Contents lists available at ScienceDirect

Food and Bioproducts Processing

journal homepage: www.elsevier.com/locate/fbp

Techno-economic evaluation of obtaining Brazilian ginseng extracts in potential production scenarios

*Renata Vardanega**, *Pedro I.N. Carvalho, Juliana Q. Albarelli, Diego T. Santos, M. Angela A. Meireles*

LASEFI/DEA/FEA (School of Food Engineering)/UNICAMP (University of Campinas) Cidade Universitária "Zeferino Vaz", Rua Monteiro Lobato, 80, 13083-862 Campinas, SP, Brazil

ARTICLE INFO

Article history:
Received 15 June 2016
Received in revised form 14 October 2016
Accepted 17 October 2016
Available online 25 October 2016

Keywords:
Process intensification
Financial ratios
Pfaffia glomerata
Beta-ecdysone
Economic evaluation
SWOT analysis

ABSTRACT

Brazilian ginseng extracts are considered as functional ingredients to promote health benefits due to its bioactive properties. The present study aims at studying a two-step intensified extraction process that operates at ambient pressure in order to recover Brazilian ginseng roots bioactive compounds. The intensified process consists in a sequential extraction system using ethanol followed by water, envisioning the improvement of the overall extraction yield of the process to make it feasible. A technical-economic analysis of the proposed process was assessed through the use of computational simulation tools. The intensified process was compared to a simple extraction process using only ethanol or water as extracting solvents. The results showed that the lowest payback time for the investment is achieved not by minimizing process cost but at maximizing beta-ecdysone production. Economic performance indicators of income statement and profitability ratios showed that, even with higher investment cost, the intensified process presented higher economic attractiveness than the single step extraction processes using ethanol or water.

1. Introduction

Brazilian ginseng (*Pfaffia glomerata*) is a plant native from the countries of South America, especially of some states of Brazil, such as São Paulo, Paraná, Mato Grosso and Goiás. It is used commercially as a substitute for Asian ginseng (*Panax* ssp.) due to its similar pharmacological effects (Freitas et al., 2003; Serra et al., 2012). The Brazilian ginseng roots (BGR) are traditionally used in folk medicine as anti-inflammatory, analgesic, tonic, aphrodisiac, anti-diabetic and antiulcer-gastric, with a number of studies demonstrating its effectiveness (Alvim et al., 1999; de-Paris et al., 2000; Freitas et al., 2004; Neto et al., 2005; Sanches et al., 2001).

Due to the reported bioactive activities of BGR products, it can be considered as a functional ingredient to promote health benefits. In fact, BGR powdered and its extract, which are sold as capsules or tablets, have been used as nutritional supplement even for athletes to assist them in their training and development due to its adaptogen effect, i.e., promotes endurance and help the body to adapt to external stresses. BGR products are also indicated for women's health to promote some benefits such as improving the hormone balance (Oshima and Gu, 2003) and protecting the skin against the aging process (Eberlin et al., 2009). These effects of BGR are mainly attributed to the presence of the steroid beta-ecdysone among their bioactive compounds (Gomes et al., 2010; Zimmer et al., 2006).

Until this moment, beta-ecdysone rich-extracts are considered the main commercial product obtained from BGR. However, recent studies demonstrated that BGR extracts contain also saponins that can act as natural surfactant for obtaining emulsions containing essential oils, such as clove oil (Santos et al., 2013) and annatto seed oil (Rosa et al., 2016). Furthermore, Caleffi et al. (2015) reported that BGR contain an important fraction of inulin-type polysaccharides, which presented a potential prebiotic effect. Based on these aspects, some efforts have been done to develop green processes focused on obtaining BGR extracts rich in beta-ecdysone as well as saponins (Bitencourt et al., 2014; Debien et al., 2015; Leal et al., 2010; Vardanega et al., 2014). Although high-pressure extraction processes are recognized as more selective, it was observed that the use of high pressure during the extraction process was not necessary for obtaining bioactive compounds from BGR (Vardanega et al., 2017).

The current market demands not only high quality products, but also processes that have competitive costs. Recent studies demonstrated that the use of integrated and intensified processes were able

---

* *Corresponding author*.
E-mail address: renatavardanega@gmail.com (R. Vardanega).
http://dx.doi.org/10.1016/j.fbp.2016.10.010

to reduce the costs of manufacturing (COM) of curcuminoids obtained from turmeric (Osorio-Tobón et al., 2014) as well as the volatile oil and terpenoids from rosemary (Zabot et al., 2015). In this context, the present paper aims at evaluating a two-step intensified extraction process that operates at ambient pressure in order to recover BGR bioactive compounds. In this intensified process, the first step consists in an ethanolic extraction to obtain high beta-ecdysone and saponins content and a second extraction step using water. In the second extraction, an aqueous extract is obtained which allowed the extraction of the remained bioactive compounds of BGR that could not be extracted with ethanol, improving the overall extraction yield of the process. The process was evaluated using simulation tools and compared to the processes using only ethanol or water as extracting solvents. The process was analyzed from an economic point of view in order to establish the best extraction process to obtain bioactive compounds from BGR.

