Bajío de San José, Jalisco.

dry matter, organic matter, neutral detergent fiber, acid detergent fiber, raw protein, and ethereal extract increased when reaching a THI of 84.3, there was a decrease of 17% of milk production. On the other hand, it is necessary to consider that animals could modify the behavior to mitigate the effect of the increase in THI when it was ≥72, as was found by Hut *et al.* (2022), decreasing the time of lying down and increasing the time of standing without activity; above all, the possibility should be considered that the animals have a genetic tolerance to caloric stress (Jensen *et al.*, 2022).

Neutral Detergent Fiber

The negative effect of NDF on milk production dismisses the possibility that it could help to improve the digestibility of certain nutrients as mentioned by Dann *et al.* (2015); it is possible that the effect from factors such as plant maturity has been negative, as mentioned by Alstrup *et al.* (2016), which would be explained by the lack of digestibility of NDF suggested by Fustini *et al.* (2017) and Hristov *et al.* (2019), since it would have avoided the decrease in milk production when there was an increase of NDF, or else having used source of non-fodder NDF that could compensate the milk production, as done by Naderi *et al.* (2016) and Saylor *et al.* (2018).

Rumination

The positive effect of the RR on milk production is possibly more related to a higher consumption of the animal, as mentioned by Stone *et al.* (2017), and as a daily pattern of rumination that was minimally altered by the type of NDF (Salfer *et al.*, 2018), since the NDF content barely showed a significant trend ($p<0.1$) on the RR, different from what was found by Byskov *et al.* (2015).

In this study the RR was not affected by the THI, as was found by Müschner-Siemens *et al.* (2020) and Hut *et al.* (2021), where they report that rumination begins to decrease from a THI ≥52 and 72, respectively, depending on the type of climate that prevails in the region, which would be justified with a possible adaptation of the animal to the climate as suggested by Jensen *et al.* (2022).

CONCLUSIONS

Monitoring of rumination through automatized systems helps to evaluate punctually the factors that could impact milk production and the health of cows, since under the conditions of this study the NDF content did not have an effect on the RR. Although it did affect negatively the milk production, it is also clear that the resistance of the cattle in the presence of variations of THI in microenvironments should be reconsidered by regions, since the cattle could develop tolerance and that quality ought to be a filter for the selection of new replacements, since the livestock showed certain resistance maintaining productive stability.

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Consumer willingness to pay for vanilla using contingent valuation analysis

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ABSTRACT

Objective: To show the willingness to pay a premium for vanilla from the Totonacapan region through contingent valuation analysis for the strengthening of vanilla in the local market.

Design/methodology/approach: To contingent valuation methodology (CV) was followed to estimate the WTP, based on consumer surveys in the Totonacapan region. The information analysis was carried out by the XLSTAT 2019 software through logistic regression of the willingness to pay data in a binary response with a confidence interval of 95% and with 100 iterations, and maximization of the likelihood function with the Newton-Raphson algorithm.

Results: The results indicate that 55.63% of the consumers agree that certification increases the potential to pay a premium; the accessibility of vanilla is important for 66.56% of consumers; previous experience with the brands and product behavior is paramount for 56.95% of all consumers; regarding the origin of vanilla, it is important for 65.23% of consumers.

Findings/conclusions: Production by small-scale local producers is an appreciated quality because it is related with the symbolic dimension and is appreciated by 68.54% of consumers.

Keywords: attributes, food, identity, market, price premium.

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INTRODUCTION

A food with territorial identity (TIF) is a product with high degree of differentiation and, therefore, market niches can be more specific, although more profitable because they offer sensations, feelings, memories, awareness of place, and connection with history and culture (Pérez *et al.*, 2020). Since it is a much more specific market, the price of a TIF is influenced by consumer willingness to pay (WTP), since the price of the good purchased not only represents the monetary value of the inputs but also the sociohistorical processes, the preparation, and the history (Ascorbe, 2018).

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In strict sense, the market of TIFs cannot exist without consumers and their consumption preferences; therefore, the knowledge of consumers as a segment of the population that consumes a specific good is fundamental. Consumers have in their hands the possibility of choosing a product over another one based on the identification of particular satisfactors (Salgado, 2019).

The consumer, as a biological entity, responds to external social stimuli and of the species' reproduction, and this causes for values and feelings to be expressed in the behavior of access to chosen products. The characterization of consumers, as axis of the market, allows estimating the way in which their needs are satisfied as society (Sonoda *et al.*, 2018). Thus, some studies have shown that human values and their preferences are predictive tools for the consumption of foods. Therefore, some disciplines, such as those related to the market, carry out their advertising campaigns in order to respond to the needs of this segment of consumers (Otero and Giraldo, 2019).

Some methodologies are reported to estimate the consumer's potential to acquire a specific good in function of the attributes required by the individual and the collectivity. Allen (2000) suggested a theory that incorporates the tangible and intangible characteristics that make up a product as mediation to understand the consumption preferences of consumers.

Consumer preferences vary with utilitarian and symbolic attributes, tangible and intangible. An attribute is utilitarian when the good acquired fulfills an instrumental function and the attribute is symbolic when the affective feelings towards the product are reflected (Hernández-Montes, 2018).

A way of estimating consumer behavior in the presence of a product is the methodology of willingness to pay, following the contingent valuation method.

Estimation of the WTP through the contingent valuation (CV) method consists in performing surveys with direct consumers of the product with the intention of obtaining the purchase intent based on incorporating a premium derived from aggregating tangible and intangible attributes (Tudela-Mamani, 2017).

The CV method is based on the consideration of preferences mentioned by the users including the sociocultural and economic perspective. The intention of the method is to include the attributes mentioned in the planning and development of products that satisfy a need felt and which generate additional economic resources for the producers (Sahagún *et al.*, 2021).

Thus, the CV method also relates the sociodemographic characteristics of the consumers since, in large part, they determine the elements to make the best decisions for the links of the vanilla value chain and their WTP regarding the preferred attributes (Jaramillo, Vargas and Rojas, 2018).

Therefore, the objective of this document is to show the willingness to pay a premium for vanilla from the Totonacapan region through the contingent valuation for the strengthening of vanilla in the local market.

MATERIALS AND METHODS

A survey was applied to 302 people to obtain the data, using the binary scale where 1 means that the consumer is willing to pay a premium for a product, in this case vanilla, considering its tangible and intangible attributes, and 0 when the consumer is not willing to pay for a differentiated product.

The information analysis was carried out using the XLSTAT 2019 software through logistic regression based on the data on willingness to pay in a binary response with confidence interval of 95%, and with 100 iterations and maximization of the likelihood function with the Newton-Raphson algorithm.

To estimate the WTP, the methodology called contingent valuation (CV) was followed. This method is characterized by the "creation" of a hypothetical market since values are estimated from particular specifications of the product studied (Roa, 2006).

In this study, the WTP scenarios were suggested for the variables:

- vanilla originally from the Totonacapan region,
- a product of natural origin,
- a product with denomination of origin,
- vanilla produced and processed by small-scale local producers,
- organic production,
- production under agroecological production schemes.

The proposals for WTP were 0%, 5%, 10%, 25%, 50%, 75% and more than 75%.

RESULTS AND DISCUSSION

The descriptive data show that 98.68% of the consumers are willing to pay a premium for vanilla from the Totonacapan region with a frequency of 298 and, on the other hand, 1.32% is not willing to pay a premium despite the distinctive characteristics of the product. When it comes to the variables considered as attributes to integrate them to the commercialization of the product and for consumers to be able to pay a premium are presented in Table 7.

The attributes of price, flavor and aroma are the characteristics preferred by consumers to pay a premium for vanilla from Totonacapan. The utilitarian dimension is considered more important than the symbolic dimension. Meanwhile, the denomination of origin, so important in TIFs, does not seem to be relevant in the presence of other attributes.

The differences in the behavior between consumers regarding paying a premium are related to multiple variables that can be analyzed further on. For example, the lifestyle, the

Table 1. Significance of logistic regressions of the willingness to pay in mezcal through the maximum likelihood method.

Variable	Min.	Max	Media	Dev. typical
With denomination of origin (DO)	1.000	5.000	4.060	1.372
Vainilla Origin	1.000	5.000	4.493	0.981
Taste	1.000	7.000	5.036	1.708
Flavor	1.000	7.000	6.288	1.236
Scent	2.000	7.000	6.659	0.764

sociodemographic relationship in the region, the knowledge about production processes, and the relation with identity, tradition, quality, and origin of vanilla.

The correlation matrix between variables for WTP by consumers indicates, statistically, that aroma and flavor is the combination of attributes most considered to pay a premium for vanilla. Meanwhile, the origin of vanilla and the denomination of origin is another one of the useful conditions to combine to pay premium; while the price and the origin of vanilla is the least likely combination to consider in order to differentiate vanilla from the Totonacapan region. The results are synthesized in Table 8.

Meanwhile, the hypothesis proves that there is no statistically significant relationship between the variables selected to pay the premium; the results of the null hypothesis test (H0) calculated by the equation Y=0.987 (WTP Variable) indicate that Pr>X^2 for -2log likelihood is 0.012, for Score it is 0.005, and for Wald it is 0.047. Therefore, the null hypothesis is rejected, and it means that each attribute is different and that there are conditions to pay a premium. The mathematical way of expressing the formula to estimate the WTP is the following:

$$Pred(DAPOR) = 1/\left(1+\exp\left(-\left(-0.531-0.873 * \text{That it has denomination of origin} \right.\right.\right.$$
$$+1.211 * \text{The origin of vanilla} - 0.899 * \text{The price}$$
$$\left. +0.255 * \text{The flavor} + 1.176 * \text{The aroma}\right).$$

Therefore, the standardized coefficients for the variable WTP reveal the values of Pr>X^2 where there is significant difference of $p<0.05$ for the origin of vanilla; meanwhile, the other variables are not statistically significant.

Table 3. Coefficients standardized for the WTP variable.

Variable	Value	Standard error	Pr>Chi²
With DO	-0.660	0.431	0.126
Origin	0.654	0.264	0.013
Price	-0.846	0.492	0.085
Flavor	0.174	0.354	0.623
Scent	0.495	0.275	0.072

DO: Denomination of origin.

Table 2. Matrix of correlations between the attributes signaled to differentiate vanilla from the region.

Variable	With DO	Origin	Price	Flavor	Scent
With Origin (DO)	1.000	0.432	0.189	0.242	0.168
Origin	0.432	1.000	0.061	0.217	0.318
Price	0.189	0.061	1.000	0.297	0.190
Flavor	0.242	0.217	0.297	1.000	0.442
Scent	0.168	0.318	0.190	0.442	1.000

When it comes to the econometric analysis, the quotients explain the WTP with attributes that consider flavor, color and aroma that make the product characteristic and distinctive from the other products. On the other hand, if the product is added with attributes such as the quality and the price, it is likely for consumers to feel less attracted to acquire the good (Cervantes *et al.*, 2020). Table 4 indicates that the statistical significance for the value *p* calculated is lower than the estimated value alpha=0.05.

And the graph to show the ranges of the standardized coefficients with a confidence level of 95% is presented in Figure 1.

The results from the surveys suggest that the frequency of consumption of vanilla in the region varies in great relation with the gender, and the results are shown in Table 11.

The number of foods and beverages with vanilla base make it a product that is consumed daily. A relevant theme to study in upcoming research is the consumption of vanilla by season of the year. The vanilla consumption intent varies in function of the product elaborated based on vanilla, whether in confectionery, foods, or beverages. The local establishments offer the product during the entire year and the consumers acquire them because of desire or for satisfaction. The low temperatures have an impact on the

Table 4. Results from the econometric model of willingness to pay (WTP) per attribute.

Parameters model				Verisimilitude	
Variable	**Marginal Effect**	**Standar Error**	**Pr>|z|**		
Price	−0.005	0.003	0.964	X^2	13.674
Taste	0.005	0.003	0.057	gl	5
Scent	0.005	0.005	0.155	p	0.018
Color	0.002	0.004	0.326		
Quality	−0.002	0.005	0.670		

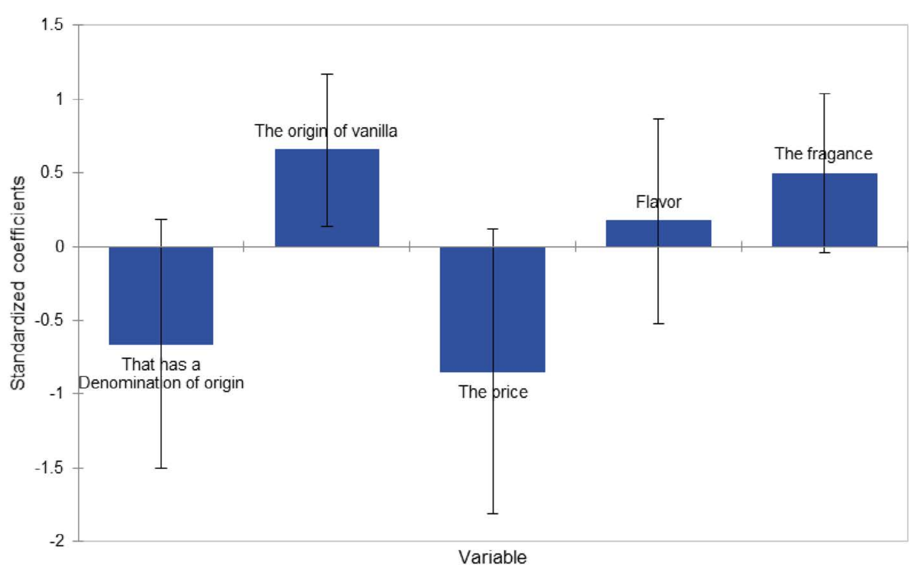

Figure 1. WTP by standardized coefficients at a confidence level of 95%.

Table 5. Frequency of vanilla consumption by gender.

Frequency	Female (%)	Male (%)	General (%)
Once a month	26.71	24.82	25.83
Once a week	11.80	13.48	12.58
More than 2 times a year	7.45	8.51	7.95
Once a year	6.21	7.09	6.62
Several times in a month	28.57	30.50	29.47
Several times in a week	19.25	15.60	17.55

increase in consumption of confectionary and hot beverages, and consumption is preferred in cold foods during the period of high temperatures.

Many times, consumers ignore the ingredients with which foods and beverages are elaborated, and this has an effect on the response regarding the frequency of vanilla consumption. Consumers choose consciously to consume several times per year the various vanilla-based products.

Based on education and gender, the preference for vanilla happens among the people with highest degree of education (38.51% for women and 40.43% for the case of men). Based on the logistic regression, schooling has a direct influence on consumption and preference, since, without it being a written rule for all the sectors, the academic degree perceives products from the goodness of consuming local, safe products of natural origin (Gutiérrez *et al.*, 2012). The complete information is presented in Table 6.

Regarding the consumption, no significant differences ($p>0.05$) were observed between the preference for products and the frequency of shopping. Knowledge is a defining factor of the attitudes and practices in socioeconomic and psychological aspects that consumers take into account when they choose to buy a product (Espinel, Monterrosa-Castro and Espinosa-Pérez, 2019).

Consumers report that vanilla is purchased by price (in Mexican pesos) and by amount of product (in liters when it is essence, extract), in grams (when purchased as pod). The essence is acquired in presentations of 250, 500, 750 mL, 1.0 and 2.0 L. The extract is purchased in containers of 100, 250, 500 mL, and 1.0 L. When it is purchased in pod, consumers prefer

Table 6. Vanilla consumption by gender and education in the Totonacapan region.

Frequency	Woman					Man				
	Scholarship				Total	Scholarship				Total
	B	MS	P	S		B	MS	P	S	
Once a month	10	14		19	43	15	8		12	35
Once a week	5	9		5	19	8	3	1	7	19
More than two times a year	2	5		5	12		7		5	12
Once a year	3	3		4	10	3	4		3	10
Several times in a month	10	16	3	17	46	10	9	2	22	43
Several times in a week	11	8		12	31	6	7	1	8	22

Note: B: basic education, HS: high school, G: graduate studies, and U: undergraduate studies.

to buy 50, 100, 250, 500 g and more than 1.0 kg. The purchase information by consumer is presented next in Table 7. Regarding the brands that offer vanilla in the region, there are up to 137 brands identified. Of them, the brand *Xanath* is the one most frequently mentioned, followed by *Zanilli*, *Papantla* and *Gaya*; and some local brands such as *Milán*, *Ojital*, *Paloma* and *Vailicpap*. Artisanal vanilla is a common way of consuming the product and preferred by 48.95% of the consumers.

