Use of a Commercial Process Simulator to Estimate the Cost of Manufacturing (COM) of Carotenoids Obtained Via Supercritical Technology from Palm and Buriti Trees

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ABSTRACT

Carotenoids are a family of phytochemical compounds known by their performance in several areas for instance as biological colorant and antioxidant. Some of these compounds are precursor of vitamin A, thus, potentially protecting against some illness. These are probably the reasons for the intensification of the number of research to obtain carotenoids derived products, therefore, increasing on their market share and production. Due to its huge biodiversity, Brazil has numberless possibilities of growing in both the raw material production and manufacturing of vegetal extracts rich in bioactive compounds fields. In these circumstances, Palm (*Elaes guineensis)* and Buriti (*Mauritia flexuosa),* which have considerable quantities of carotenoids (5,000 ppm and 10,000 ppm, respectively) in their extract obtained via supercritical technology, become possible sources to explore for obtain these phytochemical compounds. Supercritical fluid extraction (SFE) is an environmentally safe technology, which is becoming popular in the most important world-wide markets. However, the use of this technology is not yet spread in industrial scale in South America. The main reason for this is the high investment cost associated with SFE processes. Therefore researches regarding the estimation of the cost of manufacturing (COM) and scale-up of the process become essential to introduce industrial scale SFE in this region. Process simulation has the advantage of reducing the time required to develop processes. The main objectives of this study was to verify the capability of SuperPro Designer® to estimate the COM of SFE carotenoids-rich extracts obtained from two palm trees that spontaneously growth in the Brazilian Amazonian region: Buriti and Palm. The COM of carotenoids obtained from the fruits of these two palm trees were estimated at 20 MPa and 313 K and 25 MPa and 328 K for buriti and palm, respectively. These conditions were selected from literature data.

***Keywords*:** Cost of manufacturing, simulation, carotenoids, supercritical extraction.

INTRODUCTION

Nowadays, is well known that South America countries have a huge biodiversity, especially in the Amazon region, besides the richness of its flora, Brazil has a high potential for the production of great amounts of raw material at low cost because of its dimension, weather and tradition in agricultural production [1].

The oleaginous crops production has been showing a notable increase in the last decades. This evolution is due to the crescent consumption of eatable fats, as vegetable oils and its products in substitution of animal fats. This habit change is related with the concept of healthiest lifestyle and consequently a search for food with a positive contribution for health, what increases the use of food rich in compounds that had confirmed benefits [2].

Palm fruits from the Amazon region promise to be an alternative and abundant source of vegetable oils with high nutritional value [3]. Buriti (*Mauritia flexuosa*) and palm (*Elaes guineensis*) which belong to the *Arecaceae* family are palm trees natives from north and northeastern parts of Brazil. They present attractive characteristics as high aggregated value of their oils mainly due to their high carotenoids content.

Among the carotenoids knew in literature, the most important for the human nutrition is β-carotene which is precursor of vitamin A [4]. Moreover its nutritional value, carotenoids are important source of natural pigments with high antioxidant activity and taking part in scavenging free radicals and singlet oxygen quencher promoting great benefits for the human health. Beyond that, carotenoids play a role in diseases prevention, as night blindness, and growth inhibition of certain cancer cells [5].

In the last years, governmental and nongovernmental organizations have been shown crescent attention in sustainable development. For this reason, they have been stimulating the sustainable harvest of native plants by local communities and the use of green technologies which has the capacity to increase the production without degrading the environment [6]. The decision of the more appropriated extraction method to be used, should take parameters as cost, productivity, yield and environmental and public health restrictions [7]. A choice to reach all these needs is found in supercritical fluid extraction (SFE), which has been used as an alternative method in substitution to the conventional extraction processes in the obtaining and purification of carotenoids [8,9].

The improvement of supercritical extraction units in industrial scale promotes the decrease the investment. Data on scale-up and cost of manufacturing (COM) of supercritical extracts still are scarce in the literature, such information have great importance to stimulate the transfer of SFE technology from laboratory to industrial scale [10].

Computational simulation of processes reduces the time necessary for development and scale-up of a process, modeling and predicting the production costs for industrial scale [11, 12, 13]. The process simulator SuperPro Design® is a group of software tools capable of predicting process and economical parameters, quantifying the process parameters whose information forms the base for COM estimation [11]. TAKEUSHI et al. [13] used the simulator SuperPro Design® 6.0 to estimate the COM of clove oil; they concluded that it is an important tool for communication between the scientific and industrial communities.

