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Research Article

Value Chain in the Production of Sacha Inchi Oil (*Plukenetia volubilis* L.) in Cuba

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Abstract

The seeds of Sacha Inchi (*Plukenetia volubilis* L.) contain vitamins, tocopherols and fatty acids, and are a natural source of omegas 3, 6 and 9. The crop was introduced in Cuba in 2016, by the Research Center on Proteic Plants and Bionatural Products (CIPB) and has been extended to currently reach 120 ha. Since 2019, a group from CIPB has been working to extract the oil from the seeds, which has proven nutritional values, pharmacological effects and safety, and also on its marketing. The aim was analyze the results of application of manage model as value chain during the two first years to produce Sacha Inchi oil in Cuba. The management model with a value chain approach, as an organizational innovation, favored the development of completely new products and the use of wastes from the main process, which is extracting the oil. In the different links of the chain, known technologies and process and product innovations have been applied. In the productive and commercial activity, the co-innovation with the National Center for Scientific Research (CNIC) stands out, by achieving a productive chain, which guarantees the production of soft oil capsules, which offers greater reliability and attractive appearance compared to other pharmaceutical forms. Reference is made to the experimental evidence that supports the Standard Operating Procedures, to the economic benefits for national sales and exports, to the social impacts and the environmental perspective. All of the above constitutes a scientific novelty for Cuba, since it is the first time that Sacha Inchi is cultivated, industrial oil is obtained from its seeds and it is marketed in the country.

Keywords

Plukenetia volubilis, Sacha Inchi, Value Chain, Sacha Inchi Oil (SIO), Soft Gels

1. Introduction

Sacha Inchi (*Plukenetia volubilis* L.) is a plant belonging to the Euphorbiaceae family, native to the Peruvian Amazon [1]. Its star-shaped fruits have a variable number of lobes. Its seeds are oval, dark brown in color and possess exceptional nutritional qualities as they contain vitamins, tocopherols and fatty acids, in proportions that make it a natural source rich in

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omegas 3, 6 and 9 [2]. From the fruits of this plant, Sacha Inchi Oil (SIO) is obtained.

This oil has a great nutritional potential with multiple health benefits, such as, strengthening the cardiovascular system, preventing heart disease [3] and maintaining brain health [4] Moreover, the set of sterols present in the oil shows a hypocholesterolemic and antioxidant effect [5].

The natural and organic production of this powerful Amazonian seed and the industrial extraction of oil, protein flour and roasted seeds (as snacks) have been increasingly appreciated by consumers in Europe, USA and Korea, who highly value these products (Press release Government of Peru, 2023) [6]. In 2016, Sacha Inchi cultivation was introduced in Cuba, with the permanent control of the National Center for Biological Safety. From its beginning and considering the benefits provided by the use of value chains for the production of food and nutraceuticals, this form of management was considered as a viable alternative to focus the processes and products derived from the crop. The research has targeted the characterization of the application of manage model as value chain during the two first years to produce Sacha Inchi oil in Cuba.

2. Methods

2.1. SIO Production Value Chain Design

With a value chain management model, based on Porter's description, [7] the production and marketing of SIO was addressed.

The structuring of the chain, the identification of the processes with sanitary inspection, the quality control points and the innovations of the processes, was validated with the use of the Delphi Method of expert consultation, the Likert scale applied in a self-administered way and with the statistical treatment of the answers.

In the application of the consultation method, a questionnaire was designed to collect the evaluation of the panel of experts regarding: whether the primary and support activities proposed in the chain were adequate, whether the critical points of control, technological improvement and innovations in correspondence with the primary processes were correctly selected.

The stages of the chain defined in that collective work consultation [8] were the primary and secondary stages of the value chain for SIO production, the processes and critical and control points.

Each expert selected the category that best described its response according to the scale provided: very adequate (6), quite adequate (5), adequate (4), not very adequate (3) and not adequate (2). The instrument introduced the possibility that the expert consulted could express his or her lack of knowledge of the subject, don't know (1), and issue opinions, suggestions and/or proposals.

