Manufacturing Cost of Extracts from Jackfruit (*Artocarpus heterophyllus*) Leaves Obtained Via Supercritical Technology and Solvent Extraction

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Besides the great biodiversity of their flora, South American countries have high potential for the production of great amount of raw material at low cost. Over the last 50 years, the demand for vegetal extracts has gradually increased, since they are natural sources of bioactive compounds that can be used in cosmetic, pharmaceutical and food industries, among others. Jackfruit leaves (*Artocarpus heterophyllus*) are rich in phenolic compounds, which give them powerful antioxidant, anti-inflammatory and antibacterial properties; however, there are few literature data available on jackfruit leaves extraction. Adding value to raw materials using ecologically correct technologies is ideal to increase income without degrading the environment. An alternative to fulfill those requirements is the extraction of volatile oils and oleoresins using supercritical technology. In spite of being a well-known clean technology, there is still no industrial unit operating with it in South America, because of the high investment costs. Low pressure solvent extraction (LPSE) still is the most used technology in industries for recovery of oleoresins; however, this process usually extracts complex crude mixtures, so that the steps of solvent removal and purification can elevate the final product cost. On the other hand, recent studies have shown that supercritical fluid extraction (SFE) may be economically viable to obtain extracts from vegetable matrices, presenting very low operational cost. The use of simulation softwares allows substantial cost, labor and time reduction in the studying of industrial processes. The objective of this work was to compare the economical viability of SFE towards LPSE of jackfruit leaves. Literature and laboratory data for SFE and LPSE, respectively, were used to estimate the cost of manufacturing (COM) of the extract. The simulation software SuperPro Designer 6.0 ® was used to determine the COM.

Key-words: Cost of manufacturing, Jackfruit, Low pressure solvent extraction, Supercritical fluid extraction

INTRODUCTION

The genus *Artocarpus* comprises about 50 species of evergreen and deciduous trees belonging to the Moraceae family [1,2]. The specie *Artocarpus heterophyllus* Lam is assumed to have origin in India or Oceania and it is found as a cultivated tree in all tropical countries. The tree is high up 20 m and its fruits are known as jackfruits [1].

The plants of *Artocarpus* species have been used by traditional folk medicine in Indonesia against inflammation, malarial fever [3], stomachache, ulcers, abcesses, dysentery, diarrhea, defective urinary secretion and skin disease [4]. Moreover, they are a rich source of

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prenylated phenolic compounds such as geranylated flavones [5], which are being investigated for their phytochemical and biological properties [2,6].

Extracts of *A. heterophyllus* have shown a broad spectrum of antibacterial activity [7]. It was reported that aqueous extract of *A. heterophyllus* leaves possess oral hypoglycaemic activity [8]. The leaves and roots have been used for medicinal purposes, such as treating anemia, asthma, dermatosis, diarrhea, and cough as an expectorant [8,1]. The fruits, seeds and trunk wood have been described as containing chemical compounds with aphrodisiac properties (Ferrão, 1999 cited by Maia et al. [1]). Still, the fruits may provide a beneficial effect on inflammatory-mediated diseases [9]. The root bark and the heartwood have been described as containing chemical compounds with antioxidant properties [10], with abundance of flavones and flavanones [3].

Commonly, the oily extracts are prepared by traditional low pressure solvent extraction (LPSE) methods using organic solvents. Such technique has limitations in obtaining solvent-free extracts [11], and may cause degradation and loss of target components, besides the consumption of large volumes of non-friendly solvents. For this reason, new technologies with good performance in yield, quality, operation time (productivity) and/or cost are being studied. Those factors are important since yield and productivity have economic implications on the industrial viability of most processes, while selectivity is related to the quality and purity of the product [12].

In this context, supercritical fluid extraction (SFE) to obtain vegetable extracts of condimentary, aromatic, and medicinal plants has become important in international markets, generating technological improvements mainly in sectors connected to food, pharmaceutical, and chemical industries [13]. The great improvement of the SFE processes is the properties of the supercritical solvent: it presents high mass transfer capacity, the solvent power can be altered by process conditions (temperature and pressure), and is easily removed from final extract. So, these SFE characteristics reduce the cleaning and purification step, which are major time and energy consumers in conventional processes [14]. However, high investment cost is the greatest limitation for SFE spread [14].

The use of simulators allows estimating the manufacturing cost of a product, besides facilitating the design and the transfer of process technology. Therefore, the use of simulators as alternative of process setups and operating conditions allows a reduction of the costs, and time consumption on laboratory and pilot plant efforts [15].

In this study, a comparative economic evaluation of extract from jackfruit leaves obtained by LPSE and SFE is presented. The software SuperPro Designer 6.0 ®, which solves the mass and energy balances, sizes equipments, estimates purchase costs, and reports stream and equipament data, as well as capital and manufacturing costs [16], was used to perform the economical evaluation of the processes.