The objective of this work was to estimate COM of palm and buriti extracts with the aid of the SuperPro Design® software.

METHODOLOGY

Experimental data: The experimental data, that is, the overall extraction curves for buriti and pressed palm oil fibers (PPOF) were obtained from França et al [14] and França and Meireles [3] (Table 2).

Table 2 – Extraction conditions for buriti and pressed palm fiber

Raw Material	P (MPa)	T (K)	Q × 10^{-3} (kg s^{-1})	Bed Density (kg/m^3)	Time (min)	Yield (%)
Buriti	20	313	3.1	590	210	7,2
Pressed Palm Fiber	25	328	3.3	176	130	6,9

Simulations: The simulations were conducted using the software SuperPro Designer 6.0® which has a databank with several equipments, unit operations and chemical compounds that usually are used in chemical industry; it is also possible for the users to create an a large number of process using the available equipments and unitary operations. The supercritical extractor built in the SuperPro Designer 6.0® contains two supercritical extractor designed to support a maximum pressure of 80 MPa, working in a semi continuous system as show in Fig.1.

Economical Evaluation: The method utilized by the software to estimate the COM is based on Turton et al. [15] methodology, which uses for its analysis the sum of the fixed cost of investment (FCI), the cost of utilities (CUT), the cost of labor (COL), the cost of raw material (CRM) and the cost of waste treatment (CWT) involved in the studied chemical process to compose the COM. Supercritical fluid extraction is an environmentally safe technology, thus the cost of waste treatment was considered null. The utilities cost is the energy costs related to the CO_2 cycle [1]. The raw material costs are related to the material (solid substratum and solvent) used in the production; the solvent loss during the process was lumped into these costs. The cost of buriti (*Mauritia* flexuosa) used was US\$ 960.00 t^{-1} [6]; the cost of palm (*Elaes* guineensis) was considered to be zero, since the material used in this study (Pressed Palm Oil Fiber) was a residue from the palm oil pressing process. The CO_2 cost was considered US\$ 0.1 kg^{-1} [1]. The solvent lost was considered to be 2% of the total CO_2 involved in the process. The flash tank operated at 4 MPa and at temperature of 303 K [13]. The FCI estimative by the software the equipments costs involved in the process and the annual depreciation that was to be 10%. The COL used was estimated as US\$ 3.00 h^{-1} and the total operational cost was calculated considering 24 h working per day in 330 days.

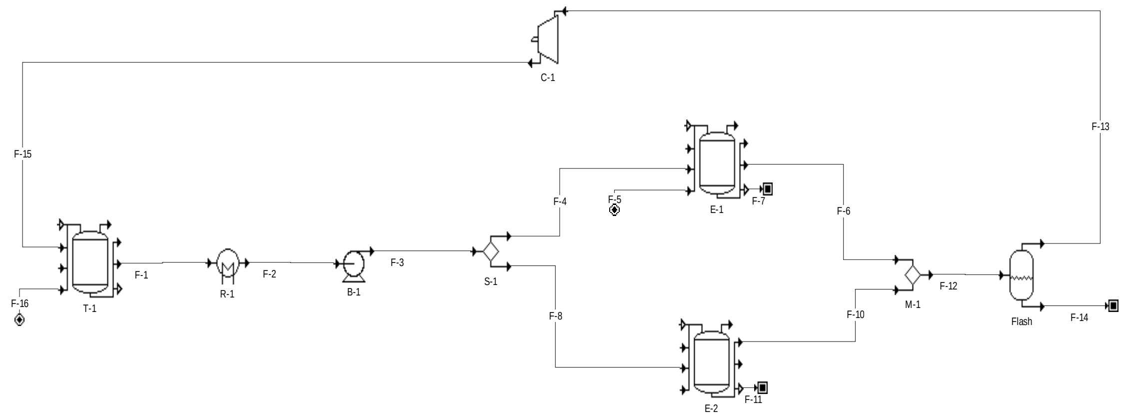

Fig.1 – Flowchart of a supercritical fluid extractor made in SuperPro Designer®

Scale up: The scale up procedure used assumes that both yield and extraction time in the industrial process will be similar of the laboratory process if the ratio between raw material and solvent flow rate are kept constant [1]. The laboratorial and industrial bed densities were considered identical. This study considered three SFE industrial setups with extractors of 0.1, 0.5, and 1 cubic meters; the costs were estimated by the six tenth rule [20] were: US\$ 750,000.00; 2,000,000.00; 3,000,000.00, respectively.