For each question in the study, the median was determined as a measure of the central tendency of the response of the group of experts and the mode, which is the value most frequently repeated in the responses and the interquartile range (IQR), in order to measure the dispersion of the sample [9]. As indicated by the Delphi methodology, the median constitutes the group response in this study [10].

2.2. Seed Propagation

For the establishment of the plots, propagation studies were carried out with different varieties of Sacha Inchi seeds: Cainazachi, Zungaracucha, Pinto Recodo, Habana, Sauce, Chica, Turuntunumba, Mishquiyaw, Coinavachi, Nukac 1 and Inca by planting in nurseries [11]. Germination experiments were conducted [12] and two concentrations of gibberellins, byproducts from the Cuban sugar industry, were used [13]

2.3. Production

For the extension of the crop, two systems were tested: trellis and creeping sowing, in eight provinces of the country. The spacing used was 3 x 3 m for a total of 1,111 plants per hectare. In the trellis system, live and dead stakes were established with 545 stakes per hectare, at a distance of 6 meters between stakes, with a height of at least 1.80 meters and two wires. In the encouragement stage, the cultural practices described in [11] was carried out. The two systems were evaluated and the results of both planting technologies were compared.

Nematode control was performed by applying bioproducts of national production: Hebernem [14-16] and Klamic [17, 18]. The trial conducted to demonstrate the effects of these products consisted of selecting 10 rows of 50th Anniversary UBP, applying the products at the time of transplanting and at six months. A total of 120 plants (40 with each product plus the control group) were randomly selected within the evaluated area. There were two treatments with each product (initial and six months after) and a control, with two replicates. The number of female flowers, growing fruits, green fruits and ripe fruits were measured in each replicate.

2.4. Harvest and Processing

Harvesting of the fruit in both technologies began between seven and eight months after planting when the fruit turned ash black and the capsules began to open. Once harvested, the fruit underwent a drying process using two technologies: sun drying racks, solar drying ovens and its combination for 24 hours in sun drying racks and 8 hours in the oven. The fruit was then dehulled in a mechanical huller.

Standard Operating Procedures were developed to cover the above activities.

2.5. Industrial Processing

The first processing plant to obtain SIO in Cuba was in-

stalled in 2017, a process based on cold pressing technology with hydraulic press. The extracted oil was characterized and its stability was evaluated [19].

Pharmacological assays were performed to demonstrate the effect of SIO on histopathological changes induced by carbon tetrachloride in rat liver tissue [20] and the acute toxicology of SIO was evaluated [21]. The technical dossier of the product was compiled.

The industrial production of SIO was analyzed through the statistical processing of the data resulting from the quality control of 45 batches of SIO, in the period from 2019 to 2021. The main production indicators of the processing plant were analyzed taking into account: kg seed/liter of oil, kg kernel/liter of oil, pressing yield, process yield.

2.6. Marketing

For the commercialization of the SIO, a cost sheet was prepared based on the results of the average yield of the field and industry studies. In 2020, this process was initiated through CNIC's Commercial and Business Management.

The above activities were collected in Standard Operating Procedures.

The economic, social and environmental benefits of the Sacha Inchi value chain were analyzed.

3. Results

3.1. SIO Production Value Chain Design

The panel of consulted experts was made up of 15 members, including specialists and managers of Production Board, specialists of the Production Units and professionals from the Science Board and the Research Unit, who are directly involved in the cultivation, agricultural processing and R&D&I of Sacha Inchi at CIPB. All the experts showed competences above 0.9 due to their wide scientific and professional experience and held categories of PhD, Advanced Technologists, Senior Specialists and Researchers, so the opinions of all the experts were included in the study.

The results of the identification of the primary activities, their sub-activities and support activities, by the experts consulted (Table 1), showed that the mode was between 5 (quite adequate) and 6 (very adequate), with a predominance of very adequate for the primary activities and quite adequate for all the support activities (5). The behavior of the median value in all the secondary activities was 5 (quite adequate), being below the majority of the primary ones, which is in correspondence with the emphasis on the key processes. As the values of all activities remained between 5 and 6, it can be concluded that the activities selected as primary and support activities make up the SIO value chain.