The origin of the vanilla consumed in the Totonacapan region is identified to be from Papantla (54.64%) and some regions of Oaxaca and Mexico City (synthetic products).

Money exchange for the merchandise happens at street stalls in the communities of the region, although the minority of the product is acquired through this path. Purchasing vanilla at the plot is common among 12.58% of the consumers; this way of exchange guarantees that the process is natural and innocuous and the price is fair for both parts: the consumer acquires a product at a reasonably lower price than the one offered in stores of the community, and the producer sells at a better price than to the intermediary. The difficulty of way of selling is in the travelling of consumers to the plots. The characteristic of this trade is that artisanal vanilla is consumed directly from the field to the table.

The candy shops, market and supermarkets are the main centers of money exchange for vanilla, since they represent 78.81% of the total purchase of brands and presentations. Meanwhile, 8.28% of the purchase is carried out in local and specialized stores in the sale of primary origin products and with scarce transformation processes.

Regarding the perspective on the quality of vanilla, 87.09% of the consumers have the opinion that the product is of excellent quality; 12.25% feel satisfied for the vanilla acquired and 0.66% of the consumers doubt the quality of the vanilla. These consumers are the most

Table 7. Preferred presentations of vanilla in the Totonacapan region to purchase in the market.

State	Presentation	Frequency	
		Totonacapan	Others
Essence	250 mL	66	6
	500 mL	49	2
	750 mL	3	0
	1 L	22	6
	2 L	4	1
Extract	100 mL	45	2
	250 mL	44	1
	500 mL	13	0
	1.0 L	5	1
Pods	50 g	7	0
	100 g	0	1
	250 g	4	0
	500 g	5	2
	>1.0 kg	5	0
Other presentations		7	1

important to attend when the purpose is to rescue the sensorial attributes of vanilla from the Totonacapan.

Willingness to pay for tangible and intangible sensorial attributes

The WTP through contingent valuation is the maximum willingness to pay by individuals through direct grouped questions and binary response. Zero for not accepting to pay premium and one for accepting to pay.

The consumers report that vanilla certification gives them security about the healthiness and safety for human consumption; 55.63% totally agree that certification will be an important attribute when buying a product obtained in the region. In contrast, 6.62% of the consumers consider that certification is not a necessary quality to integrate in the final product for the market.

According to the accessibility to vanilla in the market, the consumers are of the opinion that vanilla in the regional markets is an incentive to acquire it; thus, 66.56% of the consumers think that the vanilla is purchased because it exists in the local market. And, for their part, 8.28% of the total consumers surveyed mention that even when there is no vanilla in the market, it can be obtained because they prefer the product to use it in their daily activities.

To purchase the vanilla, previous experience with the brands and with the behavior of the product is fundamental for 56.95% of the total consumers; meanwhile, for 6.95% of these the experience is not important because they consider that vanilla, regardless of the brand and the origin, is the same from their utilitarian perspective. The preference for the origin of the vanilla has an important effect because the consumers choose vanilla produced in the region. The piece of data that supports this statement is that 65.23%

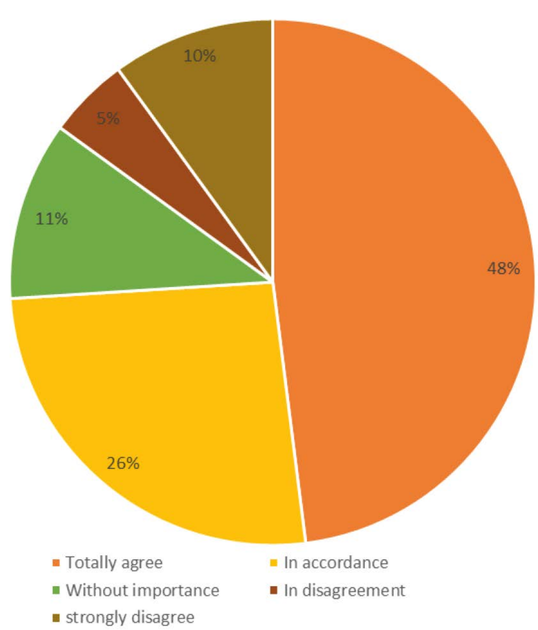

Figure 2. Willingness to pay for vanilla with certification.

recognize that they prefer vanilla obtained in the municipalities of the Totonacapan region; for 4.64% of the total consumers the origin is not relevant. Small-scale producers relate the ancestral knowledge with the culture and history of vanilla in the region; therefore, the consumers are of the opinion that vanilla produced by small-scale producers is of quality and guarantees safety. A total of 68.54% of the consumers prefer for vanilla to be produced, elaborated and sold by small-scale producers, considering that the product is healthy and generates economies of scale.

The production systems by small-scale producers retake the knowledge used in the past and contribute with 1% of the production processed in the entire world (Barrera-Rodríguez *et al.*, 2009). The economy of small-scale producers is strengthened with the production and commercialization of vanilla in the region. Other important attributes for consumers and their influence in the willingness to pay is presented in Table 14. The data reported suggest that consumers consider market attributes, such as price, as important to select a vanilla. However, in monetary terms, the price varies in function of the value which a consumer is willing to pay to acquire a good or service (Ramos, Huacchillo and Portocarrero, 2020). According to Jaramillo (2016), with a higher price the percentage of positive responses to the question of the WTP is lower. This is in the understanding that price is one of the most defining variables for a product to have acceptance among consumers.

The aroma is one of the most important attributes when it comes to choosing vanilla and as intangible attribute, the quality is. The price is one of the least important attributes when comes to preferring vanilla, as long as it is a quality product; meanwhile, for the consumers, the origin of the product is not a relevant quality. Although vanilla is a recognized product, the consumption trends consider that a product is good regardless of whether it is a local product or from another region. In other research studies, it has already been determined that it is important to understand the origin in the containers and the information supplied in the market (Lacaze, 2009). Paying a premium for a product is the maximum willingness to pay for the consumer and the existing prices in the market to identify segments of consumers in the market. The WTP assumes that, for all the consumers, the price is a defining factor in the purchasing process of the product and the willingness to pay a premium (Hernández *et al.*, 2022). The responses associated with the WTP for the different attributes of vanilla from the Totonacapan region are presented in Table 9.

Table 8. Relevant attributes for the consumer to prefer vanilla.

Condition	Quantity (%)						
	Price	Taste	Scent	Origin	Quality	SA	Origin
Totally agree	57.62	80.79	84.77	76.16	84.77	73.18	30.13
Agree	22.85	13.91	11.92	13.25	10.26	17.55	14.90
Without importance	9.60	4.30	1.66	6.29	2.98	6.95	19.54
Desagree	5.63	0.66	0.99	1.99	0.99	1.32	10.60
Totally desagree	4.30	0.33	0.66	2.32	0.99	0.99	24.83

SA: sensorial attributes.

Table 9. Willingness to pay based on the most important tangible and intangible attributes for consumers.

Attribute	Willigness to pay the premiuim (%)						
	0	**5**	**10**	**25**	**50**	**75**	**>75**
Originally from Totonacapan	2	2	5	10	32	34	15
Natural	3	2	4	7	23	39	24
With designation	3	6	14	14	24	24	16
Produce and processed by small producers	1	3	4	7	20	43	22
Produced without chemicals	2	3	5	7	17	38	26
Under agroecological principles	2	3	4	10	19	42	20

The WTP for vanilla from the Totonacapan region is likely to be paid by 65.89% of the consumers when a premium is in the range of 50% to 75%. When comparing the results with other studies conducted, it is proven that the probability of paying a premium is lower as the percentage offered to consumers increases (Pérez *et al.*, 2012). For the WTP of a premium of 0%, the results indicate that the p-value calculated is higher than the significance level alpha=0.05, and given that the proportions are equal, there is no statistical significance. The value of X^2 is 1.337 and the *p*-value 0.931.

According to the Monte Carlo method (number of simulations equal to 5 thousand), the result for the WTP for a premium of 0% indicates that the calculated *p*-value is better than the significance level alpha=0.05 and, therefore, the proportions are equal.

The statistical tests show that with the WTP with premium of 5%, the proportions are equal since the value of calculated p is higher than the significance level alpha=0.05 and, by the Monte Carlo method, the value of X^2 is 3.533 with simulations of 5 thousand.

For the premium of up to 10%, the WTP is not statistically significant when it comes to the proportions since the calculated p-value is higher than the significance value alpha=0.05. The value of X^2 is 13.830 by the Monte Carlo method with 5 thousand simulations.

For the premium of 25%, the WTP is not statistically significant because the proportions are equal according to the calculated *p*-value that is higher than the significance value alpha=0.05. The Monte Carlo method results in X^2 of 4.664. When it comes to the

Table 10. Analysis of the significance between the proportions of WTP according to the premium.

Willingness to pay	Price to pay						
	0%	**5%**	**10%**	**25%**	**50%**	**75%**	**>75%**
Originally from Totonacapan	2a	2a	5a	10a	32a	34a	15a
Natural	3a	2a	4a	7a	23a	39a	24a
With designation	3a	6a	14a	14a	24a	24a	16a
Produce and processed by small producers	1a	3a	4a	7a	20a	43a	22a
Produced without chemicals	2a	3a	5a	7a	17a	38a	26a
Under agroecological principles	2a	3a	4a	10a	19a	42a	20a

*Proportions with the same letter within columns are statistically equal ($p \leq 0.05$).

premium of 50%, the WTP is not statistically significant because the calculated *p*-value is higher than the value of significance alpha=0.05 and it is considered that the proportions are equal. The Monte Carlo method indicates a value of X^2 of 8.115.

The same situation applies to premiums of 75% and more than 75% given that the *p*-value is higher than the significance level alpha=0.05. In both cases, the Monte Carlo method indicates values of X^2 of 10.478 and 5.860, respectively. Regarding the Marascuilo method, the data indicate that there is no difference between the proportions, confirming that the groups are equal with a calculated *p*-value higher than the significance value alpha=0.05. There is no significant difference between the proportions.

CONCLUSIONS

The WTP of vanilla from the Totonacapan region through contingent valuation indicates that the attributes of price, flavor, aroma, color and quality are important to add them to the vanilla product to make the product more attractive for the local market. The WTP is probably the preference to pay by 65.89% of the consumers when the premium is in the range of 50% to 75%, and it is proven that the probability to pay a premium is lower as the percentage offered to the consumers increases. The gender and the education have an influence on the WTP for a premium that includes attributes such as flavor, aroma, price and quality. With higher degree of education, the preference is to pay a premium for attributes related to the symbolic dimension of vanilla. The knowledge of culture and history is an indication of the willingness to pay a premium, since yearning is a strong incentive to make the purchase because you acquire a "piece of history".

The promotion of vanilla as a product with territorial identity can be driven by the following strategies compiled by consumers.

- The mouth-to-mouth recommendation among consumers suggests that it is very useful when it comes to sharing the benefits of acquiring a local product. The family, friends and workmates are fine elements to share the experience of a local product, and from the confluence in the local market. Social networks, in these days, are a very powerful tool for the generation, distribution and tracking of information about a product of interest.
- The use of the internet through pages created for the promotion of vanilla in free platforms is an alternative.
- Planning and implementation of campaigns and advertising announcements in the region and publicized in social networks, media and internet.
- Sample of products elaborated with vanilla.
- Promotion of a vanilla market in the region and rescue of ancestral knowledge and other forms of trade.

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Colegio de Postgraduados

Business plan for the establishment of a sweet potato (*Ipomoea batatas* L.) processing plant in Delicias, Chihuahua, Mexico

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ABSTRACT

Objective: To develop a business plan aimed to create a processing plant in Delicias, Chihuahua, considering that local farmers obtain a low price for their sweet potato harvest, although the cultivation of this tubercle in the state has increased in recent years.

Design/Methodology/Approach: A market study was carried out in three municipalities. The Malhotra methodology was used to determine market segmentation, while the FIRCO guide was employed to analyze financial indicators.

Results: The market study showed that 77% of the sampled population consumes the tubercle in question. Out of this percentage, 85% is willing to consume the products offered by the company, particularly jamoncillo (candy) (24%), followed by candied sweet potato (20%) and chips (18%). A 5-year projection (with a 12% update rate) establish the profitability of the net present value (NPV) of $1,610,875.34, an internal rate of return (IRR) of 79%, and benefit-cost relation (BCR) of $1.16. The initial investment is recovered with a positive flow after the third year, with a $463,079.91 Mexican pesos profit.

Study Limitations/Implications: Obtaining the full amount of the initial credit for the business would be a limitation. The owners would pay the fixed and variable costs.

Findings/Conclusions: The producer can establish his factory with an initial investment of $422,472 pesos, increasing his profits, adding value to the crop, and eliminating middlemen.

Keywords: Profitability, investment, production process, agrifood production.

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INTRODUCTION

Sweet potato (*Ipomea batatas* L.) is a horticultural tubercle that has been grown in Mexico since ancient times (Vibrans, 2009) [1]. It is mainly grown in the central-southern zone of the coast of the Gulf of Mexico, in the Bajío region, and in some areas of the Pacific Ocean coast. It is also grown in several municipalities of the states of Chihuahua and Tamaulipas

Image by Éva Tóth at Pixabay

(Basurto, 2018) [2]. According to the Servicio de Información Agroalimentaria y Pesquera (SIAP) (SIAP, 2019) [3], sweet potato production has recorded a positive trend over the course of the last three decades, as a consequence of greater yield per surface unit. During the same period, sweet potato was grown in 3,201.28 ha per year. Chihuahua holds the third place nationwide: 18.57% of the sweet potato produced is sold in the state's Irrigation District 05 (SNIIM, 2021) [4]. This percentage has increased in a yearly basis, generating a rise in the offer and few sale opportunities. Consequently, the creation of a sweet potato processing plant will provide sale opportunities at fair prices for the producers, avoiding the participation of middlemen, exploiting the crop at a regional level, and adding a value to the said product.

MATERIALS AND METHODS

The company will be established in the La Merced ejido, municipality of Delicias, close to the source of raw material. The sample was obtained in the municipalities of Delicias, Rosales, and Meoquí; in total, 1,155 potential consumers were interviewed. A probabilistic sampling method was applied using Malhotra's methodology for the market segmentation process (2008) [5]. The size of the sample was determined with a 95% confidence interval. The agribusiness diagram included in the FIRCO guide was used for the financial feasibility analysis.

RESULTS AND DISCUSSION

Market study

Seventy-eight percent of the 1,155 persons interviewed in the three municipalities consumes sweet potato. Out of that percentage, 85% is willing to taste snacks made from processed sweet potato. Several individuals have on their own or at some point in their lives, consumed and enjoyed sweet potato prepared in the traditional style and are willing to taste new products made from that tubercle. Fifty-one percent of the interviewees prefer to buy the products from corner stores, because they consider that it is a more practical and quicker way to satisfy a whim. This information will help to determine which sale distribution channels are more likely to be successful. Likewise, 55% of the polled persons prefer to find information through Facebook, which will help to define marketing techniques. The following type of products were chosen for the survey: *jamoncillo* with nuts and peanuts, jam, candied sweet potato, chips, cookies, and bread. The interviewees preferred the following products: an individual 60-g *jamoncillo* with nuts and peanuts package (24%), an individual 458-g chip package (20%), and a one-piece candied sweet potato package (18.5%).

Productive process

Jamoncillo with nuts and peanuts

Sweetening and adding nuts and peanuts is a traditional process that can provide added value to sweet potato. In order to prepare this recipe, roast the sweet potatoes with their skin; after that, remove the skin and mash the pulp into a purée. In a copper pot, pour water and sugar and cook it at medium heat in order to prepare a caramel. Add the purée to the caramel, then add the nuts and the peanuts to the mixture. Remove the pot from the heat, let it cool and, once the mixture is cold, shape it into *jamoncillos* and put them into their packages. The following tools are usually used for this process: a spit roaster, a propane tank, and a copper pot. The ingredients for the recipe are sweet potatoes, water, sugar, nuts, peanuts, icing sugar, wraps, and labels.