Results and discussions

Buriti: Fig. 2 shows the overall extraction curve (OEC) and the COM of the buriti extract obtained in an industrial SFE with two columns of 0.1 m^3. The COM of buriti oil suffers a considerable increase (17.36%) as the extraction time increases from 120 minutes (US\$ 44.43 kg^{-1}) to 150 minutes (US\$ 52.14 kg^{-1}). The lowest COM (US\$

44.43 kg^{-1}) was observed at 120 minutes of extraction, at this time the yield was 6.3 % which means that 87.5% of the total extract was recovered. Fig. 3 shows the carotenoid concentration (CC) and the COM of carotenoids present in the buriti extract. At 100 minutes of extraction occurs a huge increase (46.03 %) of CC in the concentration of CC in the buriti extract [14]; at this point is US$ 7.86 g^{-1} and the CC is 72.18 % of the total obtained in SFE. The lowest COM of carotenoids is US$ 7.45 g^{-1} obtained at 120 min of extraction.

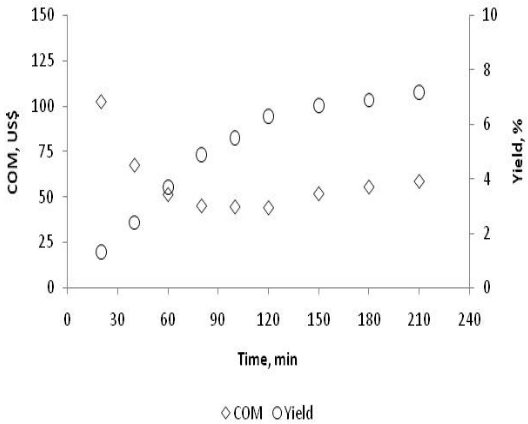

Fig. 2 – OEC and COM (US$ kg^{-1}) of buriti extract

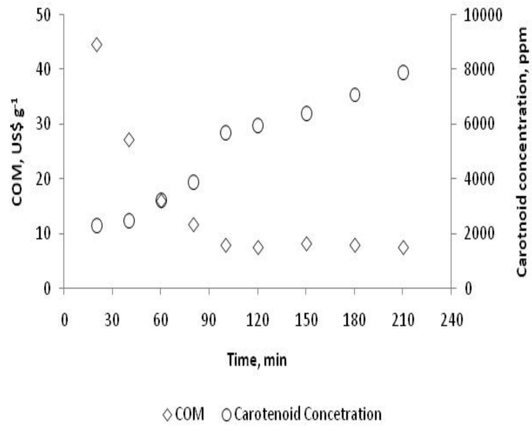

Fig. 3 – OEC and COM (US$ g^{-1}) of buriti carotenoids

Pressed Palm Fiber: The OEC and the COM for the extract from PPOF is showed in Fig. 4. The COM varies from US$ 90.66 kg^{-1} (130 min) to US$ 61.82 kg^{-1} (45 min). The lowest COM was obtained for an extraction yield of 53.62%. Fig. 5 presents the CC and the COM for PPOF. The maximum COM for PPOF carotenoids was US$ 78.29 g^{-1} obtained for short extraction time; the minimum COM was US$ 17.80 g^{-1} obtained for 75 min of extraction, where the CC is 3900 ppm.