Table 1. *Statistical results of the identification of the primary activities, their sub-activities and support activities in the first and second rounds of expert consultation.*

Primary activities, their subactivities and supporting activities	Median		Mode	
	1st	2nd	1st	2nd
Primary Activities				
1. Seed propagation	5.5	6.0	6.0	6.0
Area selection	5.5	6.0	6.0	6.0
Nursery construction	5.0	6.0	5.0	6.0
Preparation of seedlings	5.5	6.0	6.0	6.0
Cultural care	5.0	5.5	5.0	6.0
Production	5.5	6.0	6.0	6.0
Establishment of the crop	5.5	6.0	6.0	6.0
Cultural Attentions	5.5	6.0	6.0	6.0
Harvest and processing	5.5	6.0	6.0	6.0
Harvesting	5.0	5.5	5.0	6.0
drying	6.0	6.0	6.0	6.0
Fruit shelling	5.0	5.5	5.0	6.0
Sorting and Processing	5.0	5.5	5.0	6.0
Storage	5.5	6.0	6.0	6.0

Primary activities, their subactivities and supporting activities	Median		Mode	
	1st	2nd	1st	2nd
Industrial processing	6.0	6.0	6.0	6.0
Reception of raw material	5.5	6.0	6.0	6.0
Seed shelling	5.5	6.0	6.0	6.0
Sorting	6.0	6.0	6.0	6.0
Pressing	6.0	6.0	6.0	6.0
Decanting	6.0	6.0	6.0	6.0
Filtration	6.0	6.0	6.0	6.0
Packaging and labeling	6.0	6.0	6.0	6.0
Storage	6.0	6.0	6.0	6.0
Commercialization	6.0	6.0	6.0	6.0
Wholesale / Retail Market	5.0	5.5	5.0	6.0
Exports	5.0	5.5	5.0	6.0
II. Support Activities				
Transportation of seedlings	5.0	5.5	5.0	5.0
Seed transportation	5.0	5.5	5.0	5.0

The critical control points (CCP) and control action points were determined and the median obtained values between 4 and 6, that is, from adequate to very adequate (Table 2).

Table 2. *Determination of critical points and quality control actions. Statistical results in the first and second rounds of expert consultation.*

Critical points and control actions	Median		Mode	
	1st	2nd	1st	2nd
Seed Propagation				
Area selection	5.5	6.0	6.0	6.0
Posture preparation	5.5	6.0	6.0	6.0
Cultural attentions	5.5	6.0	6.0	6.0
2. Production				
Crop establishment	5.5	6.0	6.0	6.0
Cultural Attentions	5.5	6.0	6.0	6.0
3. Harvesting and Processing				
Harvesting	5.5	6.0	6.0	6.0
Drying	5.5	6.0	6.0	6.0
Storage	6.0	6.0	6.0	6.0
4. Industrial Processing				
Raw material reception	5.5	6.0	6.0	6.0
Shelling	4.0	5.0	4.0	4.0

Critical points and control actions	Median		Mode	
	1st	2nd	1st	2nd
Sorting	4.0	5.0	5.0	5.0
Filtration	6.0	6.0	6.0	6.0
Storage	5.5	6.0	6.0	6.0
5. Marketing				
Wholesale/Retail Market	4.5	5.0	5.0	5.0

The control actions proposed for hulling and sorting in the Industrial Processing reached the lowest median value (4), which corresponds to an adequate response. The CCP referred to the filtration stage and the action proposed in the storage of the Harvesting and Processing process reached the highest median value of very adequate (6). When analyzing the results of the experts, it was determined that 78.5% of the responses referring to the critical points and control actions that will be part of the chain had a mode of 5.5.