Chips

The objective of the process is to prepare a healthy snack, preserving the nutrients of sweet potato. The ingredients and materials required for this production are sweet potatoes, sea salt, water, packages, and labels. To prepare the snacks, put the sweet potatoes through a washer-peeler, slicing them with slicer. Then wash them again with water to remove most of the starch. Season the slices with sea salt and introduce the slices into a dehydrator. Once the slices are ready, put them into the packages.

Candied sweet potato

This process is the longest, since the product cannot be packaged before ten days have passed. The ingredients and materials required are sweet potatoes, food grade quicklime, water, sugar, clove, cinnamon, packages, and labels. First, wash and peel the sweet potatoes, then slice them and let them rest in water and quicklime for 24 h. Afterwards, remove the slices from the mixture and wash them. Subsequently, pierce the sweet potatoes and let them boil with cinnamon, clove, and sugar for an hour. The following five days, the sweet potatoes must boil for another hour. Then, remove the sweet potatoes from the sugar and put them on a cooling grill for five days. Finally, the sweet potatoes are ready to be packaged.

Evaluation of the investment project

Investment

The investment budget included the machinery and equipment required to produce the three products (*jamoncillo* with nuts and peanuts, chips, and candied sweet potato), as well as the delivery equipment and office supplies; therefore, an initial \$422,472 investment is required to start this business. The investment information was provided by the Santander bank. Table 1 shows the detailed budget.

Estimated production and sale cost by pieces and per month for the sweet potato processing plant

In order to establish the number of packages that would be produced from November to April, the capacity of the production machinery and equipment were considered. The results were as follows: jamoncillo, 16,500 pieces (pcs); chips, 14,200 pcs; and candied sweet potato, 16,200 pcs. From May to October, production falls by 25%. The local population usually consumes sweet potato during the cold months, and this could reduce the consumption of the processed products during the warmer months. The sale costs of the products are candied sweet potato, \$5.30 per pc, jamoncillo, \$5.00 per pc, and chips, \$5.45 per pc.

Table 1. Investment budget for a sweet potato processing plant.

Concept	Unit	Amount	Unit Cost	Amount	Total
Fixed Asset					
Washer and Peeler	Piece	1	$20,409	$20,409	$20,409
Cutter	Piece	1	$6,489	$6,489	$6,489
Dehydrator	Piece	1	$43,000	$43,000	$43,000
Sealer	Piece	1	$4,491	$4,491	$4,491
Mini Split	Piece	1	$6,400	$6,400	$6,400
100 liter gas tank	Piece	1	$24,903	$24,903	$24,903
Oven	Piece	1	$11,500	$11,500	$11,500
Copper cooking pot	Piece	2	$4,000	$8,000	$8,000
Large stainless steel spoon	Piece	2	$1,015	$2,030	$2,030
Table with stainless steel top	Piece	2	$2,790	$5,580	$5,580
Gas burner	Piece	2	$624	$1,248	$1,248
Base for saucepan	Piece	2	$1,200	$2,400	$2,400
Grills 5 packages of $285	Piece	1	$1,425	$1,425	$1,425
Containers	Piece	1	$2,757	$2,757	$2,757
Tables and office items	Piece	1	$3,000	$3,000	$3,000
Computer	Piece	1	$12,000	$12,000	$12,000
Tag printer	Piece	1	$6,180	$6,180	$6,180
Phone	Piece	1	$660	$660	$660
Delivery van	Piece	1	$250,000	$250,000	$250,000
Deferred assets					
Installation costs			$10,000	$10,000	$10,000
Total				$422,472	$422,472

The projection of the annual income included a 12% increase, as a consequence of the annual inflation rate (Table 2).

Production costs

For production, raw material, and indirect manufacturing costs a total of $873,096 variable costs and $1,407,600 fixed costs were obtained. The total cost for the first year would amount to $2,280,696.

A 12% annual inflation rate was included in the total 5-year projection cost (Table 3).

The analysis of the financial profitability of the company considered the12% update rate provided by the bank and a 12% annual inflation increase. The cash flow is positive

Table 2. Annual Income Projection.

Product	Year 1	Year 2	Year 3	Year 4	Year 5
Sweet Potato Products	$2,580,375	$2,890,020	$3,236,822	$3,625,241	$4,060,270
Total revenue	$2,580,375	$2,890,020	$3,236,822	$3,625,241	$4,060,270

Table 3. Annual operation cost of the project.

Concept/month	Year 1	Year 2	Year 3	Year 4	Year 5
Variable costs					
Raw material	639,135.00	715,831.20	801,730.94	897,938.66	1,005,691.30
Electric power	45,000.00	50,400.00	56,448.00	63,221.76	70,808.37
Gas	69,408.00	77,736.96	87,065.40	97,513.24	109,214.83
Packing	68,553.00	76,779.36	85,992.88	96,312.03	107,869.47
Gasoline	51,000.00	57,120.00	63,974.40	71,651.33	80,249.49
Subtotal	**873,096.00**	**960,405.60**	**1,056,446.16**	**1,162,090.78**	**1,278,299.85**
Fixed costs					
Concept/month	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Administration	432,000.00	483,840.00	541,900.80	606,928.90	679,760.36
Labour	672,000.00	752,640.00	842,956.80	944,111.62	1,057,405.01
Water	9,600.00	10,752.00	12,042.24	13,487.31	15,105.79
Rent	60,000.00	67,200.00	75,264.00	84,295.68	94,411.16
Internet and phone	6,000.00	6,720.00	7,526.40	8,429.57	9,441.12
Advertising	216,000.00	241,920.00	270,950.40	303,464.45	339,880.18
Office supplies	12,000.00	13,440.00	15,052.80	16,859.14	18,882.23
SUBTOTAL	**1,407,600.00**	**1,548,360.00**	**1,703,196.00**	**1,873,515.60**	**2,060,867.16**
Total cost	**2,280,696.00**	**2,508,765.60**	**2,759,642.16**	**3,035,606.38**	**3,339,167.01**

from the second year on; however, the initial investment is recovered only on the third year. Table 4 shows favorable incomes, with a cash surplus.

The project is considered viable according to the evaluation of the indicators. The following values were obtained: a>0 NPV, an IRR higher than the update rate, and a>1 BCR. Therefore, the project will obtain profits per peso, as can be seen in Table 5.

Following the guidelines of the Shared Risk Trust Fund (FIRCO) (FIRCO, 2002) [6], the organizational structure of the new company will have a hierarchical order (Figure 1).

Table 4. Profitability analysis of the project.

Year	Income	Costs	Cash flow	Rate	Updated income	Updated expenses
0		$422,472.00	$422,472.00	1.000		
1	$2,580,375.00	$ 2,333,055.46	-$175,152.46	0.893	$2,303,906.25	$2,083,085.23
2	$2,890,020.00	$2,543,120.12	**$ 346,899.88**	0.797	$2,303,906.25	$2,027,359.79
3	$3,236,822.40	$2,773,742.49	$463,079.91	0.712	$2,303,906.25	$1,974,295.12
4	$3,625,241.09	$3,035,606.38	$589,634.71	0.636	$2,303,906.25	$1,929,182.73
5	$4,060,270.02	$3,339,167.01	$721,103.00	0.567	$2,303,906.25	$1,894,733.04
Total	$16,392,728.51	$14,447,163.46	$2,368,037.04		$11,519,531.25	$9,908,655.91

Table 5. Financial indicators of the profitability analysis of the project.

NPV	IRR	BCR
$1,610,875.34	79%	$1.16

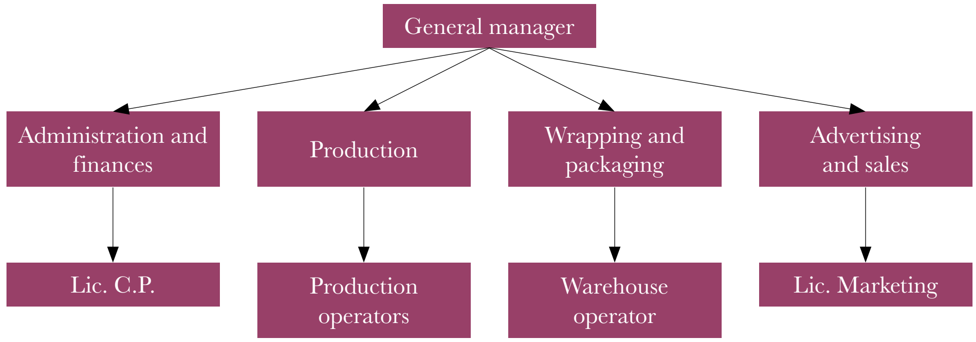

Figure 1. Organizational structure of the company.

The budget, planning, production, and equipment activities included in the process will be assigned to the appropriate department.

As a consequence of its characteristics, the company will be registered in the entrepreneurial regime as a physical person.

This study determined that the production of sweet potato snacks is financially profitable and, therefore, it is an option to increase the income of the producers, avoiding the current middlemen structure. Similar results were reported by Álvarez-Gonzaga (2013) [7]. The objective of that study was to evaluate the feasibility of founding a sweet potato snacks micro business in Loja, Ecuador. The study obtained favorable results with a USD$178,006.19 required investment. The financial results were feasible and profitable from the third year on, just like in our study. The study also complied with the financial evaluation criteria and highlighted the nutrients of sweet potato for human consumption and the economic benefits for producers. Meanwhile, Kuncar and Talledo (2017) [8] researched the feasibility of installing a sweet potato flour paste production plant in Peru. They also highlighted the nutrient value of the product. The authors obtained positive financial results; however, they pointed out that 40% of the initial investment must be provided by independent investors, while the remaining 60% must be provided by a financial institution, to guarantee its feasibility and a positive cash flow from the second year on. Unlike this case, our study completely depends on a bank. Sweet potato is a nutritive food for humans, which nevertheless can also be beneficial for the animal food transformation industry. Orozco-Lepe (2014) [9] studied the profitability of purple sweet potato flour for livestock nutrition in Quintana Roo. The results obtained were positive, according to the financial evaluation: the net cash flow resulted in a $46,664.57 NPV (the benefit once the investment ends), a 239% IRR, and a $9.01 BCR. During the first year, the numbers were positive: $66,215.76. Sweet potato is full of nutrients and has many economic advantages, providing added value to several products through its transformation.

CONCLUSIONS

Producers can obtain higher profits from sweet potato through the transformation of this tubercle into snacks and sweets. Its nutrient properties can turn it into a healthy alternative for the diet of Mexicans —*i.e.*, adding value to the crop. Sweet potato is a versatile tubercle that can be transformed and industrialized. Consequently, this is an opportunity to drive sweet potato cultivation. However —and despite the sweet potato production increase in Chihuahua during the last decade—, there are no strategies aimed to give added value to its production and, as in most parts of the country, the middlemen still obtain the highest profits. The market segmentation in this research shows that there is a great potential (78% of the interviewees) for the consumption of products derived from sweet potato. The minimum initial investment to purchase machinery and tools is $422,472. From the third year on, the profit could reach $463,079.91. The results of the profitability indicators —obtained through a 5-year projection, with a 12% update rate— shows that the creation of this type of companies is feasible, considering that, in Mexico, the companies are usually managed by a family. This proposal can allow families to obtain higher economic benefits from their crops, having already established sale points, packages preferences, and marketing strategies that must be carried out in order to achieve the goal.

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Colegio de Postgraduados

Embryonic losses between the early diagnosis and the confirmation of gestation in dairy cows from different farms for one year

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ABSTRACT

Objective: To determine embryonic losses between the early diagnosis and the confirmation of gestation in dairy cows from different farms for one year.

Design/Methodology/Approach: A total of 3,413 confined Holstein cows from three different dairy farms in the Mexican Altiplano (highlands) were studied. Cows were milked three times a day with an average daily production of 36.5±1.5 L. Gestation diagnosis was performed by ultrasonography at 34±7 d after the artificial insemination, while gestation was confirmed at 60±5 d. Average pregnancy loss was determined and embryonic losses were compared taking into account farm and month.

Results: The overall average of embryonic losses was 18.8%. Neither the month factor nor the month×farm interaction affected the percentage of embryonic losses ($p<0.05$). Differences per farm ($p<0.05$) were observed and farms 1, 2, and 3 recorded losses percentages of 4±1.6%, 11.4±1.6%, and 22.9±1.6%, respectively.

Study Limitations/Implications: Detailed differences between farms were not studied, since cow management was similar in all three of them. Embryonic losses must be recorded, given their significant impact on the farm.

Findings/Conclusions: There is a high variability among farms regarding embryonic losses between the early diagnosis and the confirmation of gestation. This situation may be the result of management differences, since the breed and environmental conditions were the same in all three farms.

Keywords: embryonic losses, Mexican Altiplano, dairy cattle.

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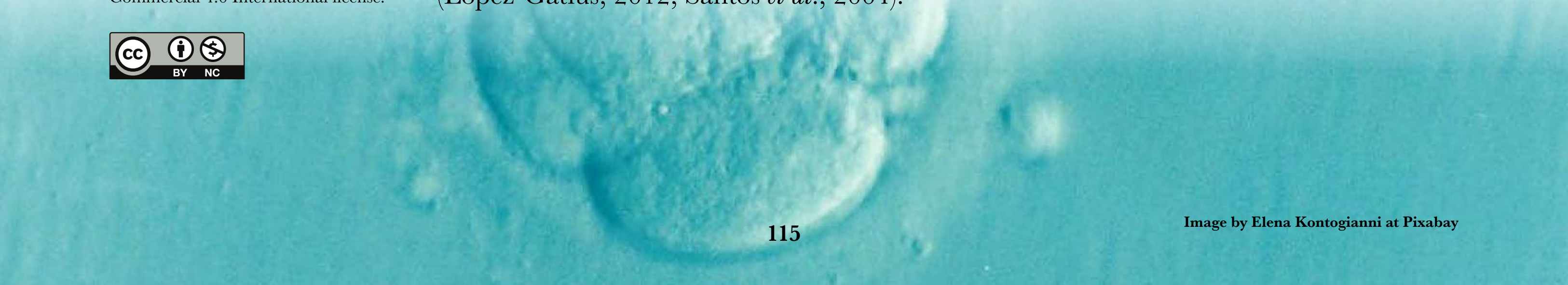
INTRODUCTION

In recent years, specialized dairy cattle have shown higher milk yields as a result of intensive genetic selection and recent genomic evaluation of young bulls (Rearte *et al.*, 2018). However, intensive genetic selection is expensive and the reproductive efficiency of high-yielding dairy cows has decreased worldwide, mainly in the first services (Lucy, 2019). There is great concern about the increase and economic impact of late embryonic mortality (Quintero *et al.*, 2019) and fetal losses in cows (Abdalla *et al.*, 2017). Pregnancy loss in specialized dairy cattle is severe: losses up to 50 and 60% of pregnancies were observed from fertilization to calving in some studies and only one out of two gestations was successful (López-Gatius, 2012; Santos *et al.*, 2004).



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In 2016, Diskin *et al.* (2016) documented an increase in embryonic losses of Holstein cows from 28% to 43% during the 1980s.

Likewise, Lucy (2019) proved that fertility rates are no longer dropping in some countries and the fertility decline was interrupted. Embryonic losses have an important economic impact on the production system. Most of the reports about the cost of pregnancy loss come from the United States. However, Albuja *et al.* (2019) developed the first report for Mexico, valued in Mexican pesos. They pointed out that a pregnancy loss in the first, second, and third quarters can cost $5,440.00 MXN ($272.00 USD), $10,000 MXN ($500.00 USD), and $ 22,800.00 MXN ($1,140.00 USD), respectively. These figures are important, since business profitability could be affected by the high percentage of pregnancy losses. The objective of the study was to establish yearly embryonic losses between the early diagnosis and the confirmation of gestation by ultrasonography in specialized dairy cows that had been confined in different farms from the Mexican Altiplano.

MATERIALS AND METHODS

The study was conducted from January 1st to December 31st, 2018 in a geographic region with the following characteristics: 2,230 m above mean sea level, a semi-arid and temperate climate, an average annual temperature of 16.8 °C, and a relative humidity of 40%. Cows were managed in intensive production systems and had free access to shade, individual stalls, clear water, white salt, sodium bicarbonate, and a complete ration. Cows were milked 3 times a day, recording an average daily production of 36.5 ± 1.5 L.