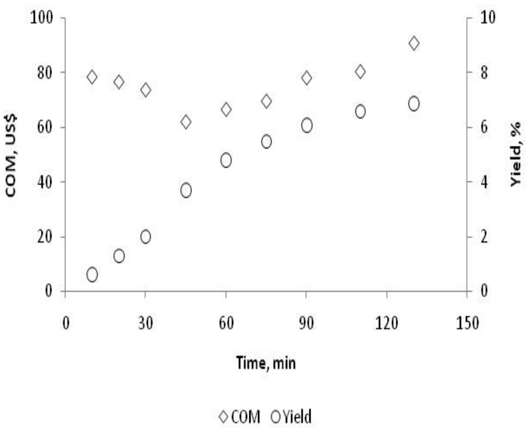

Fig. 4 - OEC and COM (US$ kg^{-1}) of pressed palm fiber extract

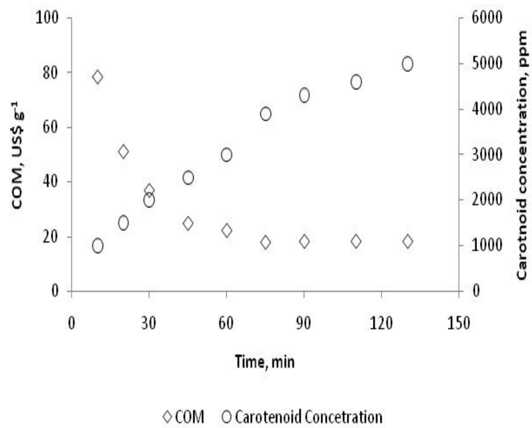

Fig. 5 - OEC and COM (US$ g^{-1}) of pressed palm fiber carotenoids

Scale Up: The scale up COM was made for a 120 min. SFE duration to buriti, as show in Fig.7, and for 75 min. process to palm, Fig.8, at these times 75.38 % of all carotenoids obtained via SFE were extracted in buriti process and 78 % in palm extraction procedure, indicating the lowest COM of carotenoids observed. It is possible to view that the CRM kept more participation in the COM composition when the extractor volume is augmented, while the COL and FCI fractions decrease in the buriti case, contrasting with the COM of pressed palm fiber whose the mainly influence is due the FCI fraction, specifically in this study the CRM did not had an influence in palm COM like in buriti COM because the cost of pressed palm fiber is null while buriti has a cost of US$ 960.00 t^{-1}.

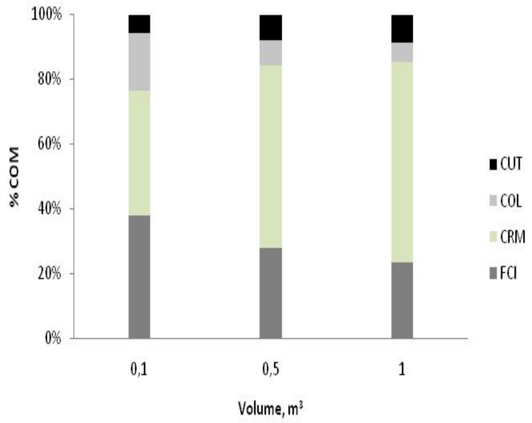

Fig.7 – Buriti costs fraction that contribute on COM formation

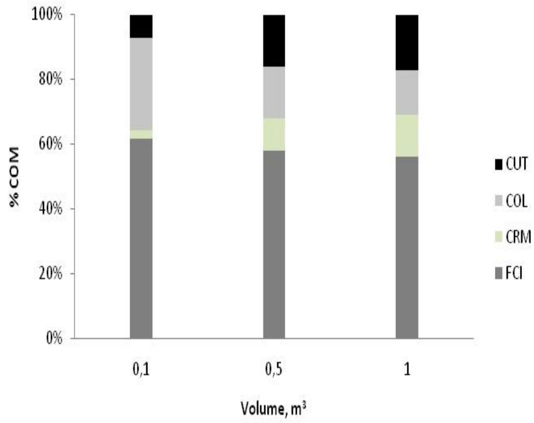

Fig.8 – PPOF costs fraction that contribute on COM formation

Comparing the COM of carotenoids from buriti and PPOF in the three industrial setups (Fig.9) is possible to observe the difference between the COM of carotenoids is approximately 139 % and decrease when the extractor volume is raised until 64%. This effect is caused because a greater amount of raw material is demanded when a larger extractor is used, then, the CRM fraction represents a larger participation in the final COM.

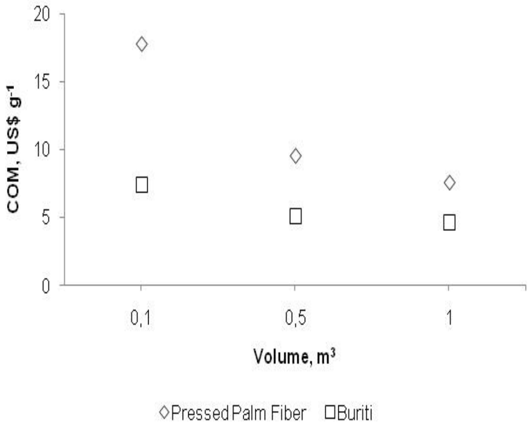

Fig.9 – Comparison of COM for Buriti and PPOF carotenoids SFE vessels of different capacities.

Conclusion

Long extractions time favored carotenoids extraction, thus, if is desired an extract with a high CC is preferred increase the extraction time. Buriti presented lowest COM's than PPOF. The CRM had a great influence in the final COM of carotenoids when buriti was studied; instead FCI played a bigger role in PPOF COM due to the raw material cost. When the scale up from buriti and PPOF was compared, the first presented lower COM of carotenoids. However, actually the industry demand on buriti was very high due to its utilization in biodiesel production, while pressed palm fiber has an abundant production.

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