As for the introduction of technology and innovation, the median of the results was between quite adequate (5) and very adequate (6) (Table 3), reaching the category of very adequate in most of the sub-activities proposed, such as: construction of the nursery, cultural care (Seed Propagation and Production), harvesting, drying, shelling (Harvesting and Processing), pressing, decanting, filtration, packaging and labeling (Industrial Processing). The mode also behaved between quite adequate and very adequate.

Table 3. *Statistical results of the introduction of technology and innovation in the first and second rounds of expert consultation.*

Technology and Innovation	Median		Mode	
	1st	2nd	1st	2nd
Seed Propagation				
Nursery construction	6.0	6.0	6.0	6.0
Cultural Attentions	6.0	6.0	6.0	6.0
2. Production				
Cultural Attentions	6.0	6.0	6.0	6.0
3. Harvesting and Processing				
Harvest	6.0	5.5	6.0	6.0
Drying	6.0	6.0	6.0	6.0
Shelling	6.0	5.5	5.0	5.0
Sorting and Processing	5.5	5.5	6.0	5.0
4. Industrial Processing				
Reception of raw material	5.0	6.0	5.0	5.0
Pressing	6.0	6.0	6.0	6.0
Decanting	6.0	6.0	6.0	6.0
Filtration	6.0	6.0	6.0	6.0
Packaging and Labeling	6.0	6.0	6.0	6.0
5. Marketing				
Wholesale/Retail Market	5.0	5.5	5.0	4.0

The analysis of the results of the first consultation of the calculation of the interquartile range (IQR) determined, showed that there is no consensus for the Primary activities, support activities and their sub activities (Table 1), critical points (Table 2), nor technology and innovation (Table 3), as their values were higher than 1.5 (An acceptable degree of convergence (consensus) will be estimated among the experts when IQR $\leq$ 1.5). Therefore, a second round of expert consultation was carried out.

In the second round, the results obtained with their analysis were presented and the experts were asked to make a new assessment. Of the total number of experts participating in the first round, twelve returned their responses, which were considered in their entirety. The median values for primary and support activities increased for all activities in the second round, while the mode was 6 (very adequate) except for secondary activities whose value was 5 (Table 1).

As for the response in the second round regarding Critical points and control actions (Table 2), the median values increased for 12 of the 14 sub activities analyzed and two remained the same, and were in the range of 5 (quite adequate) and 6 (very adequate). The mode remained between 5 and 6 for all activities except for hulling, which was 4 (adequate).

Regarding the proposed introduction of technology and innovation (Table 3). The mode decreased only in the sub-activity: selection and processing, reaching a value of 5

(quite adequate) and in the sub-activity Wholesale/Marketing, reaching a value of 4 (adequate). The median decreased only in the Harvesting and Shelling activities; in the rest of the activities, it remained the same, with the experts' answers prevailing with a median value between 5 and 6.

After analyzing the results of the second round of consultation, the experts reached a consensus when the IQR ≤ 1.5.

The results of the identification of primary and support activities and their sub-activities by the experts consulted showed that they were all between "quite adequate" and "very adequate", so it can be concluded that the activities identified defined the value chain of Sacha Inchi oil production.

The critical control points were rated between adequate and very adequate, with controls on: seed selection, preparation of seedlings, harvesting, drying, reception of raw material and filtration process.

Regarding the introduction of technologies and innovation, the category of very adequate was reached in most of the sub-activities in which they were proposed, such as: cultural attentions (seed propagation and production), drying, processing, pressing and decanting.

The phases of the value chain were defined as part of the management model for SIO's production and marketing process and are shown in Figure 1.