The three farms had similar management. However, in broad terms there were differences among them, including: cow flow in pens, overcrowding in pens, peripartum care, difference in ration inputs, and vaccination programs.

All cows were fed a high-forage diet (60%) and 16% CP from three weeks prior to calving up to 14 days after parturition, followed by a transition diet consisting of 53% forages and 18% CP. One week later, they were moved to production pens, where they received a diet of 47% forages and 16% CP. The ration was composed mainly of alfalfa hay, corn silage, rolled corn, soybean meal, cotton seed, wheat straw, distillers' dried grain with soluble (DDGS), molasses, vitamins, and minerals.

Reproductive management was similar among farms which had a voluntary waiting period of 65 ± 5 d. Once a week, cows were incorporated into a pre-synchronization program (Moreira *et al.*, 2001) with two prostaglandin $PGF_2\alpha$- injections (12 to 14 d between applications). Seven days after the last $PGF_2\alpha$- injection, they were incorporated into an OvSynch program (Pursley *et al.*, 1995). Gonadorelin acetate (300 μg per cow) was used as a source of GnRH and dinoprost tromethamine (25 mg per cow) was used as prostaglandin $PGF_2\alpha$.

Cows showing estrus (18-24 d post-insemination) were inseminated again. Gestation was diagnosed by ultrasonography (Easi-Scan, BCF technology, Universal Goggles, Scotland) at 34 ± 7 d after insemination. Pregnancy was detected through the amniotic vesicle and the presence of a viable embryo (confirmed by a heartbeat). Pregnancy diagnoses were confirmed by ultrasonography (gestation of 60 ± 7 d). The percentage of embryonic losses was calculated dividing the number of non-pregnant cows at 60 d by the number of pregnant cows at 34 d.

The DairyComp 305 software (2018) was used to store information about the 3,413 initial gestations. Chi-square was used to compare pregnancy losses per month and per ranch. The statistical analysis was performed using the STATISTICA 7 software (StatSoft, Hamburg, Germany).

RESULTS AND DISCUSSION

The month did not affect ($p \geq 0.05$) the percentage of embryonic losses, which were very similar throughout the year, despite the monthly variability (13.1-38.4±9.6) (Figure 1).

These results are different from those of other works in which heat stress is reported to increase embryonic losses by 10 to 50% (Dash *et al.*, 2016; Wiltbank *et al.*, 2016). Heat stress has an extremely significant effect on embryonic losses in dairy cows. Temperature and relative humidity were lower (18±6 °C and 40±5 %) in this study than those reported by other authors; therefore, temperature and humidity index are higher (Dash *et al.*, 2016) and may have made the difference between studies.

The month×farm interaction ($p \leq 0.05$) impacted embryonic losses. There was a higher percentage of embryonic losses in farm 3 during the months of April, November, and December than in farms 1 and 2 (Figure 2).

Embryonic losses in this study amounted to 18.8% and there were 4.1 to 22.9% differences among farms. Other researchers (Dash *et al.*, 2016; Lonergan *et al.*, 2016; Quintero Rodríguez *et al.*, 2019) reported similar results, with 3.2% to 42.75% differences in embryonic loss and a 12.5% average (6.3% lower than in this study). Despite having a high average, the results of this study have a similar range to those recorded in other studies (Ferreira *et al.*, 2016; Rani *et al.*, 2018).

The average embryonic loss was 18.8%. There was also a farm effect ($p \leq 0.05$): farm 1 had the lowest percentages of late embryonic losses, followed by farm 2, while farm 3 had the

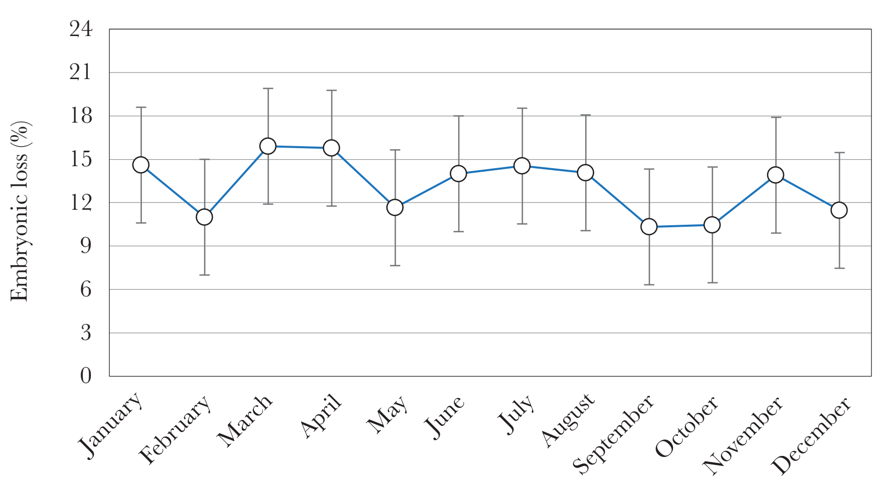

Figure 1. Embryonic losses between the early diagnosis and the confirmation of gestation in specialized non-affected dairy cattle confined in farms ($P \geq 0.05$) per month (2018).

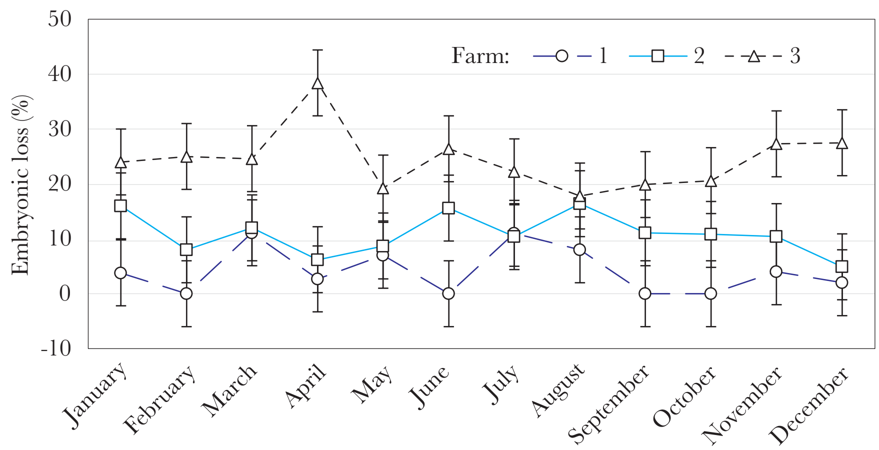

Figure 2. Embryonic losses between the early diagnosis and the confirmation of gestation in specialized and affected dairy cattle ($p \leq 0.05$) per month×farm (2018).

highest percentages (Figure 3). This study and many others confirm that embryonic losses in high-yielding dairy cattle from different regions of the world have similar percentages; therefore, it is advisable to research possible solutions to this major problem.

These results may be caused by to the impairment of the reproductive tract ability of lactating cows at 60 d postpartum to maintain a developing embryo observed by Maillo *et al.* (2012). This phenomenon may contribute to early embryonic deaths. The body condition of cows at drying (prepartum, 30 and 60 days postpartum) was not considered as a variable that determined the possible loss of body condition. This decision could explain the high number of embryonic losses. For their part, Middleton *et al.* (2019) reported that cows with body condition losses in early lactation (first 30 d in milk) are more likely to suffer pregnancy loss, which implies a greater risk that the cows could not get pregnant before 130 d in milk.

Recently, Fricke *et al.* (2022) reported that the fertility or pregnancy problems among high-yielding dairy cows has been solved through the use of various reproductive hormones

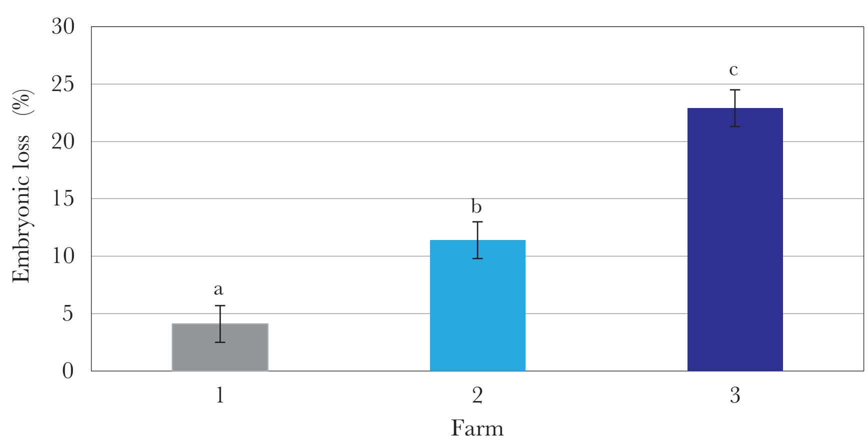

Figure 3. Farm effect on embryonic losses between the early diagnosis and the confirmation of gestation in dairy cows from the Mexican Altiplano (bars with different letters differ: $p < 0.05$).

in different fixed-time artificial insemination protocols. Nevertheless, the current problem is not getting cows pregnant, but preserving gestations. Fricke *et al.* (2022) also emphasized that the loss or gain of body condition peripartum has a great impact, not only on fertility in the first services, but also on the loss or maintenance of gestation.

In the meta-analysis carried out by Reese *et al.* (2020) —which included studies from 1978 to 2017—, gestations were diagnosed from day 29 to day 60, along with 30,500 pregnancies and 5.8% of late embryonic losses (13% below the results of this study).

Rather than trying to explain the multiple causes of the potential differences among the farms with a variable embryonic loss, the point is to approach these results with a practical focus and assess the economic losses, since pregnancy loss can have a major impact on the economic performance of dairy farms (Bekara and Bareille, 2019). Albuja *et al.* (2019) estimated that a pregnancy loss in the same region as this study had a cost of $5,449.00 MXN ($272.45 USD) during the first quarter. The increase from 12.5% (1997-2016 reports) to 18.8% (this study) represent 214.9 more embryonic losses in the latter group, which entails an economic loss of $1,171,184.00 MXN ($58,559.20 USD) in the observed farms.

CONCLUSIONS

Embryonic losses between the diagnosis and the confirmation of gestation were 19% on average, regardless of the month of gestation. There were differences in percentages of embryonic losses among the farms, which may have been the result of the management of each facility. High percentages imply high costs that impact the profitability of the production units. According to the results of this research, serious consideration should be given to the collection and analysis of pregnancy losses data from the first early diagnosis to the confirmation of pregnancy. The ultimate purpose would be to make appropriate decisions and consequently to reduce any losses, since the figures reported in our country imply considerable economic losses.

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Colegio de Postgraduados

Biostimulants on yield and its components in common bean (*Phaseolus vulgaris* L.)

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ABSTRACT
Objective: To study the effect of biostimulants on yield and its components in Azufrado Higuera beans in northern Sinaloa.
Design/Methodology/Approach: Randomized complete block design with three repetitions, a common bean variety, and five treatments (four biostimulants and one control). Assessed variables: plant height, yield, and its components.
Results: The seaweed-based (*Ascophyllum nodosum* and *Macrocystis pyrifera*) Fia Kelp® biostimulant caused a remarkable increase in plant height, seed yield, number of seeds per pod, and 100-seed weight.
Study Limitations/Implications: The study was carried out during a single crop cycle. Therefore, an ongoing assessment of the biostimulants used must be carried out during more consecutive cycles to prove their effect on the aerial biomass characteristics, harvest index, and number of pods per m^2.
Findings/Conclusions: Foliar application of biostimulants had a positive effect on seed yield and some of its components with respect to the control. The number of normal pods per m^2 was the variable with the highest correlation percentage regarding seed yield.

Keywords: plant nutrition, foliar application, sustainable production.

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INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) (Fabaceae) is a socioeconomically important crop in Mexico and it is an important source of minerals, protein, vitamins, and fiber (Martirena-Ramírez *et al.*, 2019). The state of Sinaloa contributes 15% of the national production, it has a sowing area of 83,477 ha, produced 140,730 t in 2020, obtaining a 1.72 t ha^{-1} average yield. The state holds the second place in the country, while the municipalities of Guasave and Ahome recorded the highest yields (SIAP, 2020). However, the quantity and quality of bean production is affected by abiotic factors, such as increased temperature, drought, and soil salinity.

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Therefore, the use of biostimulants —that include products that promote tolerance to the abovementioned factors— is being implemented to mitigate these problems. Biostimulants are defined as substances or microorganisms whose application has positive effects on plant growth, promote tolerance to salt stress, drought, and extreme temperatures, improving the quality of crops and the efficiency of their nutrition (Du Jardin, 2015).

The application of products with biostimulant effect can be considered as a strategy to obtain high yields in crops with nutritional value and to reduce environmental impact (Parađiković *et al.*, 2011). Biostimulants are mainly classified as seaweeds, protein hydrolysates (amino acids), growth-promoting microorganisms, and humic and fulvic acids (Halpern *et al.*, 2015; Du Jardin, 2015).

Recently, biostimulants have become popular in the agricultural industry, because they increase crop yields in a sustainable way. An increase in the number of pods (El-Sawy *et al.*, 2020), aerial biomass (Calero-Hurtado *et al.*, 2016), and number of seeds per pod in beans has been documented (Vuelta-Lorenzo *et al.*, 2017).

Regarding yield, Ortiz-Enriquez *et al.* (2022) assessed different biostimulants in Bill Z common bean, determining a 48% increase in seed yield compared to the control, when amino acids were added. Greater plant height, stem diameter, number of leaves per plant, dry matter, grains per pod, seed weight, and seed yield in common bean were determined by Quintero-Rodríguez *et al.* (2018), through the foliar application of beneficial microorganism-based biostimulants.

Therefore, the use of biostimulants can be considered as a more environmental-friendly production strategy to obtain high yields in crops with high nutritional value. Based on this background, the purpose of the present work was to assess the effect of four commercial biostimulants on the production of common bean Azufrado Higuera under field conditions.

MATERIALS AND METHODS

Location and conditions of the experiment

The study was carried out at the Campo Experimental Valle del Fuerte (CEVAF), National Institute of Forestry, Agriculture and Livestock Research (INIFAP), Juan José Ríos, Guasave, Sinaloa (25° 45' 47" N, 108° 49' 46" W and 14 m.a.s.l.) in the 2020-2021 autumn-winter cycle. The prevailing climate is very dry and warm BW (h') (Garcia, 2004), with an annual rainfall of 383.1 mm and an average temperature of 25.9 °C (Station 25048 Juan José Ríos, CONAGUA-DGE, Cuenca de Bahía Lechuguilla-Ohuira-Navachiste). Seeds of common bean (Azufrado Higuera variety) were used. This variety is characterized by its adaptability to irrigation areas and reaches acceptable production levels under residual moisture conditions —for example, it has obtained high yields in northern Sinaloa. Plants can reach a height of 40 cm, they have a specific growth habit, and their seed coat is yellow (Salinas-Pérez *et al.*, 1995).

The experiment had five treatments (four commercial biostimulants and a control): 1) Fia Kelp® (S), which contains seaweed extract (18.4% of *Ascophyllum nodosum* and 7.2% of *Macrocystis pyrifera*; 2) Agrimin 200® (AA) with 20% free amino acids; 3) BioBravo® (BM), a consortium of growth-promoting microorganisms and nutrient solubilizers based on mycorrhizal fungi of the genus *Glomus* spp (10,000), *Trichoderma* spp. 1×10^{8}, and *Azospirillum brasilense* 2×10^{11}; 4) Humiphy® (HFA) with 26.02% of humic substances derived from leonardite and 12.02% of fulvic acids, and 5) control, did not receive biostimulant application. Fia Kelp and Agrimin 200 were applied on the leaves, while BioBravo and Humiphy were applied at the base of the stem. Treatments were applied at 39, 49, 60, 75, and 89 days after sowing (das), using a dose of 5 mL L^{-1}. Treatments were established under a randomized complete block design with three repetitions per treatment; the experimental unit consisted of three 5.50-m long furrows established 80 cm apart from each other, with a density of nine plants per linear meter. The useful plot in each experimental unit was represented by the central furrow. On October 30, 2020, sowing was carried out in humid soil. Previously, 200 kg ha^{-1} of urea had been applied as a source of nitrogen, while 100 kg ha^{-1} of diammonium phosphate was used as a source of nitrogen and phosphorus. Irrigation was carried out before the beginning of flowering (38 das) and during grain filling (67 das). A dose of 0.3 L ha^{-1} of the insecticide Imidacloprid (68 das) was used to control whitefly (*Bemisia tabaci*) and aphid (*Aphis fabae*). A dose of 1 L ha^{-1} of the herbicide Fomesafen® was applied at 19 and 89 das to control bindweed (*Convolvulus arvensis* L.).