2. Material and methods

2.1. *Description of the proposed process for valorization of extracts from Brazilian ginseng roots*

In the present study, the extraction of bioactive compounds from Brazilian ginseng roots (BGR) using low pressure was evaluated. The required mass and energy balances of the processes were estimated by the commercial simulator SuperPro Designer® version 8.5 (Intelligen Inc., Scotch Plains, USA).

Three different operational scenarios were suggested: Scenario I represents the process carried out using only ethanol as extracting solvent producing an ethanolic extract; Scenario II represents the process carried out using only water as solvent producing an aqueous extract; and Scenario III represents the intensified process carried out in a sequential two steps mode using both ethanol and water as extracting solvents, respectively, producing two products: an ethanolic extract and an aqueous extract. The processes layout proposed for each operational scenario is presented in Fig. 1. Gantt charts are also provided to illustrate the start and finish of each operation for the proposed production scenarios (Fig. 2).

For the BGR a preparation step of the material was needed in which the roots were cleaned, air dried and milled. This preprocessing unit was not simulated and a cost of 40.00 US$/ton of raw material was assumed (Veggi et al., 2014). The prepared roots were then sent to a low-pressure solvent extraction process.

For both Scenarios I and II, the extraction reactor consisted in a single batch reactor in which the solvent, ethanol or water, was pumped at the desired proportions and temperature. In Scenario III, at first, the extraction using ethanol as solvent was carried out until reach the pre-determined solvent to feed ratio (S/F), then the ethanol stream was closed and the extracted raw material remained in the extractor to start the second step by opening the water stream. In all scenarios, the extracting temperature was fixed at 333 K. As, in general, the raw materials used for obtaining bioactive compounds are not commodities and farmed in small quantities, manufacturing plants with too big capacity are not mandatory needed and it is recommended to start with extractors of 10–100 L, and if necessary, increase the capacity by adding more extractors (Zabot et al., 2015). Based on this, extractors with capacity of 50 L were used in this study.

After extraction, the used solvent was separated from the extracted compounds by evaporation and recycled to the process. When ethanol was used as solvent, a distillation column operating at 0.1 MPa and 13.85 stages was considered. For water recuperation and recycling, it was needed an evaporator to concentrate the aqueous extract until 60% of moisture and then a spray-dryer to obtain the dried extract (Santos et al., 2012). The recycling system counts with losses of solvent mainly in the evaporation equipment, therefore, up to 98% of ethanol and 97% of water was recovered and recycled.

The extraction process was modeled based on experimental results performed by the authors (Vardanega et al., 2017). To obtain yields in industrial scale, it was assumed that for a given process time, the extraction behavior has the same performance as that obtained experimentally in the laboratory scale unit when the solvent to feed mass ratio and operating parameters (temperature, pressure, density and porosity) are kept constant. The operational conditions admitted are shown in Table 1.

2.2. *Strengths–Weaknesses–Opportunities–Threats (SWOT) matrix evaluation*

Usually, the first step in the evaluation of any project should be the analysis of the Strengths–Weaknesses–Opportunities–Threats (SWOT) matrix. The SWOT analysis is a structured planning method used to take the information from an objective of the business venture or project and separate it into internal (strengths and weaknesses) and external issues (opportunities and threats). As a whole, the evaluation of the SWOT matrix determines what may assist the company in accomplishing its objectives, and what obstacles must be overcome for the project to become feasible. If the conclusion of the SWOT analysis is positive, the following steps comprises the detailed economic evaluation of the process (Fernández-Ronco et al., 2013).

2.3. *Technical-economic evaluation*

From the data obtained in the simulations it was possible to determine the beta-ecdysone productivity, which represents the total amount of beta-ecdysone produced per year (Eq. (1)).

$$\text{BEP} = \text{EY} \times \text{BEC} \times \text{number of batches} \tag{1}$$

where BEP is the beta-ecdysone productivity, EY is the extraction yield (Eq. (2)), BEC is the beta-ecdysone concentration in the extract (Eq. (3)) and number of batches is the number of batches carried out in a year.

$$\text{EY} = \text{mass of dry extract}/\text{mass of dry raw material} \tag{2}$$

$$\text{BEC} = \text{mass of beta-ecdysone}/\text{mass of dry extract} \tag{3}$$

The economic analysis firstly evaluated the total capital investment of each scenario and the operating costs. The total capital investment refers to the fixed costs that are associated with the process and includes the direct fixed capital, working capital and startup costs. Direct fixed capital (DFC) represents the fixed assets of the project, such as plant and equipment and it is calculated as the sum of direct, indirect and miscellaneous costs that are associated with a plant's capital investment. The direct cost includes cost elements that are directly related to an investment, such as cost of equipment, process piping, instrumentation, buildings, facilities, etc. The indirect cost includes costs that are indirectly related to an investment, such as costs of engineering and construction. Additional costs such as the contractor's fee and contingencies are included in the miscellaneous costs. By default, the