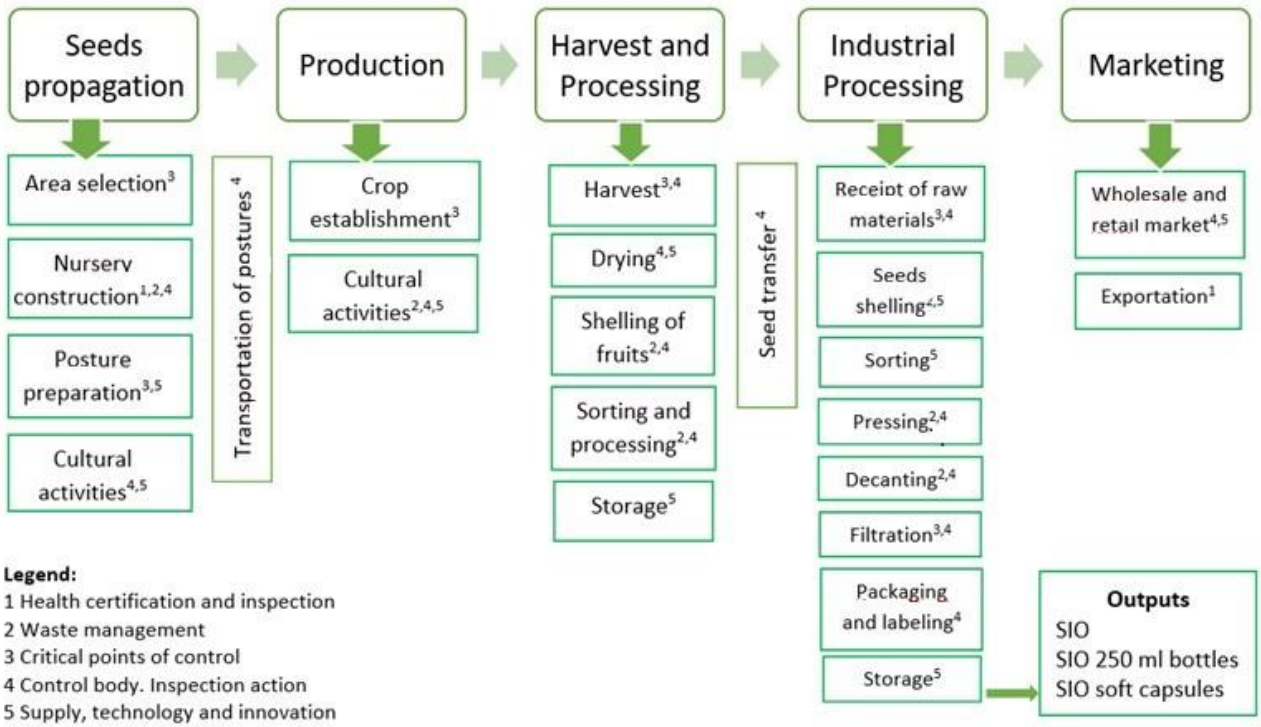


Figure 1. *Value chain diagram of Sacha Inchi oil production.*

3.2. Seed Propagation

As a result of the propagation studies, the Inca variety was generalized in production units. Germination was achieved in two stages: pre-germination in boxes, and then transfer to bags, the average germination percentage was 78%, being lower in the less warm stage of December-January. The results were improved by using gibberellins, a byproduct of the Cuban sugar industry [13].

3.3. Production

For the establishment and extension of the crop, the "Technical Guide for the cultivation and production of Sacha Inchi" was prepared [11], the application of which implies a process innovation. The regionalization studies allowed the development of a technology for planting and plots promotion stage. In the creeping technology, the plants developed as a 2 m high bush, fruit production generally developed on the periphery of the plant. The comparative results between the two planting systems (creeping and trellis, Figure 2) showed the superiority of trellis in terms of agricultural yields: 400 kg/ha in creeping and 800 kg/ha with trellising.

A B

Figure 2. *Sacha Inchi plantations (A). Trellis cultivation (B). Creeping cultivation.*

The applications of Hebernem and Klamic resulted in excellent plant health based on agricultural yield (from reproductive structures). Plants treated with both nematicides achieved better responses to florigen application compared to control plants; the action of Hebernem was superior to Klamic (Table 4).

