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pág. 173

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Cost-efficiency in the production of strawberry plant CP-Jacona under two techniques

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ABSTRACT

Objective: to estimate the production price of strawberry "mother" plant of the CP-Jacona variety in both TIS and TS, and to compare these prices with the price of the imported "mother" plant.

Design/Methodology/Approach: micropropagation methods have been used as an effective means for the mass production of pathogen-free plants, in small spaces and relatively short periods of time. In particular, *in vitro* Temporary Immersion Systems (TIS) applied to the production of strawberry "mother" plants have been shown to offer technological and quantitative benefits, as well as a higher proliferation rate, compared to the *in vitro* Traditional System (TS). Despite the benefits of TIS, these systems have not been evaluated in terms of the price at which the "mother" plant can be produced and whether it is a profitable option to supply strawberry producers. The traditional method of financial analysis was applied.

Results: the price of the CP-Jacona variety plant obtained from the third production period through TIS was lower than the price of the imported Festival or Camarosa varieties.

Findings/Conclusions: both the high production rate and the low rate of loss from handling in TIS were fundamental aspects to obtain lower prices than those of imported varieties.

Keywords: Efficiency-cost, micropropagation, bioreactors, temporary immersion systems.

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INTRODUCTION

Strawberry is a fruit of high demand at the global level due to its nutritional properties, delicious flavor and versatility in the kitchen. It is rich in vitamins, antioxidants, and essential minerals, and at the same time it is low in calories and fat. In addition to its nutritional value, the strawberry fruit is considered a functional food with multiple benefits for health. The accumulated evidence proves that there are antioxidant, anti-inflammatory, anti-hyperlipidemia, anti-hypertensive, and anti-proliferative effects that counteract the problems caused by chronic diseases (Basu *et al.*, 2014). In addition, the high demand is explained by its availability during most of the year, its use in the food industry and, in recent times due to a significant increase in face of the generalized worry about the SARS-CoV-2 virus (COVID-19) (Morales, 2021).

Until the year 2021, the main strawberry-producing countries were China with 6,770,098.38 t, the United States of America (USA) with 1,211,090 t, Mexico with

669,195 t, Turkey with 542,890.63 t, and Egypt with 470,913.1 t, which contribute more than 76% of the total volume of global production. In addition, the main exporting countries until 2021 were Spain with 316,413.06 t, Mexico with 182,540.49 t, USA with 137,495.29 t, Greece with 68,427.36 t, and the Netherlands with 65,592.36 t; Mexico stands out as the third producer and second exporter of strawberry in the world (FAOSTAT, 2022).

In the country, during the fall-winter agricultural cycle of the year 2020, there were a total of 9,342 ha of strawberry, with production of 425,007 tons. The main producing states are: Michoacán (66.86%), Baja California (31.21%) and Baja California Sur (1.50%), states that generate 99.57% of the total national production of strawberry (SIAP, 2020).

Micropropagation methods play an important role for the mass production of pathogen-free strawberry plants, at low cost, in reduced spaces, and in short periods of time. In addition, they allow ensuring the compliance of specific safety, genetic and quality standards that are required for the certification of the plant material. The strawberry crop is established using the asexual multiplication of runners obtained from "mother" plants. Thus, in a hectare with around 80,000 strawberry plants, and with an average of 7 daughter plants for each "mother" plant, approximately 11,428 "mother" plants per hectare are required annually, which can be used during a period of four years (Rodríguez *et al.*, 2012; Fondo Sectorial de Investigación, en materia agrícola, Pecuaria, Acuacultura. Agrobiotecnología y Recursos Fitogenéticos, 2012). In the case of strawberry production for export, producers in Mexico import varieties of "mother" plants from the USA such as Festival, Camino Real, Sweet Charly, Camarosa and Albión. This practice has been conducted since the 1950s causing not only the technological dependency on such plant material, but also for producers to face high prices representing up to 26.3% of the total production costs (Olmos *et al.*, 2015). In the presence of this situation, producers have stated the need to have more inexpensive and productive national varieties, with quality fruits that can compete in flavor and consistency with the imported strawberries (Barrera and Sánchez, 2003).

Research institutions such as Colegio de Postgraduados, in collaboration with Universidad Michoacana de San Nicolás de Hidalgo, have developed the varieties CP-Zamorana, CP-Jacona, CP-Roxana and CP-Paola, designed for the producing zone in Michoacán, the most important in the country (Rodríguez *et al.*, 2012). For its part, the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, in collaboration with the Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, have developed the varieties Buenavista, Cometa, Nikté and Pakal. The varieties cited have been developed as a more inexpensive alternative for strawberry producers in the country, and at the same time, allowing the reduction in technological dependency on the United States (Dávalos *et al.*, 2011).