Response variables

Plant height (PH, cm): the length of the longest stem or branch was measured from the soil surface to the terminal apex, with a graduated ruler in three physiologically mature plants per experimental unit.

Seed yield (SY, g m^{-2}): it was established by weighing normal seeds and dividing seed weight by the harvested area.

Aerial biomass at physiological maturity (AB, g m^{-2}): it was obtained by harvesting and establishing the dry weight of the plants in each useful plot.

Harvest index (HI, %): it was calculated by dividing the SY by the AB $\left[HI=\left(SY\ /\ AB\right)*100\right]$.

Normal pods (NP m^{2}): it was calculated by counting the total number of total pods in each useful plot. For the purposes of this experiment, a normal pod had at least one normal seed with the size and color of the Azufrado Higuera variety. Seeds per pod (SP): the average number of seeds per pod was counted in 20 normal pods, randomly selected from the sample used to establish seed yield. 100-seed weight (SW, g): it was obtained by weighing 100 seeds —randomly selected from the sample used to establish seed yield— with a Sartorius CP224S analytical balance.

Statistical Analysis

The assumption of normality (Shapiro and Wilk, 1985) was established and an analysis of variance (ANOVA) was applied to the response variables that met this assumption. ANOVA was performed with the SAS statistical software (2009), version 9.1 for Windows, and Tukey's test ($P\leq0.05$) was used for the comparison of means. A 5% Pearson correlation coefficient was performed for all the variables assessed.

RESULTS AND DISCUSSION

A wide variation in the maximum and minimum air temperature (°C) was observed, with a weekly maximum and minimum average temperature of 26 and 9 °C, respectively. During the reproductive phase of the crop, a high temperature prevailed. After the flowering stage, a weekly average value above 25 °C and a variable minimum temperature with mean values of >10 and 7 °C were recorded (Figure 1).

The cumulative weekly rainfall during the crop cycle (624 mm) also showed strong variations. Figure 1 shows that the scarcity of rainfall during the reproductive phase of the crop affected the reproductive stage, considered the most sensitive to water scarcity (Nielsen and Nelson, 1998).

Table 1 shows the comparison of means for the PH variables, yield, and its components. The S treatment showed significant differences and was superior to the rest of the treatments in SY, SP, SW, and PH. Additionally, NSP was higher with the AA treatment, while SW and PH were higher with the BM and HFA treatments. AB, HI, and the number of NP m^2 were statistically equal (Table 1).

SY (50%), NSP (14%), and SW (6%) were higher when S was applied on the leaves than with the control. Although there were no significant statistical differences ($P>0.05$) between treatments for AB and the number of NP m^2 there was an upwards trend with the application of S regarding the rest of the treatments. Similar results were observed by Szparaga *et al.* (2018) who applied biostimulants in the crop of soybean cv. Atlanta and reported that the number of pods was similar in all treatments, including the control.

AA also encouraged an 11% increase in NSP, while BM and HFA promoted an increase of 4 and 5% in SW, respectively. According to the bibliography, there is evidence showing a similar trend in which yield and some of its components are positively affected by the biostimulants use.

A higher seed yield and seed weight was observed in southern Sonora by Ortiz-Enriquez *et al.* (2022) when amino acids were used in the Pinto Bill Z bean variety with respect to the

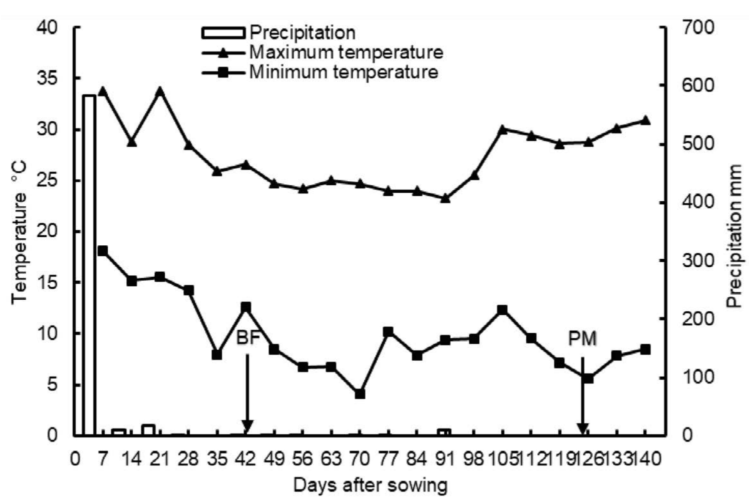

Figure 1. Weekly average maximum and minimum air temperature and cumulative rainfall per week during the 2020-2021 fall-winter cycle. Juan José Ríos, Guasave, Sinaloa. BF=beginning of flowering; PM=physiological maturity.

Table 1. Yield and its components in bean (Azufrado Higuera variety) under the effect of different biostimulants. Autumn-winter cycle (2020-2021). Juan José Ríos, Guasave, Sinaloa, Mexico.

Treatments	SY (g m^{-2})	AB (g m^{-2})	HI (%)	NP m^2	NSP	100SW (g)	PH (cm)
Fia Kelp (AM)	343.0 a	744.9 a	47.3 a	873.7 a	4.4 a	49.5 a	41.2 a
Agrimin 200 (AA)	251.1 ab	574.5 a	43.7 a	790.0 a	4.3 a	48.0 ab	39.1 ab
BioBravo (MB)	285.6 ab	575.4 a	50.3 a	822.7 a	4.2 ab	48.4 a	40.1 a
Humiphy (AHF)	221.4ab	601.4 a	37.0 a	762.7 a	4.2 ab	48.7 a	40.2 a
Control (C)	171.8 b	616.5 a	28.7 a	707.0 a	3.8 b	46.5 b	36.4 b
General average	254.6	622.5	41.4	791.2	4.2	48.2	39.42
F	5.04*	1.33 ns	2.27 ns	3.45 ns	6.11*	11.7**	11.02**

SY (RS)=Seed yield; AB (BMA)=Aerial biomass at physiological maturity; HI (IC)=Harvest index; NP m^2 (VN m^2)=Normal pods per m^2; NSP (NSV)=Number of seeds per pod; 100SW=100-seed weight; PH (AP)=Plant height; F=F values and their significance; *=Significance at 0.05; **=Significance at 0.01; ns=Not significant.

control. However, an increase in seed yield and 100-seed weight was reported by Zewail (2014) who applied seaweed extracts and amino acids to common beans in two different agricultural cycles. Similarly, Kocira *et al.* (2020) reported a 32.08% increase in bean yield compared to the control when using seaweed extracts.

In other experiments performed on common beans, an increase in seed yield was also observed when applying beneficial microorganisms (Quintero-Rodríguez *et al.*, 2018) and humic and fulvic acids (El-Sawy *et al.*, 2020). For their part, Petropoulos *et al.* (2020) reported a higher number of seeds per pod when applying seaweed. Finally, higher seed weight was reported with the application of seaweed (Kocira *et al.*, 2020), beneficial microorganisms (Petropoulos *et al.*, 2020), and amino acids (Zewail, 2014).

In this study, the aerial biomass, the harvest index, and the number of pods per m^2 were similar in the bean variety Azufrado Higuera with type I growth habit for all the treatments assessed. Contrary to these results, statistically significant differences in these variables were obtained by Quintero-Rodríguez *et al.* (2018), who reported higher values as a result of the foliar application of different biostimulants than the control, in the common bean variety Bat 304 with type III growth habit under field conditions.

The application of seaweed (S), beneficial microorganisms (BM), and humic and fulvic acids (HFA) increased plant height by 19.7, 16.5, and 16.8%, respectively. In other research works on beans, an increase in AP was also observed with respect to the control when products based on amino acids, beneficial microorganisms, and humic and fulvic acids were applied. An increase from 13 to 46% in the PH of common bean was reported by Zewail (2014) in two field experiments, when seaweed and amino acids were applied in different individual doses and when both biostimulants were combined. An increase in AP with the application of different doses of fulvic acids in three varieties of green beans was determined by El-Sawy *et al.* (2020). Similarly, Quintero-Rodríguez *et al.* (2018) pointed out that PH increased compared to the control, when three consortia of beneficial microorganisms were applied in beans. The correlation analysis established a positive and significant relationship between SY and its components and PH, except for AB. NP m^2 had the greatest influence on yield, followed by HI, NSP, seed weight, and PH (Table 2).

Table 2. Correlation coefficients between plant height, yield, and its components.

Treatments	SY (g m^{-2})	AB (g m^{-2})	HI (%)	NP m^2	NSP	100SW (g)	PH (cm)
SY (g m^{-2})	1	0.59 ns	0.89**	0.99**	0.87*	0.85*	0.85*
BA (g m^{-2})		1	0.15 ns	0.55 ns	0.41 ns	0.48 ns	0.39 ns
HI (%)			1	0.90**	0.80*	0.75*	0.80*
NP m^2				1	0.89**	0.87**	0.87**
NSP					1	0.93**	0.92**
100SW (g)						1	0.99**
PH (cm)							1

SY (RS) = Seed yield; AB (BMA) = Aerial biomass at physiological maturity; HI (IC) = Harvest index; NP m2 (VN m2) = Normal pods per m2; NSP (NSV) = Number of seeds per pod; 100SW = 100-seed weight; PH (AP) = Plant height; F= F values and their significance; *= Significance at 0.05; **= Significance at 0.01; ns = Not significant.

Szparaga *et al.* (2018) also observed a positive and significant correlation between yield and plant height, number of pods, and number of seeds per pod, when applying synthetic biostimulants during three agricultural cycles of soybean (*Glycine max* L.). In addition, Quintero-Rodríguez *et al.* (2018) mentioned that the number of pods is an important yield indicator, since the increase of this variable is a strong stimulus for an increased plant productivity.

CONCLUSIONS

Biostimulants had a positive effect on seed yield and some of its components with respect to the control. The seaweed-based (*Ascophyllum nodosum* and *Macrocystis pyrifera*) Fia Kelp® biostimulant had an outstanding performance resulting in an increase in plant height, seed yield, number of seeds per pod, and 100-seed weight. The number of normal pods per m^2 was the yield component that showed the highest correlation percentage with seed yield.

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Increase of phytomass and protein in hydroponic green forage through fertilization in Casanare, Colombia

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ABSTRACT

Objective: To evaluate the effect of two types of fertilizers on the phytomass and protein content of hydroponic green forage (HGF) of corn (*Zea mays* L.), rice (*Oryza sativa* L.), and soybean (*Glycine max* L.).

Design/Methodology/Approach: A 32×32 bifactorial design was implemented. The seeds were immersed in 1% chlorine for 15 min for their disinfection. A hydroponic system with nebulization irrigation was used; the plants were irrigated for 1 minute every 4 hours. Five cm^3 of organic fertilizer (OF) and 5 cm^3 inorganic fertilizer (IF) were applied per liter of irrigation water. Plant height (cm), fresh phytomass production (kg), actual phytomass yield (kg^{-1} m^{2-1}), and crude protein content (%) were measured. The data were analyzed by means of an ANOVA and a Tukey comparison test ($p \leq 0.05$), using the SPSS® Statistics 24 software (IBM).

Results: A phytomass yield of 50.7 kg/m^2 of HGF and a protein content of 17% were obtained using 7.102 kg of corn seed; meanwhile, a yield of 30.53 kg/m^2 and a protein content of 15% were obtained with rice seed. Finally, soybean obtained a yield of 19.17 kg/m^2 of HGF and a protein content of 38%.

Study Limitations/Implications: The nitrogen content of the fertilizers can be considered as the main limitation factor in the production and quality of HGF.

Findings/Conclusions: Inorganic fertilization has a significant effect on phytomass production and the protein production of HGF.

Keywords: soilless forage, HGF, phytomass, protein.

INTRODUCTION

Casanare is one of the 32 departments of Colombia. One of its main economic activities is cattle production: 87% of its surface (3,499,806 ha) is used for this activity. Out of the total of its territory, 2,465,302 ha are used to grow native grasses which feed 1,861,776 cows (ICA 2016). Cattle production in Casanare is divided among breeding stock (73%), fattening livestock (16%), dual-purpose livestock (10%), and dairy cattle (1%) (FEDEGAN 2014). In this region, cattle production is focused on a pastoral system that provides cattle with a food resource. However, the variable and intense weather that prevails in the region —a bimodal pluviometric regime (4 months of drought, from December to March) and an

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intense precipitation regime (which causes floods from April to November)— frequently impacts cattle production (PEGA 2015). This situation causes grass shortage and scarce nutrient content, leading to high mortality and weight loss among cattle. From April 2013 to April 2014, 232 cows and 8,382 capybaras died as a consequence of the dry season that impacted grasses, crops, aquifers, and wild life in four municipalities of Casanare (Contraloría, 2014).

Currently, 30% of the continuous grazing ranches do not have forage or protein banks for the different seasons of the year (PEGA, 2015) and producers prefer to use silos, hay, or other supplements (such as concentrated feeds) to replace grass (FEDEGAN, 2019), raising the price and, consequently, the feeding costs. Therefore, producing an efficient and sustainable feed —through the research of other technologies to implement protein banks that provide nutrients and improve the food supplements for cattle— is fundamental. In this regard, the hydroponic green forage (HGF) is a very efficient technique for the production of vegetal biomass. This technique uses the initial grow of plants in their germination state and the early growth of seeds (pulses and cereals) to produce feeds. The species traditionally used for this technique are barley, wheat, oats, rice, or corn (FAO 2001). This forage is used to feed cattle, sheep, goats, horses, pigs, rabbits, and poultry (Müller *et al.* 2005 a, b; Herrera *et al.*, 2007). Campêlo *et al.* (2007) and Mata (2011) used rice husk as organic substrate, given its moisture-retention capacity. This substrate supports the development of the roots of the seedlings used in the production of HGF. However, Della *et al.* (2002) recorded a 90% silicon content in rice husk: a high amount of this mineral in the forage can inhibit the consumption of dry matter (DM) and fiber digestion. Rocha *et al.* (2007) recommended using only small amounts of substrate in the production of HGF.

Its short harvest time (10-15 days) means that HGF is a sustainable alternative that can be produced all year round. Additionally, not only can it be developed in small areas, but its energy and protein content, as well as its digestibility, are high, while its neutral detergent fiber and lignin contents are relatively lower than in other feeds (FAO, 2001; Müller *et al.*, 2005b). Meanwhile, 1 m^3 of water is required to produce 1-8 kg of dry matter of feed using crops in soil, while the same volume of water used in hydroponic green forage produces about 100 kg (FAO, 2001). The viability, physiological and phytosanitary state of the seed is fundamental (González-Cortés *et al.*, 2015). Similarly, fertilizers applied during irrigation can provide the macro and micronutrients required for plant growth in the production of HGF (Maldonado *et al.*, 2013). This will create a forage layer that includes leaves, stems, and roots, in which 20-30 cm tall plants will grow in an 8-12 days period (Resh, 2001). The harvest of the hydroponic forage must be carried out after 10-13 days (25.4 kg to 2714 kg m^{-2}), because plants have a higher nutrient, lysine, and tryptophane content during this period (FAO, 2001 and García *et al.*, 2017). McDonald *et al.* (1981) pointed out that, the more the HGF grow, the more the protein content decreases; however, this situation can be reversed applying nitrogen fertilizers. Maldonado *et al.* (2013) mentioned that adding nitrogen (in the form of nitrate) increases height, conversion ratio, yield per m^2, protein content, and the amount of nitrate in the plants.

MATERIALS AND METHODS

Geographic location of the experimental area

The research was carried out during summer, in the El Recuerdo ranch, located in the vereda Matapantano, in the municipality of Yopal, department of Casanare, Colombia (05° 37' N and 72° 35' W). The environmental conditions during the experiment were: a 31 °C mean temperature and a 63.8% relative humidity.