Table 4. *Behavior of the different reproductive structures with the application of Hebernem and Klamic after the application of the florigen with respect to the control.*

Structures per m^2	Hebernem (2.5 Kg/ha)	Klamic (12 Kg/ha)	Control
Female flowers	88	55	32
Growing fruits	4	4	11
Green fruit	18	11	2
Mature fruit	2.5	3	2

3.4. Harvest and Processing

During harvesting, capsule-shaped fruit of 3.5 to 4.5 centimeters in diameter were obtained, with a distribution of fruit between 4 and 6 lobes, with morphological characteristics similar to those of other regions of the world. The drying process allowed obtaining the fruit with a humidity between 8 and 10% in the three technologies used. As a result of the shelling process, the first rind was removed, which represented approximately 50% of the fruit weight.

The agronomic studies that were carried out confirmed the feasibility of growing Sacha Inchi (*Plukenetia volubilis* L.) in the soil and climatic conditions of Cuba.

The drying technologies were better using combination of sun drier and oven during between 24-48 hours.

Ten Standard Operating Procedures were developed. The activities tested constituted process innovations that enhanced the value chain of the Sacha Inchi crop and were part of the Standard Operating Procedures.

3.5. Industrial Processing

In the achievement of a technological procedure to extract SIO, the initial characterization of the oil that has the fatty acids C18:3, C18:2 and C18:1 in the proportions 40-50 %, 30-40 % and 8-15 %, respectively, was made consistently and the high percentage of polyunsaturated fatty acids was confirmed, in ranges similar to those reached in other latitudes [22, 23].

Quality specifications were completed with absence of *Escherichia coli*, aerobic microorganisms.

The SIO subjected to accelerated degradation for 12 months showed no changes in organoleptic characteristics (light yellow oily liquid with characteristic odor and flavor). In the other quality parameters, the oil batches complied with the established acceptance limits for specific weight, acidity index, omega 3, 6 and 9 fatty acid content (FA) and microbiological control, therefore, the SIO packaged in amber glass jars with high density polyethylene (HDPE) screw cap is stable for 12 months in the storage conditions (40 ± 2) C and (75 ± 5) % RH [19].

The SIO, subjected for 24 months to the climatic conditions of Zones II (25 ± 2 ℃ and 60 ± 5% RH) and IV (30 ± 2 ℃ and

70 ± 5 % RH), showed no changes in its organoleptic characteristics or in the other specified determinations in both Zone II and Zone IV, a result that confirmed that it is stable for 24 months under the conditions of these climatic zones [19]. This result allowed establishing two years as expiry time of the product, from its manufacturing date.

It was demonstrated that SIO reduced the oxidative effects caused by carbon tetrachloride in the liver tissue of rats, [20] it also showed a very low toxicity, without having toxic signs at the maximum recommended dose (2000 mg/kg), thus guaranteeing the quality and safety of the Cuban SIO, [21], similar to products marketed in the world as food and supplements [24].

The results of the product quality control and production indicators of the processing plant obtained in the period 2019 to 2021, evidenced the reproducibility and feasibility of the technological and analytical process at a productive scale and the consolidation of industrial production (Tables 5 and 6).

Table 5. *Quality control results of ODS batches manufactured in the 2019-2021 period.*

Tests	Media	Min.	Máx.	SD
Relative density (g/ml)	0.92	0,92	0,93	0,0046
Acid number (mg KOH/g)	1.82	0,30	2,89	0,6272
Peroxide value (meq O2/kg)	8.20	1,52	12,98	2,4066
C18:1 (Omega 9)	10.51	9,23	12,81	0,8234
C18:2 (Omega 6)	36.73	34,92	39,82	1,1474
C18:3 (Omega 3)	45.61	40,01	49,49	2,2921

Table 6. *Production indicators of the Sacha Inchi Processing Plant.*

Index (kg kernel/liter of oil)	4,7
Ratio kg kernel/ Liter of oil	3,3
Pressing yield (% v/m)	30
Process yield (% v/m)	21