Under the premise that the CP-Jacona variety presents similar characteristics to the varieties imported in terms of high yields, presence of large fruits, excellent flavor, early maturity, lower degree of acidity, and high percentage of exportable fruit (Calderón *et al.*, 2009; Bolaños *et al.*, 2008), this study suggests that the production price of this variety is similar or even lower in comparison to imported varieties such as Festival or Camarosa. Based on interviews carried out with private businesses, the import prices of these varieties ranged between $25.00 MX and $36.00 MX during 2022. Thus, the import price will be compared to the production prices of "mother" plant obtained under the *in vitro* Traditional System (TS) and the Temporary Immersion System (TIS). In this regard, it is expected that the use of these micropropagation systems will have an impact on the reduction of production costs due to the high production scale. By its nature, the number of plants that can be obtained through in vitro plant micropropagation is unlimited, the space required is minimal, and the time when the process can be conducted is relatively short in comparison to the traditional commercial propagation method (Domínguez *et al.*, 2008).

Micropropagation through the TS is an alternative used successfully since the 1970s, and it allows efficiency in the propagation of crops, obtaining material of high genetic and phytosanitary quality; on the other hand, TIS was created in 1995 by the CIRAD (La Recherche Agronomique Pour Le Développement, 2009) and have the characteristics of semi-automatization of some micropropagation stages, in addition to a reduction in the loss of plant material as a result of more control over the process (Castillo *et al.*, 2020).

The TS allows a numerous production of plants; however, in the multiplication phase, due to the use of specialized labor and gelling agents such as microbiology growth culture medium (agar), the costs increase significantly (Pérez *et al.*, 1998; Adelberg *et al.*, 2007). TIS is a viable alternative in comparison to the TS, because of high micropropagation rate and by the substitution of the gelling agent by a programmed immersion system. Still, although the use of bioreactors reduces production costs in obtaining plants in 50 to 60% (Domínguez *et al.*, 2008, Winkelman *et al.*, 2006), the initial investment costs can be significant.

In general, plant micropropagation consists of 6 phases: selection of plant material, preparation of the culture medium, disinfection of plant material, establishment, multiplication, rooting, and acclimation. In this study, since it is a comparison of costs between TS and TIS, it stands out that acquiring plant material represent an important cost in both systems. That is, the installation and acquisition of laboratory equipment such as laminar flow hood, agitator, sterilizer, represent a high cost in both systems, as well as the essential micronutrients for the *in vitro* micropropagation. In the TS in particular, inputs such as the gelling agent (agar), containers for the propagation and multiplication, and the workforce are important costs for the production system, while the acquisition and installation of bioreactors is the main cost in TIS.

According to the certification program from California, the phases of propagation take place during the first 5 conventional clone generations from the "mother" plant (nuclear stock) (Dávalos *et al.*, 2011).

It is important to highlight that the "mother" plant imported to Mexico is a plant in the last sequence of propagation (certified plant). The "mother" plant generated in Colegio de Postgraduados is a plant that, according to the propagation sequence (Table 1), is from "nuclear stock" since it is only multiplied in *in vitro* medium for one month, to later be transported to greenhouses for the acclimation stage, and finally, to be sold to nursery keepers who will propagate it for the next 2 years to generate a "registered plant" that will be distributed to strawberry producers. One of the main benefits for strawberry producers to receive "registered plants" is that they will obtain higher strawberry yields, plant of better quality, longer life in plantations, and/or higher strawberry productivity.

MATERIALS AND METHODS

The research was done during the years 2021-2022 in Colegio de Postgraduados, Campus Montecillo, with information from the Graduate Studies Program in Genetic Resources and Productivity-Fruit Growing. The "mother" plant that is used in the production area was generated from 2,000 annual explants for each of the systems, extracted from the strawberry "mother" plant of the CP-Jacona variety, to later become established in an *in vitro* medium in TIS and TS, in the temporary immersion laboratory of the general laboratory area, which is a basic laboratory with level 2 biosafety, in a risk 2 group, according to the classification of the World Health Organization (WHO) and which has dimensions of 125 m^2.

In the acclimation stage, dome trays with 100 cavities were used in a greenhouse of 2500 m^2, which is a curved-roof greenhouse with an intermediate level of technology and approximate value of $200,000.00 MX, property of Colegio de Postgraduados Campus Montecillo.

Taking into consideration that comparing the prices of the imported "mother" plant with those of the national "mother" plant will be carried out, the source of information is described next. The sale prices in Mexico of the imported strawberry "mother" plant, of varieties Festival or Camarosa from USA and the European Union, were obtained through interviews with private businesses, and they range between $25.00 MX and $36.00 MX. In the case of the prices of the national "mother" plant, they were obtained from the production costs of the "mother" plant both for the *in vitro* traditional system (TS) and for the *in vitro* Temporary Immersion system (TIS). The information of costs was obtained from interviews with experts in the topic and private companies that supply biotechnological equipment. Based on these costs, a profit was estimated from the CETES (Certificados de la Tesorería de la Federación, Treasury Certificates) rate at 364 days in the period 2021-2022, which was 11.13%.