MATERIALS AND METHODS

Plant Material

Leaves of *Artocarpus heterophyllus* collected in the University of Campinas (Campinas, Brazil), in February, 2008, were washed and dried, subsequently comminuted in a knife mill (Marconi, model MA 340, Piracicaba, Brazil), packed in plastic bags and stored in a domestic freezer (Metalfrio, São Paulo, Brazil) at -15 ºC.

Experimental Procedure

Low Pressure Solvent Extraction (LPSE)

The extraction was performed using 10 g of plant material and 100 mL of ethanol (> 99.0 %, Ecibra, lot 17697, São Paulo, Brazil) in a 250 mL Erlenmeyer. The mixture was agitated (Marconi, model MA 420, Piracicaba, Brazil) under temperatures of 313 K and 323 K with agitation frequency of 165.2 rpm. The solvent was removed using rotavap (Heidolph Instruments, model Laborota 4001, Viertrieb, Germany) with vacuum control (Heidolph Instruments, model Rotavac, Viertrieb, Germany) kept at 0.12 bar and 313 K with speed of rotation of 60 rpm. The extractions were carried out for 30, 60, 90, 120, 150, 180, 210 and 240 min.

Supercritical Fluid Extraction (SFE)

The experiments were carried out on a Spe-ed SFE system (Applied Separations, Allentown, USA) equipped with a 6.57×10^{-6} m^3 column (Thar Designs, Pittsburg, USA). The column was filled with 2.4 g of jackfruit leaves. The temperature and pressures selected for the extraction were 323 K at 15, 20, 25 and 30 MPa. Carbon dioxide (99.5% purity, Gama Gases Especiais, São Paulo, Brazil) was admitted in the system at 8.33×10^{-5} kg/s. The extraction time was 2 h.

Economical Evaluation

The estimation of cost of manufacturing (COM) of the extracts obtained by SFE and LPSE was carried out using the simulation software SuperPro Designer 6.0 ®. The main costs that compose the COM are given by total capital investment and operating cost. The total capital investment cost represents the direct fixed capital, working capital and start-up cost. The first one involves expenses with equipments, installation, territorial taxes, engineering, etc., while the second one represents operating liquidity available to a business, and finally, the start-up cost is associated with the beginning and validation of the process. The operating cost represents direct costs and is directly dependent on the production rate; it is composed by the costs of raw materials, utilities, operating labor and so on. In this way, the estimated COM is related to those costs and the annual production of the extract supplied by the software.

In order to estimate the COM it is important to know the yield for a determined extraction time. The scale up procedure assumed that the industrial scale unit has the same performance as the laboratorial scale unit, if the ratio between the mass of solid and solvent are kept constant, as well as particle size and bed density. The process is designed to run 7920-h per year, which corresponds to 330 days per year of continuous 24-h per day shift. The commercialization price of jackfruit leaves is US$ 4.20/kg (Superextra, São Paulo, Brazil).

LPSE Process

For the LPSE process it was considered a two extractor vessels unit. The extraction procedure consists in placing a known mass of jackfruit leaves immersed in a known volume of solvent inside an agitated tank. Besides the vessels, the industrial unit is composed by two storage tanks, one for the extraction solution and other one for the recycled solvent, a centrifugal pump, a multiple effects evaporator and a condenser.

The vegetable material's true density was 1225.8 kg/m^3. The scale-up was done to a 0.4 m^3 extraction vessel, and the amount of raw material used per industrial batch was 37 kg immersed in 290.65 kg of ethanol. The specific cost of ethanol is US$ 0.65/kg .The yields and operational conditions used were the same as the laboratorial scale.

SFE Process

The study of COM for the SFE process was carried out using as industrial unit an equipment with two columns of 0.4 m^3 each, operated in a semi continuous way, 330 days per year full timed over three shifts. Three operators per shift are needed at a labor cost of US$ 3.00/h. The bed density was 365 kg/m^3, the temperature of the vessel was 323 K and the total extraction time was 120 min. The solvent CO_2 cost was considered US$ 0.10/kg.

RESULTS

LPSE

Figure 1 presents the variation of COM with the yields of the overall extraction curve (OEC) of jackfruit leaves PLSE. The maximum yield was 5.51% at 313 K and 7.24 % at 323 K. The COM ranged from US$ 268.91 to US$ 183.22 for 313 K and from US$ 219.00 to US$ 145.28 for 323 K.