Hydroponic material

Three iron vertical shelves with 5 levels were built with angle bars and secured with nuts; the dimensions were 2 m (height) × 1.26 m (length) × 0.61 m (width). They also had a 10° horizontal support inclination which allowed them to drain water. Their storage capacity included 10 black hydroponic polyethylene trays (50 cm long × 25 cm wide × 2.5 cm high). The metal structure was covered with a 6 mm greenhouse plastic sheet. The irrigation system per shelf was made up of a PVC pipeline, a 120 L bin connected to a water pump, 5 stopcocks, 5 tees, 4 degree elbows, and 5 irrigation lines with two nebulizers per line (360° radius), located 0.36 m away from the hydroponic trays (10 nebulizers in total). The crop was irrigated for 1 minute every 4 hours. This procedure took place during 10 days of the crop cycle. Water consumption amounted to 48 L per day, with a volume of 0.2 L/seg^{-1}. Fertilization took place from the first day of sowing (das) until two days before the harvest. Irrigation continued until the tenth day, using drinking water to remove the excess of salts, which makes the forage suitable for consumption (Sousa *et al.*, 2014).

Experimental design

A 32×32 bifactorial design was used. Factor 1 consisted of the following types of fertilization: a) inorganic fertilization; b) organic fertilization; and c) control (drinking water). Factor 2 included the following seed types: a) corn; b) rice; and c) soybean. A total of 9 treatments, with three replicates were used, resulting in 27 experimental units. Each experimental unit consisted of a 0.264-m^2 black polyethylene tray. Table 1 shows the design of the treatments.

Table 1. Design of the treatments for the evaluation of the effect of organic and inorganic fertilization on the production and quality of hydroponic green forage (HGF) prepared with corn (*Zea mays* L.), rice (*Oryza sativa* L.), and soybean (*Glycine max* L.).

Fertilizer type	Plant	Treatment
Organic fertilizer (FO)	Corn	1
	Rice	2
	Soybeans	3
Inorganic fertilizer (FO)	Corn	4
	Rice	5
	Soybeans	6
Water (control)	Corn	7
	Rice	8
	Soybeans	9

The commercial fertilizers were prepared following the instructions of the manufacturer. A 5 cm^3 dose of OF and a 5 cm^3 dose of IF were used per liter of water, adjusting both solutions to a 5.8 pH. According to the analysis carried out by the ACUALIM SQR S.A.S lab, control (drinking water) had the following characteristics: 8.23 pH, 39.9 dS m^{-1} EC, 15.2 total hardness, $<$1.0 cloudiness, 4.7 mg NO^3 L^{-1}, and a lack of total and fecal coliforms. Table 2 shows the chemical composition of the inorganic and organic fertilizers.

Seed treatment

Certified seeds from commercial brands, without chemical treatments, were used for this experiment: yellow corn variety Corpoica V-114; rice variety Victoriosa 10-39, and soybean variety Panorama 357. The forage was produced in 10 days; sowing density (seed kg per tray) was different for each species: 1.5 kg of corn seed and 300 g of wet rice husk as substrate; 1.8 kg of rice seeds; and 0.165 kg of soybean. The germination of soybean is special, because it does not develop a root layer (Sousa *et al.*, 2014). In order to produce an innocuous HGF, all the impurities and broken seeds were removed, using an indirect flotation method proposed by López *et al.* (2005). Subsequently, the seeds were immersed in a 1% sodium hypochlorite solution (chlorine), for 15 minutes, to disinfect them. Finally, the seeds were washed three more times with drinking water. The same procedure was carried out to disinfect the substrata (rice husk), using hot water instead of drinking water. For the pre-germination of corn and rice, the seeds were immersed in water for 24 h; the water used was changed twice a day (Contreras *et al.*, 2015). Subsequently, the seeds were placed in a perforated bin and covered with a black plastic to shield them from light and to encourage their germination during the next 48 h. Afterwards, the seeds were evenly sown in hydroponic trays, according to the sowing density assigned to each species. Soybean seeds were immersed for 5 h in water, which was changed after the first two hours. Subsequently, seeds were placed in 44 cm long × 32 cm wide × 4 cm deep black polyethylene trays, with 0.025 L of water. Finally, they were covered with a black plastic bag for 67 h and the water was changed every 12 h. This species has an epigeal germination, because its cotyledons grow above ground level. Consequently, soybean was sown directly over a polyethylene net, previously placed on the plastic trays, to encourage the root to grow through the holes of the net. Using this method, the roots can be in contact with the fertilizer received by each irrigation tray.

Table 2. Chemical composition (minerals) of the fertilizers evaluated to produce hydroponic green forage (HGF) prepared with corn (*Zea mays* L.), rice (*Oryza sativa* L.), and soybean (*Glycine max* L.).

Type of fertilizer	N	P	K	Ca	Mg	S	Fe	Mn	B	Cu	Zn	Cl	Si
	%						Mg kg^{-1}						
Organic fertilizer (FO)	1.2	1.1	0.9	1.1	1.7	0.13	10	66	10	1.0	2.0	0.0	0.0
Inorganic fertilizer (FI)	2.0	0.6	2.4	2.1	0.4	0.01	3.0	13	1.0	1.0	11	3.0	0.0

Table developed by the authors based on the data provided by the manufacturers of the commercial products.

Measuring the variables

The crude protein (CP) content was determined using the Kjeldahl method. In each of the 9 treatments, a 200-g sample of HGF was taken from the center of each experimental unit in triplicate, obtaining a total of 27 samples. Seedling height (SH) was measured at 10 days. A sample of 10 seedlings was taken from the center of each hydroponic tray and corn and rice were measured, using a ruler (mm), from the seed to the apex of the leave (cm). Soybean was measured after the opening of the cotyledons (day 5). The length of the foliar area (from the cotyledon to the primary leaves) and the root were measured separately. A Pesatronik® precision electronic scale (0.001 g) was used to determine the fresh biomass (FB) production. The growth of layer was measured on the harvest day. Fresh forage yield was determined, based on fresh biomass and seed weight per tray (Equation 1).

$$Conversion\ efficiency = \frac{Fresh\ biomass\ (kg)}{Weight\ of\ corn\ seed\ (kg)}$$

Statistical analysis

The data from the variables obtained during harvest day were subjected to a normality and homogeneity verification. After both assumptions were determined to be right, the results were subjected to an ANOVA (with a $p \leq 0.05$ significance level) and to a Tukey comparison test, using the SPSS Statistics 24 software (IBM).

RESULTS AND DISCUSSION

Hydroponic green forage production is a feeding strategy for all the breeding livestock (poultry, rabbits, sheep, goats, dairy cows, etc.) during critical drought or flood periods, when grass is scarce. Only water is usually used to produce HGF; however, different seed species and the application of fertilizers in the irrigation systems should be evaluated to increase the production and quality of HGF. This research clearly points out that fertilization and seed species (corn, rice, and soybean) have a significative effect ($p \leq 0.05$) on the production and quality of HGF. From the beginning, the amount of phytomass per species (corn, rice, and soybean) is different for each species (Figure 1).

Plant height of the HGF: Regarding the plant height variable, there were significative differences ($p \leq 0.05$) between the type of fertilizers and seed species. The corn plants of

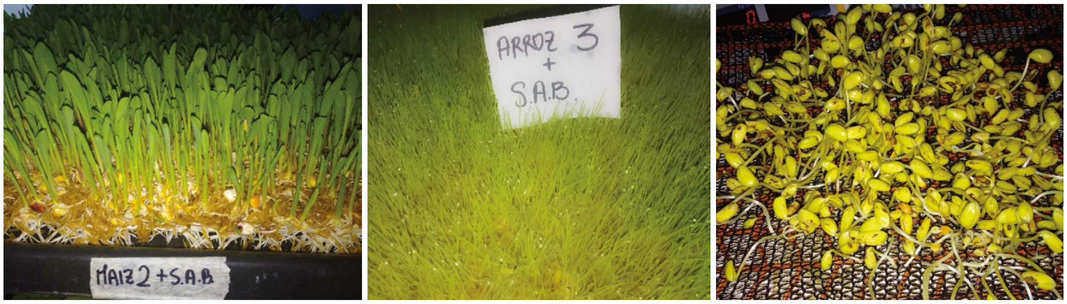

Figure 1. Seeds germinated to produce hydroponic green forage. From left to right: corn (*Zea mays* L.), rice (*Oryza sativa* L.), and soybean (*Glycine max* L.).

the treatment that received a chemical fertilizer reached a height of 42 cm. The corn plant of the treatment fertilized with OF reached a height of 30.8 cm. In contrast, control only received water and reached a plant height of 29 cm. A 45% increase in growth was recorded when fertilizers were applied instead of irrigation systems that only use water. The rice HGF also showed a different growth response depending on the type of fertilization. These plants reached a height of 15.4, 7.4, and 6.2 cm, using IF, OF, and only water, respectively. Nevertheless, the soybean HGF showed no significative differences, reaching a 13.5 cm mean height (Table 3).

Fresh phytomass production (kg) of HGF. There was a significant difference ($p \leq 0.05$) in the HGF production between the types of fertilizers and the seed species. The corn HGF fertilized with IF obtained the highest yield (10.7 kg), followed by the OF treatment (9.4 kg), and the water treatment (9.3 cm). Fertilization did not have a significate impact on the rice HGF. The yields obtained were 7.8 (IF treatment), 7.0 (OF treatment), and 6.7 kg (control). Meanwhile, the soybean HGF recorded a mean yield of 400 g, using 165 g of seeds (Table 3).

Phytomass actual yield (kg kg^{-1} m^2). In order to estimate the forage production for a particular area and the number of animals to be fed, calculating the potential phytomass yield of the HGF per m^2 is fundamental. This research recorded the following yields, using 7.102 kg of corn seed: up to 50.70 kg m^2 of HGF, with corn fertilized with IF; 44.31 kg of HGF, with corn fertilized with OF; and just 43.89 kg when the HGF only received water. These results show that, using the IF treatment, an increase of 7 kg was obtained, while only a small increase (0.42 kg) was recorded with the OF control treatments. In the case of the rice HGF, the highest yield recorded was 30.53 kg (IF treatment), followed by 27.68 kg (OF treatment), and 26.27 kg (control), obtaining a small increase of 1.42 kg. Meanwhile, the soybean HGF recorded 19.17 kg (IF), 17.04 kg (OF), and 14.20 kg (control) yields (Table 3).

Table 3. Effect of organic and inorganic fertilization in the production and quality of corn (*Zea mays* L.), rice (*Oryza sativa* L.), and soybean (*Glycine max* L.).

Fertilizer type	Plant species	Treatment	Plant height (cm)	Production fresh phytomass (kg)	Phytomass real yield (kg m^2)*	crude protein (%)
Organic	Corn	1	30.8 b	9.40 b	44.31	12.5 ab
	Rice	2	7.40 b	7.00 a	27.69	10.6 b
	Soybeans	3	13.8 a	0.40 a	17.04	35 b
Inorganic	Corn	4	42.0 a	10.7 a	50.70	17 a
	Rice	5	15.4 a	7.80 a	30.53	15 a
	Soybeans	6	15.4 a	0.45 a	19.17	38 a
Water (control)	Corn	7	29.0 b	9.30 b	43.89	11.5 b
	Rice	8	6.20 b	6.70 a	26.27	10.5 a
	Soybeans	9	11.3 a	0.33 b	14.20	30 c

* Yield (kg) of the HGF for every 7.102 kilograms of seeds per m^2.
Measures with different letter show significative statistical differences (Tukey's test, $p \leq 0.05$).

Crude protein content (%) of the HGF. This research recorded an increase of protein in the HGF. Two types of fertilizers were evaluated: organic fertilizer and inorganic fertilizer. The inorganic fertilizer had a higher nitrogen (2%), potassium (2.4%), and calcium (2.1%) content than the organic fertilizer (1.2% N, 0.9 % K, and 1.1% Ca). The analysis of the CP content 10 days after the HGF was harvested recorded a significative increase ($p<0.05$) between treatments (type of fertilizers and seed species). The highest CP increase was recorded with the corn seed + IF treatment (17% protein), followed by the corn seed + OF treatment (12.5%), and the control + water treatment (11.5%); therefore, there is a significant protein increase (up to 48%) in the HGF when the IF is applied than when the HGF only receives water. For its part, the rice HGF recorded a CP content of up to 15% (IF treatment), followed by 10.6% (OF treatment), and 10.5 % (control); therefore, a 42% increase regarding the OF and water treatments was obtained with application of IF. Finally, in the case of the soybean HGF, an increase of CP was also recorded. The following values were obtained: 38% (IF treatment), 35% (OF treatment), and 30% (control). The IF treatment recorded a 26% increase in CP compared with the OF and water treatments.

Fertilization (N, K, and Ca concentration) is a determinant factor of plant growth; in particular, nitrogen causes a better foliar development (Maldonado *et al.*, 2013). Most of the scientific research about HGF production are focused on corn, likely as a consequence of its low cost, easy availability, and high yield. In this study, corn seed recorded excellent results regarding plant height (42 cm), which are higher than the results recorded by other authors. González *et al.* (2015) reported a 14.4 cm maximum height on white corn. Quispe *et al.* (2015) found out that, 11 days before the harvest, the plants reached a 26-30 cm height. Silva (2008) obtained a 28.7 cm, while Ramírez *et al.* (2017) applied nutrients to the water irrigation system and obtained a height of up to 30.2 cm. Maldonado *et al.* (2013) pointed out that height increases along with sowing density, as a result of the competition for light between the plants, which promotes etiolation. Additionally, a 13-16 h period of natural or artificial light is essential to obtain a better HGF. Meanwhile, Vargas (2008) recorded that, at 20 days, rice HGF reached a height of 25 cm and Müller *et al.* (2005b) obtained a 10.6 cm height. In the case of soybean HGF, Jitsuyama (2013) reported that hydroponic soybean is included in the V3-V4 growing stage, with several trifoliated leaves for 1-2 weeks and a 20.2-cm long root.

In this research, the best phytomass yield was obtained with the corn HGF + IF treatment. The rice HGF yield is similar to the yields reported by Müller *et al.* (2005 b). For his part, Vargas (2008) recorded an HGF of 14.35 kg at 20 days; however, 13 days after the sowing, the nutrient value of the HGF starts to decrease. The phytomass of the soybean HGF is lower than with the other species, as a consequence of the sowing density. There are no studies that evaluate this variable; nevertheless, Jitsuyama (2013) studied soybean under hydroponic conditions. Ramírez *et al.* (2017) mentioned that fresh biomass is related to the genotype used, the days of harvest, and the sowing density. According to CONtexto ganadero, a cow eats 1.5-10% of its body weight per day in forage. Consequently, the phytomass variable allows to determine how much forage should be sown to meet the food supplement required by the animal diet. Therefore, production must be cyclical in order to provide food every day of the year. Valdivia (1997) obtained a 5 kg yield of HGF per seed kg; however, up to 7 kg/kg[1] could be potentially produced.

Loomis *et al.* (2012) pointed out that forage with a >16% of CP can be considered a good quality forage that meets the requirements of different types of livestock, although a 7% minimum CP is required for the HGFs. For their part, Albert *et al.* (2016) recorded a 13% CP content in corn HGF, while Naik *et al.* (2012) found a 10.67% CP also in corn HGF. Therefore, the CP content of the control HGF, which received only water, falls within these parameters. These results prove that the N content of the fertilizer promotes not only an increase of phytomass, but also of the CP content, obtaining a significant increase (up to 47%) and surpassing by far the CP content of the corn silage (8.35%) reported by Hazard *et al.* (2001). The results obtained in this research for rice + IF treatment were 7.92% higher than the results recorded by Vargas (2008) and 8.15% higher than the results obtained by Müller *et al.* (2005 b). Currently, rice straw or harvest residues are used as hay to feed animals and they provide 5.1% protein (Engormix, 2009). Olave and Castellar (1987) indicated that soybean crops in open fields produce 18.3% CP in fresh forage. Currently, soybean is the best choice to feed animals, as a result of its high protein content (30-40%) (Garzón *et al.* 2013). Silva (2008) pointed out that sowings with a >2.0 kg/m^{-2} density favor an increase in the protein content of hydroponic forages.