For each system, the real Total Costs (TC) were determined, subdivided into Variable Costs (VC) and Fixed Costs (FC); they were counted for a period of 10 years, which is the

Table 1. Stages and categories of plant according to the certification program from California, USA.

Year	Propagation Sequence	Propagation Sites
1	Nuclear Stock	Greenhouses
2	Multiplication of nuclear plant	Greenhouses
3	Foundation plant	Nurseries
4	Registered Plant	Nurseries
5	Certified Plant	Nurseries

Source: Taken from Dávalos *et al.*, 2011.

depreciation period given for the fixed asset costs, with the exception of the laboratory and the greenhouse, based on the "Guide for estimated useful life and depreciation percentages" published in the DOF on August 15, 2012. The National Consumer Price Index (NCPI) from December 2022 was considered to carry out the calculation of real costs and revenues.

Next, the Unitary Cost (UC) is calculated in each of the systems, and this will allow understanding the convenience in the use of a specific system based on the period and number of plants obtained.

Later, the potential revenues (Y) of each system were calculated. For the calculation of said revenues, the costs generated in each of the systems will be taken into account, to which will be added the benefits that should be generated if those costs were invested at a CETES rate (i), and the result will be the expected income in each system (Equation 1).

$$Y = \left(Benefits + costs \right) \tag{1}$$

Based on the potential revenues, the price per "mother" plant is obtained, as well as the number of "mother" plants generated in each of the systems, and with this, the convenience of acquiring the imported "mother" plant versus the national one will be determined.

RESULTS AND DISCUSSION

To begin with the calculation of the Costs and Revenues, it is essential to understand the productivity in each of the systems; this study starts in the year 2022 and suggests a projection until the year 2031. Based on previous studies conducted by the Postgraduate Program in Genetic Resources and Productivity-Fruit Growing, TIS generate 5.8 plants per explant, while the TS generates 2.3 plants per explant.

Although one of the advantages in both in vitro systems (TS and TIS) is spatial efficiency, it is true that space is not a limited resource, and this is why some of the main limitations in this study are the size of the laboratory and the nursery. In this regard, the establishment of 2,000 explants annually in each of the systems is suggested, which will increase annually at a rate of 5.8 explants in the case of TIS (10 explants are established by bioreactor), and 2.3 in the case of TS (one explant per assay tube), with losses from manipulation of 2% and 4%, respectively, for the systems mentioned (Table 2).

Based on this level of productivity and the limitations of the research, the "mother" plant produced was destined to supplying plants in nurseries (50%), while the rest was destined to the micropropagation process (50%) (Table 3).

In both systems, the FC and VC vary and increase since they depend on the level of production. In the case of TIS, the FC associated to bioreactor modules of 1 liter capacity stand out, which increase annually in function of the productivity requirements. Other important FC are those related to micronutrients, acquiring plant material, and substrates such as agrolite or peat moss. It is important to mention that because of the automation present in TIS, production costs are reduced because less labor is employed and no gelling agents are required (Table 4).

Table 2. Annual production of "mother" plant in TIS and TS.

Year	Traditional System		Temporary Immersion System	
	Explants production	Mother plant production	Explants production	Mother plant production
2022	2,000	4,416	2,000	9,957
2023	2,208	4,875	4,978	24,784
2024	2,438	5,382	12,392	61,693
2025	2,691	5,942	30,847	153,567
2026	2,971	6,560	76,784	382,260
2027	3,280	7,242	191,130	951,522
2028	3,621	7,995	475,761	2,368,528
2029	3,998	8,827	1,184,264	5,895,740
2030	4,413	9,745	2,947,870	14,675,676
2031	4,872	10,758	7,337,838	36,530,693
Total	32,493	71,744	12,263,864	61,054,422

Source: Prepared by the authors, 2023.

Table 3. Destination of production.

Year	Traditional System		Temporary Immersion System	
	Plant nursery	Micropropagation	Plant nursery	Micropropagation
2022	2,208	2,208	4,978	4,978
2023	2,438	2,438	12,392	12,392
2024	2,691	2,691	30,847	30,847
2025	2,971	2,971	76,784	76,784
2026	3,280	3,280	191,130	191,130
2027	3,621	3,621	475,761	475,761
2028	3,998	3,998	1,184,264	1,184,264
2029	4,413	4,413	2,947,870	2,947,870
2030	4,872	4,872	7,337,838	7,337,838
2031	10,758		36,530,693	
Total	41,251	30,493	48,792,558	12,261,864

Source: Prepared by the authors, 2023.