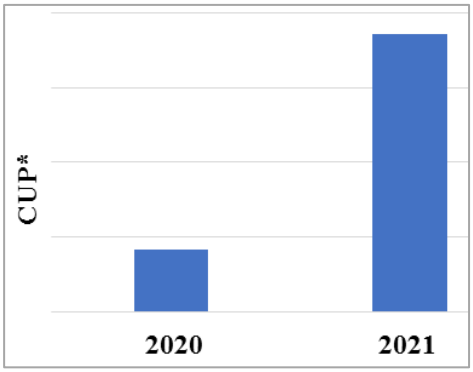
As a result of the production chaining process with the CNIC, a technology was developed to obtain soft capsules of SIO. The commercialization in Cuba of SIO in the form of soft capsules and the export of oil as raw material was widely accepted in both markets.

The described activities represented process innovations and were included in seven Standard Operating Procedures. The Sanitary Registry was approved by the National Institute of Hygiene, Epidemiology and Microbiology (INHEM) and ownership of the DAVIDA trademark was granted.

3.6 Marketing:

In the first two years of capsule production, there was an increase in oil yield/year/ha (Figure 3).

In 2021, the production of soft capsules was stabilized, and the process management and profitability were better with respect 2020 (Figure 4). That is why it was considered as a consistent production.



*CUP: Cuban peso

Figure 3. *Production of SIO /year/ha detinated to softgels.*

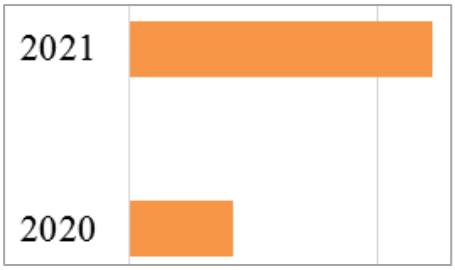


Figure 4. *Domestic sales of SIO soft gels.*

The exportation of SIO in 2021 was increased fivefold compared to the previous year.

In 2022, due to encapsulation equipment failures, it was not possible to compare the results obtained. During the months in which it was possible to produce soft capsules, the yield was slightly higher than 2021.

4. Discussion

The demand for Sacha Inchi oil is constantly growing in other parts of the world due to its nutritional properties and health benefits [25].

The value chain inspired by the model described, has been valued in agricultural processes and post-harvest improvement as a more efficient management model than the production chain and in particular in the production of Sacha Inchi oil [26-28], as well as the definition of critical points and control actions in correspondence with the HACCP guidelines.

The economic results, based on the increase in annual profits; social, by the generation of new jobs and the provision

[6] appreciated by the population. The environmental impact by achieving an ecological product without the use of chemical substances or additives, which contributes new genetic material to biodiversity in Cuban agriculture, are all elements that refer to the consolidation of the value chain in the production of Sacha Inchi oil.

5. Conclusions

By analyzing the results of the innovations stemming out of the different processes, the value chain for extracting SIO in Cuba was characterized, and its critical points and control actions. There were organizational, economic, social and environmental impacts.

The application of the supply chain management model to a crop introduced for the first time in Cuba represented an organizational innovation.

The economic impacts were positive based on financial indicators obtained during the two first years it was applied; the sales of SIO showed that till 2021, the supply of the product does not meet the demand because the beneficial effects of its consumption are highly recognized by the population.

The alliance for the production of soft capsules with the CNIC enterprise is an innovation as also the linkage for exports with this center and its business model.

The main social impact results were a source of jobs and linkages with national and international industries was generated, such as the cases of agricultural production cooperatives in several provinces that cultivate Sacha Inchi and market their fruits.

Environmental impacts were the agroecological principles applied to the Sacha inchi plots; the focus on the value chain management model, in which environmentally friendly innovations such as the use of bioproducts (gibberellins) and biological controls were given priority.

As part of the value chain, products were used, such as cake flour resulting from oil extraction and the shells in animal and human food and others. It was to develop a circle economy.

Being an introduced genetic material under the control of the National Center for Biological Safety, biodiversity was contributed, and no environmental damage was detected.

Abbreviations

SIO Sacha Inchi Oil

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Conflicts of Interest

The authors declare no conflicts of interest.

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