The HGF generated with the evaluated species can supplement the diet of a cow, which requires approximately 2.5% of its weight in dry matter (Fedegan, 2019) —*i.e.*, 12.5 kg of dry matter for a 500 kg cow. The protein percentage is suitable in the three varieties and can be used to feed different livestock species. Cattle reduce their consumption of forage when its protein content falls below 8% (Aregheore *et al.*, 2006). A small fraction of neutral detergent fiber (NDF) in the corn, rice, and soybean HGF indicates a high-quality forage. According to Van Soet (1982), forages with >60% NDF content are considered low-quality forages, because they can interfere with digestion and consumption. Some researchers pointed out that the time of harvest is related to the degree of digestibility of the food, because when forage matures and the cellulose fiber and lignin content increases, the protein content decreases, reducing forage digestibility.

CONCLUSIONS

According to the results obtained in this study, the nutrient solution applied with the inorganic fertilizer had a significant effect in the protein content, biomass, and plant height of the HGF of the three species used in the experiment. The species is a key factor related to the protein content. For instance, soybean had a 38% protein content; this value surpasses by far the protein content of corn (17%) and rice (15%) at 10 days of treatment.

The three species recorded a high fresh biomass content at 10 days. The layer weight and the conversion efficiency were low in corn, rice, and soybean, because sowing density promotes biomass growth.

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Colegio de Postgraduados

Social and Economic Analysis of the Production of Maradol Papaya (*Carica papaya* L.): Case study in the coast of Oaxaca, Mexico

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ABSTRACT

Objective: To analyze the social, production, and profitability indicators of a conventional agribusiness producing Maradol papaya in the coastal region of Oaxaca.

Methodology: This research was conducted at the agribusiness "Productores de la Costa Posa Verde, S.P.R. de R.L" from June 2020 to August 2021. Semi-structured interviews with the producer and his family were conducted. The economic analysis was done using the activity-based budgeting method.

Results: The studied company is a family agribusiness run by the head of the family, a 47-year-old man with a high school education and approximately 35 years of experience in the cultivation of papaya. During the period of study, the production cost was \$365,190.01 ha^{-1}. From the total variable costs, the largest expenditures per cultivated ha went to harvesting (38.2%), irrigation (17.5%), and phytosanitary control (14.3%). The cost-benefit relationship (CBR) obtained by the agribusiness was 1.31. A net profit of \$117,633.6 ha^{-1} was observed, together with a profitability of 24.4%, and an equilibrium point of 31,268.86 kg.

Conclusions: This papaya farming agribusiness is profitable. Moreover, papaya farming is an important source of work, which contributes to improving the quality of life among the region's inhabitants.

Keywords: Economic indicators, Production costs, Production profitability.

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INTRODUCTION

The papaya (*Carica papaya* L.) is a fruit native to Central America [1]. It is well-known for its medical and gastrointestinal qualities, and as a source of antioxidants, vitamins, minerals, and fiber [2]. It is currently cultivated in tropical and subtropical countries. The papaya is the third most consumed tropical fruit in the world and is therefore economically important [3].

The cultivation of the Maradol variety predominates in Mexico [2, 4], with a yield of 1,134,753.09 t in 2021. This production was led by Oaxaca, Colima, Chiapas, Veracruz,

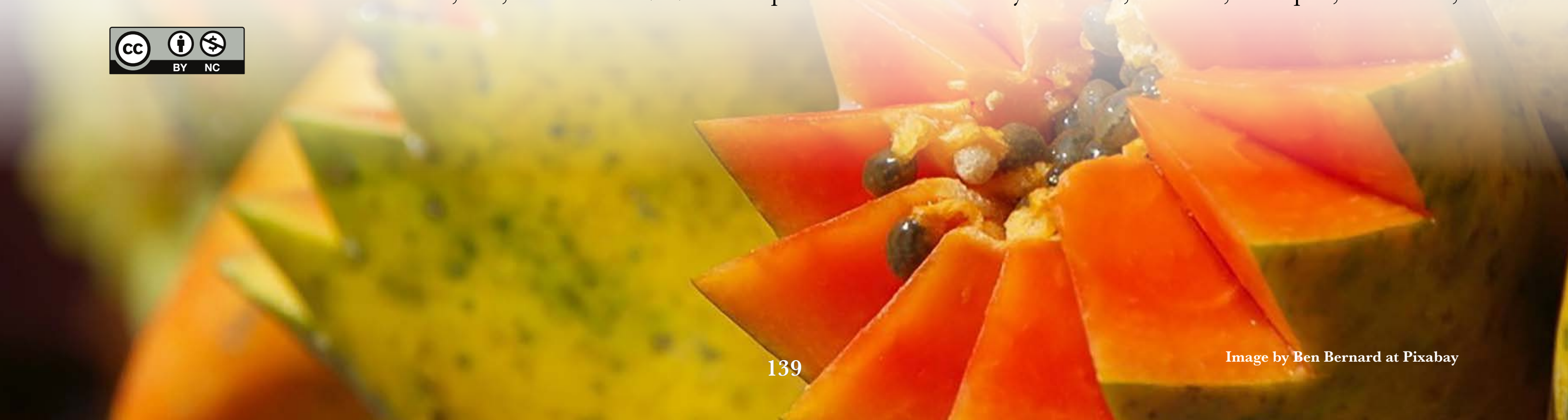

Image by Ben Bernard at Pixabay

and Michoacán, who together represent over 80% of the country's total production [5]. During the last years, this activity has faced difficulties that hinder is competitiveness. Producers are tackling financial problems, low availability of technology and infrastructure, lack of training and organization for production and commercialization, as well as a lack of strategies to develop human capital, all of which affects production yield [3].

In this scenario, the papaya producers of tropical regions must improve their production systems and make them efficient and profitable. One way of achieving this is by identifying their costs, withouth ignoring the social and production aspects [6].

Based on all of the above, the objective of this research was to analyze the social, production, and profitability indicators of a conventional agribusiness that produces Maradol papaya in the coastal region of Oaxaca.

MATERIALS AND METHODS

Study area

The research was conducted at the papaya farming agribusiness "Productores de la Costa Posa Verde, S. P. R. de R. L.", located in José María Morelos, municipality of Santa María Huazolotitlán, Oaxaca (16° 12' 54" N, 97° 54' 45" W, at 46 masl). The region has a hot sub-humid climate, with summer rains (Aw_1), an average temperature of 27 °C, and an average annual rainfall of 1,237 mm [7]. The agribusiness had 15 ha of Maradol papaya (Figure 1), with an initial density of 8,250 plants ha^{-1} and a final one of 1,571 plants ha^{-1}.

Data collection

Data were collected from June 2020 through August 2021. First, a semi-structured interview with the producer and the relatives who help him with the activites was conducted based on a number of elements taken from Vasilachis's qualitative research [8]. The following aspects were considered: 1) participation of family members in the

Figure 1. Delimitation of the Maradol papaya field at the study area. Source: Own elaboration.

agribusiness; 2) hired labor; 3) technical assistance and financing; and 4) organization and commercialization.

Second, we conducted an economic analysis using the activity-based budgeting methodology [9], whereby we determined the total cost (TC) for the main agricultural supplies, hired labor, fuel, as well as the fixed costs (FC) and variable costs (VC) involved in the activities of the production process: 1) land preparation; 2) seedling production; 3) transplanting; 4) irrigation; 5) weed control; 6) phytosanitary control; 7) fertilization; 8) cultural tasks; and 9) harvesting. This data correspond to the 2020-2021 production cycle and were modelled based on the current prices of the period.

The unit cost (UC) per t and per ha was estimated based on the TC and then classified in VC and FC. The total income (TI) from papaya sales was subsequently obtained by adding the total cost of each cut at different times, and considering a current average sales price of \$7.54 kg^{-1}. This information served as a basis to estimate the structure of costs and incomes, which led to the cost-benefit relationship (CBR), the net income, the unit cost, and the equilibrium point, by using the formulas described by Granados-Rivera *et al.* [10].

RESULTS AND DISCUSSION

Social analysis

The studied company is a family agribusiness run by the head of the family, a 47-year-old man with a high school education and approximately 35 years of experience in the cultivation of papaya. Some authors report that most papaya small-scale producers of the Loma Angosta region in Veracruz have a primary education [11]. In this regard, the producer's educational level and experience are key points related to his capacity to identify areas of opportunity that will allow him to improve his company's net profit [10]. Alongside the producer, two family members (father and brother) —who are mainly in charge of sowing— are involved in the company's activities. This observation is consistent with researches conducted in the state of Veracruz, where finding a maximum of three activity partners, related by kinship, is common [11]. Besides producing papaya, the studied agribusiness allocates part of its land to cultivating coconut palm (*Cocos nucifera*) and plantain (*Musa balbisiana*), as well as to breeding cattle.

The agribusiness's hired labor comprises workers that come from neighboring places and are hired mainly during harvest time (June and November). This contributes to the region's social benefit through the creation of jobs; however, the producer mentioned a current lack of labor that has hindered the expansion of papaya crops in the region. The agribusiness receives sporadic technical assistance, chiefly regarding crop nourishment and health. It is important to consider that pests and diseases are some of the main problems for the cultivation of papaya in Mexico [12].

To date, the producer has not received any credit or aid to improve his company's infrastructure, facilities, or production processes. This is due to the fact that papaya producers lack the necessary contacts to establish ties or relationships with other social actors outside their hometowns [11]. Therefore, macroeconomic policies and research development leave them on the margins.

Until some years ago, the agribusiness commercialized its fruit through retailers or buyers from the supply centers in Mexico City, Puebla, and even Tijuana —the latter catering for the North American market. This observation resembles reports by another author, according to whom the production of papaya in the state of Tabasco is mainly sold in the national market, *e.g.* in Mexico City, Guadalajara, and Monterrey. The product is transported to the final destination warehouse by the retailers [13], which is detrimental for producers, since it is the former who get the greatest profit [2]. For this reason, five years ago the agribusiness decided to deliver its production directly to commercial companies (AGROMOD and AGROCARICA) who distribute the product in supermarket chains in Monterrey, Nuevo León.

Production costs and income

During the studied period, the agribusiness had a yield of 69.0 t ha^{-1} and an income of $482,823.67 ha^{-1} (considering an average sale price of $7.54 kg^{-1}). The yield obtained was higher than the one reported by some authors for the state of Veracruz, which was of 41.52 t ha^{-1} [2]. For its part, the yield reported for the state of Campeche was of 100 t ha^{-1}, with a total income as high as $400,000.00 ha^{-1}. The observed variation was due to fruit quality, the season, and market cost [14]. There is evidence that the fertilization type affects the crop yield directly: observed average yields varied depending on whether fertilization was chemical (95.16 t ha^{-1}), organic (56.58 t ha^{-1}), or biological (48.56 t ha^{-1}) [15].

Table 1 summarizes the VCs required to produce 1.0 ha of Maradol papaya in the studied agribusiness. These costs correspond to goods that cannot be imported or exported, and include manual and mechanized labor, land, and hired services (irrigation and water, among others). The total sum of these goods plus the commercial supplies represents 100% of the total cost structure [16].

The production cost was $365,190.01 ha^{-1} which includes materials and equipment depreciation. From the total VCs, the largest expenditures per cultivated ha went to harvesting, irrigation, phytosanitary control, and fertilization. These results coincided with the findings for the state of Campeche, where the TC per ha of cultivated papaya was $103,687.50 (without depreciation), with the largest expeditures going to harvesting (27.18%), fertilization (22.86%), and phytosanitary control (14.06%) [14]. Similar observations were reported for other economically important fruits in Mexico, such as the pinapple. In this case, the costs related to crop establishment and maintenance represent the production unit's larger expenditure [16,17].

Economic profitability

The CBR obtained for the studied agribusiness was 1.31, which means that it is economically profitable: for each Mexican peso invested in the production of 1.0 ha of papaya, approximately 1.31 pesos are recovered, which means that the producer earns 31 cents. Similarly, a net income of $117,633.6 ha^{-1} and a profitability of 24.4% were observed. The equilibrium point was 31,268.86 kg; this indicates the quantity of fruit that the agribusiness would have to sell in order not to lose or gain. The expected income

Table 1. Production costs of 1.0 ha of Maradol papaya in the coast of Oaxaca, Mexico. Source: Own elaboration.

Concept	Amount ha^{-1} ($MX)	Participation (%)
Variable costs		
Land preparation	$19,522.61	5.4
Stockpile preparation	$1,993.33	0.5
Transplant	$1,755.00	0.5
Irrigation	$63,065.57	17.5
Weed control	$16,653.76	4.6
Phytosanitary control	$51,523.53	14.3
Fertilization	$46,287.90	12.8
Cultural work	$22,508.67	6.2
Harvest	$137,805.27	38.2
Subtotal	$358,709.01	100
Fixed costs		
Depreciation	$6,481.00	100
Subtotal	$6,481.00	100
Total cost	$365,190.01	-

One dollar equivalent to 20 Mexican pesos ($MX).

would be $235,767.22. As the agribusiness goes past the equilibrium point, the difference between income and cost will be increasingly greater, which in turn will generate a positive balance (Figure 2). The economic profitability (CBR) value observed in this research was lower than the one reported to produce papaya in the states of Tabasco (2.1) [13] and Campeche (1.93) [14].

Two papaya farming models were recently assessed. The authors observed that the sustainable model achieved a CBR of 2.24 and an equilibrium point of 38.47%, while the conventional model allowed a CBR of 1.08 and an equilibrium point of 90.11% [4]. The authors conclude that the conventional model is economically unfavorable, while

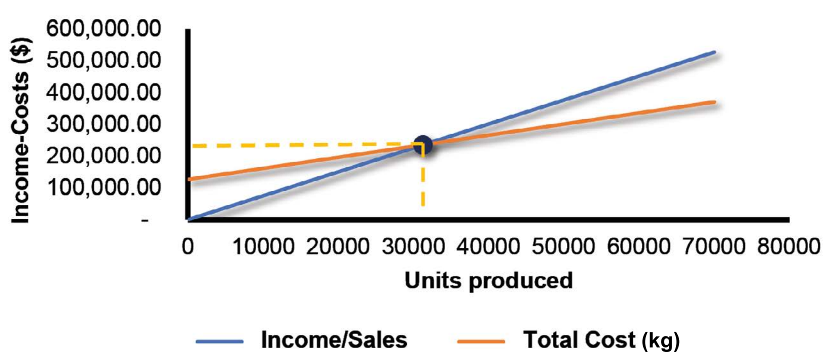

Figure 2. Equilibrium point observed in the production of Maradol papaya in the coast of Oaxaca. Source: Own elaboration.

the sustainable model is economically attractive and presents a better use of local natural resources. The observed differences in the studies might be due to market conditions (price), offer and demand at the time of the transaction, as well as to environmental and technical factors during the agronomic management of the crop [4].

CONCLUSIONS

Based on the results of the research, we can say that the papaya-farming agribusiness "Productores de la Costa Posa Verde, S. P. R. de R. L." is profitable. Besides being economically viable, papaya farming is an important source of work since the demand for labor is high in every activity of the production process. This contributes to improve the quality of life of the region's inhabitants.

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Benefits of homemade chocolate consumption on human health

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ABSTRACT
Objective: To describe the benefits of homemade chocolate consumption on human health in La Chontalpa, Tabasco, Mexico.
Design/Methodology/Approach: We interviewed 49 persons in La Chontalpa, along with 30 contacts from social networks; additionally, a participatory workshop was held with 15 persons trained in making homemade chocolate. A traditional specialist doctor who uses cacao as a medicinal base was interviewed and we were observers during cacao ceremonies. The information was analyzed using opinion analysis and the Chi-square test.
Results: Ninety-seven-point nine percent of the interviewees agreed that consuming homemade chocolate is beneficial for health, while 89.8% mentioned that consuming chocolate makes them feel good. Fifty-five percent of the consumers consider that chocolate provides them energy; 51.1% say that it helps them to control hunger and thirst; and 36.7% feel that consuming it takes away sadness and laziness. The benefits of chocolate consumption reported in the ceremonies, workshops, and interviews were that it controls depression, promotes concentration, and causes joy; it also cures diarrhea, anemia, headaches, and stomach ache.
Study Limitations/Implications: The sanitary restrictions derived from the COVID-19 pandemic limited face-to-face interviews in 2021, which were instead carried out using social networks. It is forbidden to record and take photos and videos of cacao ceremonies; therefore, we were unable to document them.
Findings/Conclusions: In La Chontalpa, Tabasco, the population consumes homemade chocolate because they believe that chocolate provides mental and physical health benefits.