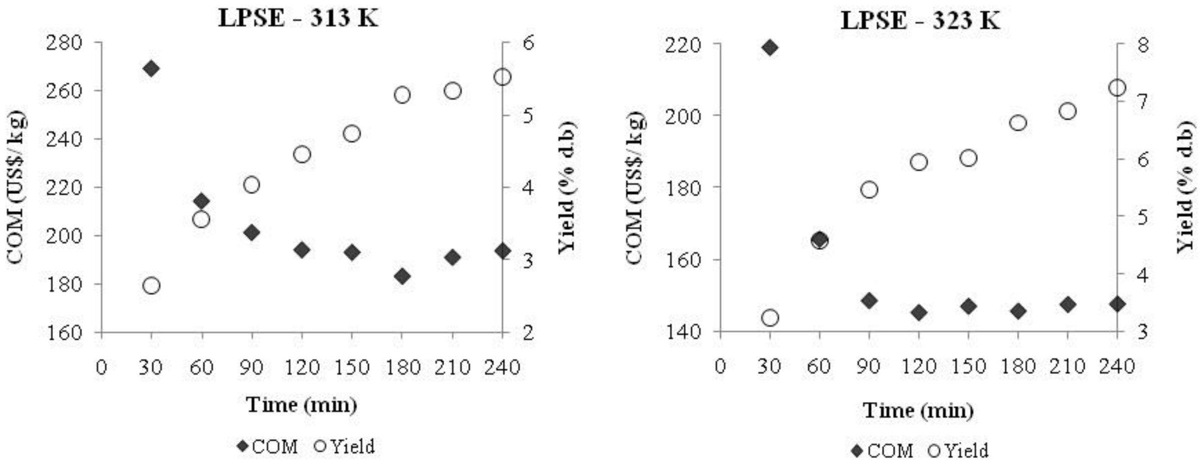

Figure 1: Impact of extraction time and temperature on the cost manufacturing of jackfruit leaves by LPSE.

It can be observed that COM is inversely proportional to yield up to 120 min of extraction. When short extraction times are used, the extraction bed is not efficiently exhausted, leading to low yield and high COM. The behavior observed of increase in COM for both temperatures after 120 min is due to the small increase in yield with large increase of batch time. This way, the number of cycles per year decreases significantly with a small increase in productivity, leading to increased COM.

The number of annual cycles is inversely proportional to the cycle time, thus, a short batch leads to a high number of cycles and therefore a high annual operational cost because of the demand of raw material and utilities. Therefore, the lowest COM as a function of longer cycles is directly related to the reduction of operational cost and the amount of extract produced annually.

Comparing the kinetic behavior of the two temperatures, it can be seen on Figure 1 that a higher yield was obtained at 323 K, presenting lower COM. The lowest COM at this temperature was at 120 min (US$ 145.28/kg), with 5.94% of yield. At this point the operating cost composition was 48.40% of raw material, 27.83% of utilities and 11.28% of operational labor. The total capital investment was US$ 1,041,000, where 80% correspond to the direct fixed capital, 9.5% correspond to the working capital and 10.5% correspond to the start-up cost. The depreciation was calculated over a 10-year period. The number of cycles estimated was 1939 batches per year and the total man-hour per operational-hour needed was approximately 4, according to Peters et al. [17], including personnel costs except for those which were part of the cost of laboratory, quality control, and quality assurance.

SFE

Figure 2 shows the global yield and the COM of jackfruit leaves extract for an industrial SFE unit. It is possible to verify a considerable decrease (24.67%) in the COM at the pressure of 25 MPa, where the yield raises 32.76 % when compared to extraction at 15 MPa. The lowest COM was observed at the pressure of 30 MPa (US$ 320.05/kg).

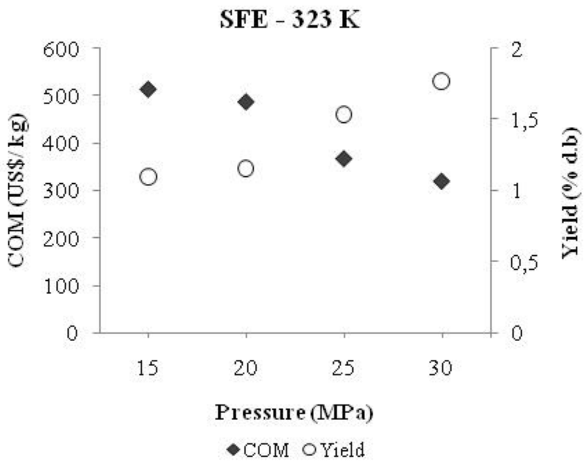

Figure 2: Global yield and COM of jackfruit leaves extract for SFE industrial process with 30.5 kg min^{-1} solvent flow rate at 323 K.

Comparing LPSE and SFE, it can be seen that LPSE presents lowest COM due to higher yields. For 120 min, COM was US$ 145.28/kg (5.94% of yield) and US$ 320.05/kg (1.77% of yield) for LPSE and SFE, respectively. Therefore, considering only yields, LPSE is pointed as the best method for obtaining jackfruit leaves extract, presenting a COM 45.3% lower when compared to SFE. However, it is important to remember that the yield is not the only factor that should be evaluated when an extraction method is considered for a determined raw material. The chemical composition of the extract is also important, since it is directly related to the product quality. Thus, the determination of the chemical composition focused on the target compounds could help in a more accurate comparison between processes, considering both productivity and quality.

CONCLUSION

Low pressure solvent extraction was found as a better alternative for processing jackfruit leaves than supercritical fluid extraction due to higher yield (7.2% against 1.8%) and low cost of manufacturing (US$ 145.28/kg against US$ 320.05/kg). However, chemical composition data should be also evaluated in order to consider productivity and quality of the product extracted by different methods.

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