Table 4. Principal real costs during the propagation period in TIS (in MX pesos base 2022).

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
National consumer price index	**7.90%**	**6.27%**	**3.89%**	**3.28%**	**3.09%**	**3.03%**	**3.01%**	**3.01%**	**3.01%**	**3.01%**
Plants	9,957	24,784	61,693	153,567	382,260	951,522	2,368,528	5,895,740	14,675,676	36,530,693
Total cost	1,435,631	845,955	1,271,203	2,396,816	4,430,667	9,935,928	23,274,875	55,688,433	143,928,441	321,661,221
Unit cost	$144	$34	$21	$16	$12	$10	$10	$9	$10	$9

Source: Prepared by the authors.

For the case of the TS, the most important costs are the acquisition of plant material, agar, workforce (WF), and the use of containers for micropropagation (Table 5).

In that regard, while the Total Cost (TC) in the propagation period is lower in the TS compared to the TIS, the Total Unitary Cost (TUC) is lower in TIS than in TS. As a result, the Average Total Unitary Cost (ATUC) is lower in TIS compared to TS (Table 6).

To calculate the potential income (Y), the costs per system were taken into account, to which the benefits were added that would be generated under the assumption that the amount corresponding to the costs had been invested in CETES (i) (Table 7).

Finally, the price of the "mother" plant of imported varieties which ranges between $25.00 MX and $36.00 MX was compared with the estimated price in each system. For this purpose, the expected income was divided by the number of plants produced in each of the systems, which resulted in an average price per "mother" plant of $170.00 MX and $10.00 MX for TS and TIS, respectively (Table 8).

It can be appreciated that starting on the third period (year 2024), the price in TIS is lower compared to the imported varieties; however, this system has the disadvantage that

Table 5. Principal real costs during the propagation period in the TS (in MX pesos base 2022).

year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
National consumer price index	**7.90%**	**6.27%**	**3.89%**	**3.28%**	**3.09%**	**3.03%**	**3.01%**	**3.01%**	**3.01%**	**3.01%**
Plants	4,416	4,875	5,382	5,942	6,560	7,242	7,995	8,827	9,745	10,758
Total cost	1,844,963	1,061,835	1,028,603	1,238,787	980,323	959,498	951,184	1,120,237	904,689	889,835
Unit cost	$418	$218	$191	$208	$149	$132	$119	$127	$93	$83

Source: Prepared by the authors, 2023.

Table 6. Total unitary cost (in MX pesos base 2022).

		2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	ATUC
TIS	TUC	$160	$38	$23	$17	$13	$12	$11	$10	$11	$10	$10
TS	TUC	$464	$242	$212	$232	$166	$147	$132	$141	$103	$92	$170

Source: Prepared by the authors, 2023.

Table 7. Income Budget (in MX pesos base 2022).

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Temporary immersion system income	$1,595,273	$940,025	$1,412,560	$2,663,342	$4,923,358	$11,040,804	$25,863,041	$61,880,987	$159,933,284	$357,429,949
Traditional system income	$2,050,123	$1,179,912	$1,142,984	$1,376,541	$1,089,335	$1,066,194	$1,056,956	$1,244,808	$1,005,290	$988,784

Source: Prepared by the authors, 2023.

Table 8. Price of the "mother" plant (in MX pesos base 2022).

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Temporary immersion system price	$160	$38	$23	$17	$13	$12	$11	$10	$11	$10
Traditional system price	$464	$242	$212	$232	$166	$147	$132	$141	$103	$92

Source: Prepared by the authors, 2023.

its costs are higher compared to costs in TS, so the investor should evaluate adequately both the amount to be invested and the size of the market to be supplied.

Based on the results obtained, the following advantages are confirmed when implementing TIS compared to TS: 1) Automatization of its processes (Preil, 2005; Ziv, 2005), which allows providing more uniform growing conditions during the micropropagation process (Adelberg, 2007); 2) greater productive efficiency (Delfino *et al.*, 2020); 3) lower loss caused by manipulation (Quiala *et al.*, 2012; Cruzat, 2009; Pérez *et al.*, 1998); 4) reduction between 50% and 60% in production costs per plant (Winkelman *et al.*, 2006), as consequence of the mechanization of some of the micropropagation stages (Castillo *et al.*, 2020); and 5) lower price in TIS compared to the imported varieties.

CONCLUSIONS

This study shows that the price of the plant variety CP-Jacona estimated from the third production period through TIS was lower than the price of the imported varieties, Festival or Camarosa. The reasons that explain this result were due to both the high production rate and the low rate of losses caused by the plant manipulation. On the other hand, despite the lower prices obtained through TIS compared to the TS, TIS require greater amounts of investment which need to be assessed.

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