Keywords: cacao, ritual, homemade chocolate, benefits, and self-consumption.

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INTRODUCTION

During the great hierophanies of the Mayan and Mexica peoples, the sacred cacao (*Theobroma cacao* L.) was consumed in medicinal, ceremonial, spiritual, and nutritional drinks, which were prepared with roasted or ground cacao, whisked with water, or sometimes mixed with achiote (*Bixa orellana* L.) and vanilla (*Vanilla planifolia* Jacks. Ex Andrews) and served in *tecomates* (a type of gourd bowl) and clay pots (Uriarte, 2019). Its

nutritional, medicinal, spiritual, and industrial value has given cacao an important role in the history of both Mexico and the Americas. The Spanish marveled at the use that the inhabitants of pre-Hispanic Mexico gave to cacao and took it to Spain, where it was widely accepted for human consumption (Delgado de Cantú, 2015).

The consumption of cacao provided health benefits to the population of Mesoamerica: it took away laziness and cured anemia, diarrhea, sadness, headaches, and stomach aches (Coe and Coe, 2018). It also provided the Mexica warriors with energy, since a cacao drink, served in clay containers or *jícaras* (another type of gourd bowl), would allow them to resist a whole day of battle (Hernández, 2021; Camacho *et al.*, 2017).

The energetic, protein, and medicinal richness of cacao lies in the nutritional composition of its varieties: Trinitario, Forastero, Criollo, and improved Criollo Var. Carmelo (Motamayor *et al.*, 2008). Another species of the genus *Thebroma*, *pataste* (*T. bicolor* L.), also known as Jaguar Tree, is likewise used to make cacao beverages for human consumption, due to its richness in fat, protein, minerals, and amino acids (Tinajero-Carrizales *et al.*, 2021).

The traditions of cacao consumption and cultivation are an Olmec heritage (Uriarte, 2019) that remains in the collective memory of the Mexican people. The native varieties of cacao have been preserved from generation to generation by uses and customs (Camacho, 2018). The use of pre-Hispanic instruments and materials —such as firewood, *chiquihuites* (a small woven basket), *yahuales* (a padded ring used to carry things on the head), *tollas* (fermentation boxes made from regional wood), and *cacaxtles* (a wood backpack)— in the production of homemade chocolate constitutes the cultural essence of the cacaoteros (cacao producers) of La Chontalpa, Tabasco (Pérez-Flores *et al.*, 2021; Camacho 2018).

The use of cacao fruits and beans for disease control is not disseminated in the mass media. The scarce or lack of interest of the state in the promotion of both food policies and the benefits of craft chocolate means that the production of cacao and homemade chocolate cannot supply the demand of the domestic market (Tinajero-Carrizales *et al.*, 2021). Therefore, the objective of this research was to describe the benefits of chocolate consumption on the health of the population of La Chontalpa region in Tabasco.

MATERIALS AND METHODS

Study area

In Mexico, the main cacao-producing states are Tabasco, Chiapas, and Oaxaca. Most of the cacao sold in Mexico is produced in La Chontalpa, which is the region of Tabasco with the largest cultivation area (Gobierno de Tabasco, 2021). The study was carried out in four of the five municipalities that comprise this region: Comalcalco, Cárdenas, Cunduacán, Huimanguillo, and Centro. Villahermosa, the main city and capital of the state, is located in Centro. The other municipalities hold, in the abovementioned order, the first four places in cacao (SIAP, 2020) and chocolate production. The latter is produced by 30 microenterprises and three companies (Sol *et al.*, 2016; Córdova *et al.*, 2018).

Research Methods

The study was carried out from April to November 2021. From April to May, five face-to-face and participatory workshops were held at the Campus Tabasco of the Colegio de Postgraduados with 15 participants trained in chocolate making. The following teamwork dynamic was employed: each workshop had three participants, who provided information about the benefits of homemade chocolate consumption. In May, an electronic interview form was sent to 30 contacts registered in Huimanguillo's Instagram and WhatsApp groups. The information from the forms was transcribed for analysis.

In June, a traditional Mayan ancestral medicine doctor from Miahuatlán, Cunduacán, who uses cacao as a sacred base to heal people, was interviewed in depth. In the church of the Ranchería Plátano y Cacao of Centro, we participated as observers in a ceremony aimed at thanking cacao for the benefits of the traditional medicine project and to spread the cultural and pre-Hispanic richness of cacao.

From July to September, an opinion survey was randomly applied to find out what people think about the benefits of chocolate consumption. These interviews were conducted in homes in Ranchería Azucena 2da. Section (13) and the Ejido José María Morelos y Pavón (27) in Cárdenas and in the downtown neighborhoods of both Cunduacán (6) and Comalcalco (3).

In November, a cacao ritual was attended during the week-long "Fiesta del Cacao" in the Ranchería Miahuatlán. The event was coordinated and directed by a Mayan priest. The event had thirty participants, both Mexicans (from Mexico City, Tabasco, Guerrero, Oaxaca, and Chiapas) and foreign guests (from Cuba, the United States, France, and Guatemala).

The interviews and the observations of the rituals were transcribed to describe the benefits of cacao and chocolate consumption on human health. The responses to the questionnaires were analyzed using frequency tables and the Chi-square test, using the SPSS v.26 software (IBM).

RESULTS AND DISCUSSION

Based on the opinion survey, the 40-60 age range accounted for 42.64% of the sampled population. The average age was 40.7 years. The youngest consumer was 18 years old and the oldest 84 years old. Seventy-one-point-four percent were women and the rest were men. All participants (100%) consume homemade chocolate.

Ninety-seven-point-nine percent of the participants have a positive opinion about the benefits of consuming homemade chocolate. Eighty-one-point-seven percent of the interviewees think that the consumption of chocolate does not harm them and 89.8% mentioned that they feel good in terms of health. In contrast, most people responded that the consumption of industrial chocolate —which has less than 30% cacao beans, high sugar content, and other added components— is harmful for their health (Table 1). Sixty-seven-point-two percent reported acne or obesity as a result of the consumption of industrial chocolate; other damages include cavities, headaches, and diarrhea.

Table 1. Perception of benefits of the consumption of homemade chocolate (n=49).

Variable and measure scale (%)	Frecuency	Measure (%)	Chi-square (value and probability)
I eat homemade chocolate (yes/no).	49	100 yes	-
I buy homemade chocolate (yes/no).	38	77.5 yes	-
Homemade chocolate benefits me (yes/no).	48	97.9 yes	45.082 p=0.0001
Eating homemade chocolate hurts me (yes/no).	40	81.6 no	19.612 p=0.0001
Eating commercial chocolate causes me harm (yes/no)	40	81.6 yes	19.612 p=0.0001
Eating homemade chocolate I feel: good/ Illness	44	89.8 good	31.041 p=0.0001

Jaramillo *et al.* (2018) mention that the consumption of homemade chocolate in Cárdenas, Tabasco is related to the age, gender, and monetary income of the consumer. Consumers over the age of 60 prefer craft chocolate and those between the ages of 20 and 50 prefer to buy commercial sweet chocolate. In the study municipalities, all the interviewees stated that they consumed homemade chocolate. Seventy-nine-point-five percent consume it from 2 to 7 times a week and 20.5% only on festivities. Regarding the way in which it is consumed, 48.9% of the interviewees drink it, 4.1% use it to prepare meals, and 46.9% use it for both purposes. These results match the findings of Córdova-Ávalos *et al.* (2020) and Hernández (2021) who reported that homemade chocolate (with 80% cacao paste) is best for beverages and that these provide physical and mental benefits to human health.

Homemade chocolate drinks are mostly consumed from September to February (Norte wind season). Chocolate is one of the sources of food for the rural and urban population of La Chontalpa (Camacho, 2018; Córdova *et al.*, 2018; Jaramillo *et al.*, 2018). A 39-year-old woman told us that: *I feel happy, energized, and satisfied when I consume cacao, in drinks, food, powder, chocolate, desserts, or as an ingredient in cakes and meals*. Fifty-five percent of the interviewees pointed out that cacao consumption provides energy, 51.1% said that it controls hunger and thirst, and 36.7% mentioned that it takes away sadness and laziness (Table 2).

Table 2. Perceived health benefits from the consumption of homemade chocolate.

Expressed benefits	Frequency	%
Energy at work	27	55
Control hunger	22	44.8
Eliminate laziness	13	26.5
Quenches thirst	8	16.3
Eliminate sadness	5	10.2
Another	1	2.0

A 49-year-old woman informed us that: *chocolate stops depression, helps blood circulation, gives concentration, eating or drinking it makes you happy; its consumption interferes with the production of neurotransmitters, it increases sexual stamina*. This makes sense because the nutrients, minerals, and proteins of cacao contribute to the stability of human health (Pérez-Flores *et al*., 2021).

Chocolate is rich in B vitamins and minerals such as Mg, Mn, K, P, Cu, and Zn, and it provides tryptophan. This amino acid is a precursor of serotonin, a hormone related to happiness. It also improves mood and fights depression (González-López, 2018).

A 38-year-old woman said that: *Consuming chocolate is good for the heart, cacao improves blood circulation, contains antioxidants that fight free radicals and prevents the premature aging of cells*.

Chocolate contains antioxidants, polyphenols, and flavonoids in higher concentration than red wine, green tea, or some fruits (*e.g*., apple). Diets rich in flavonoids are inversely correlated with cardiovascular risk. Therefore, cacao has anti-inflammatory effects which help to prevent this type of disease (Gómez-Juaristi *et al*., 2011).

The flavonoids found in chocolate have antioxidant activity. They can protect tissues from oxidative stress, one of the metabolic alterations described in arterial hypertension (González-López, 2018). For example, 6 g of cacaoat night reduced mean systolic blood pressure by 2.9 ± 1.6 mm Hg and diastolic blood pressure by 1.9 ± 1.0 mm Hg without changes in body weight, plasma lipid levels, glucose, and 8-isoprostane (Corti *et al*., 2009).

Physicochemical analyses report that cacao contains: fat (50%), water (30%), total nitrogen (2.28%), protein nitrogen (1.50%), theobromine (1.71%), caffeine (0.085%), glucose (0.30%), sucrose (1.58%), polyphenols (7.54%), and other elements (Tinajero-Carrizales *et al*., 2021). The nutritional composition of chocolate depends on the cacao's solids content: the higher the concentration of cacao, the more energetic the chocolate is. One-hundred grams have more than 500 kcal, which is equivalent to 25% of the required daily energy of each person. In addition, a higher cacao concentration implies a decrease in sugar, an increase in mineral content, and consequently a healthier chocolate (Moreno, 2012).

For the Mexica, cacao beans were as valuable as gold and silver and were used as currency, food, and medicine (Coe and Coe, 2018). A key informant, a traditional doctor from Miahuatlán, Cunduacán, who uses cacao as a base for healing, said: *sacred cacao is a food that provides for our families, for our community, for our town, and from there, the cacaotal [cacao plantation] as an agroecosystem will find an interaction between different plants and animals that also serve to cure and heal. Our ancestors taught us, told us, that the Ajaw (God), when he made us, he took the spirit that we carry from the sacred cacao. For this reason, cacao gives us the strength of life, the strength of joy, the strength of hope that we have, so there is an intimate relationship between us and cacao, because it is part of us*.

The bitter-tasting cacao drinks were served and used for spiritual and healing rituals and food; in some cases, they were sweetened with honey from hoverflies, seasoned, colored, and flavored with flowers, fruits, and seeds, and served cool or hot (Coe and Coe, 2018). This tradition is still maintained in southeastern Mexico. In this region, there are plants that give notes of flavors, aromas, and that benefit human health. The leaves, flowers, fruits, dry seeds, tree barks, roots, and tubers are used for several purposes. The plants most used to prepare food and drinks with cacao include: vanilla, (*V. planifolia*); rosita de cacao (*Quararibea funebris* (La Llave) Vischer), pataste (*T. bicolor*), anise (*Pimpinela anisum* L.), mint (*Mentha piperita* L.), cinnamon (*Cinnamomum verum* J. Prels), allspice (*Pimenta dioica* L. Merril), ginger (*Zingiber officinale* Rosc.), coyoli palm (*Acrocomia aculeata* (Jacq.) Lodd. Ex Mart.), coconut (*Cocos nucifera* L.), achiote (*B. orellana*), and amashito or bird pepper (*Capsicum annum* L. var. *glabriusculum*). In this way, the consumption of cacao contributes to the permanence of natural resources and uses and customs.

The farmers of Tabasco usually consume *pozol*, a sour cacao drink accompanied by *amashito* roasted on a griddle, seasoned with lemon and salt. The consumption of *pozol* has health benefits, because it prevents the dehydration caused by the heat of the humid tropical climate. The drink quenches thirst and hunger and gives energy to resist working days of 8 to 10 hours in the field (Córdova *et al.*, 2018).

The dried, roasted, and ground seeds of the mamey sapote or *pixtle* (*Pouteria sapota* H.E. Moore and Steam) —called *tzapotl* in Nahuatl— are used to make the homemade chocolate drinks known as *pozol* and *tejate*. *Pixtle* is added to the mixture of corn (*Zea mays* L.) dough with cacao to make *pozol*. The fruits of the mamey sapote are obtained from the trees that coexist in the cacao plantations. The *pozol* with *pixtle* is prepared for self-consumption, which increases during the patron saint festivities, the chocolate fairs, and the Day of the Dead, generating joy and happiness in the ceremonial gatherings of La Chontalpa, Tabasco.

At the opening of the Cacao Festival, a cacao ritual during which drinks made with cacao, *pataste*, and corn were offered up took place. One portion of each drink, along with cacao beans, *pataste*, corn, beans, rice, and raw, whole, and plucked sacrificed pullets were deposited in the hollow of a *madre de cacao* tree. An altar was set up near the hollow. Cacao drinks were handed out during the ritual, while pre-Hispanic music was played on native instruments: drums, conch shell trumpets, flutes, and *jícaras*. These rituals are similar to those carried out in the ranches, orchards, and plots of Chiapas and in the Yucatán peninsula (Córdova-Ávalos *et al.*, 2020).

In the face-to-face interview, the 55-years old traditional doctor described the benefits of cacao for human health as follows: *as you can see, cacao helps us to heal, to cure, to harmonize, and to maintain the balance of the four bodies, the four bodies into which ancestral Mayan medicine divides the body: the spiritual body, the physical body, the emotional body, and the rational body. These four bodies take us to the ethereal body that we call the dimension or what we also call... the transcendence in the universe, when we achieve that harmony and balance in the four bodies, we transcend and the sacred cacao helps us, it helps us to heal emotions, it helps us heal negative thoughts. So that's where we start to heal. For example, if you want to heal emotions from traumas and everything you have, we do what we call a trecena de cacao (thirteen dry cacao beans). We make a ceremony for cacao, with respect and everything. That the workers are not exploited, that those who work do it with joy, with love, and with affection.*

In pre-Hispanic times, cacao transcended for the uses and health benefits it provided to the Mayan people. As a sacred, medicinal, spiritual, and nutritional tree and fruit, it was used in agricultural rituals by the people of Mesoamerica (Hernández, 2021; Córdova-

Ávalos *et al*., 2020). The cacao rituals, celebrated in La Chontalpa, Tabasco, generate positive effects on the participants, on spiritual, ritual, and harmonious terms.

CONCLUSIONS

Cacao and chocolate form a binomial of cultural sacredness of ancient traditions of consumption of beverages and foods made from cacao. The consumption of cacao in homemade chocolate drinks does not harm human health and products with more cacao have a greater impact on physical and mental health. Homemade craft chocolates are preferred by the elderly, while the younger population prefers industrial chocolate. Considering the traceability of the authentic homemade chocolate from La Chontalpa will provide the consumers with greater security, based on the knowledge about its handling, origin, and manufacture.

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