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Simulation of an Integrated Sustainable Production of Extract from Brazilian Ginseng Roots with a Cogeneration Plant

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Pfaffia glomerata, which is so-called as Brazilian ginseng, is widely cultivated in South American countries such as Brazil, Ecuador, and Panama. The roots of this plant are used as a Brazilian folk medicine as tonic and for the treatment of diabetes. Since the extract from the roots of *P. glomerata* has been reported to possess similar effects to ginseng (Panax spp.), large amounts of this plant material are being exported to Japan for production of their extracts. Taking into account the important economical role of adding value to Brazilian ginseng roots in Brazil this study was done. SuperPro Designer 6.0® was used to develop an energetically viable scheme for the production of dry Brazilian ginseng roots extract. Pressurized liquid extraction (PLE) using water as extracting solvent followed by concentration and spray drying steps were employed to produce dry extracts. Additionally, the use of the solid residue from the proposed extraction process as a fuel to produce electricity and steam to fulfill the energetic requirements of the dry extract production process was evaluated. An overall process-yield of approximately 25.6 % employing the experimental extraction yield obtained of 40.5 % w.b. was estimated, which corresponds to 92.1 t of dry Brazilian ginseng roots extract produced per year and to 124.7 t of residue employing 360 t of fresh raw material. Since the utilization of only the residue from extraction (roots previously extracted) showed not to be attractive, the use of the aerial parts also as fuel was also evaluated. It was determined that an amount of 49.3 % of the total amount of aerial parts left in the field during the harvest of the roots is necessary to fulfill the energy requirements of the dry extract production for the proposed process. A moderate pay-back time of 3 years and 9 months to recover the cost of investment (US$ 117,694.44) was obtained for the installation of a cogeneration plant.

1. Introduction

The use of pressurized liquid extraction (PLE) is an attractive alternative for obtaining extracts because it allows for fast extraction and reduced solvent consumption. Sometimes referred to as pressurized solvent extraction (PSE) and accelerated solvent extraction (ASE), PLE has been successfully used for the extraction of bioactive compounds from various plants (Petersson et al., 2010).
The recognition of the efficiency of PLE coupled with the additional advantages offered by the use of water as an environmentally friendly solvent has prompted researchers to investigate the potential of PLE for industrial-scale extraction of natural products (Guçlu-Ustundag and Mazza, 2007).

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Species of the genus Pfaffia (Amaranthaceae) are commercialized in Brazil as substitutes for Panax spp. (ginseng, Araliaceae). Due to the similar morphology of its roots to those of ginseng, they are popularly known as “Brazilian ginseng”. Around 90 species of Pfaffia are known in Central and South America (Zimmer et al., 2006). In Brazil, 27 species have been described, being *Pfaffia glomerata* the most important specie. Since besides similarity in appearance Brazilian ginseng roots (*Pfaffia glomerata*) extracts have also similar effects to ginseng, large amounts (approximately 30 t monthly) of this plant material are being exported to Japan for production of their extracts (Gomes et al., 2006).
Taking into account the important economical role in Brazil of adding value to Brazilian ginseng roots this study was done. SuperPro Designer 6.0®, a commercial process simulation tool, was used to develop an energetically viable scheme for the production of dry Brazilian ginseng roots extract. Pressurized liquid extraction (PLE) using water as extraction solvent followed by concentration and spray drying steps were employed to produce dry extracts. Additionally, the use of the solid residue from the proposed extraction process as a fuel to produce electricity and steam to fulfill its own energetic requirements was also evaluated.

2. Material and methods

2.1 Plant material

Brazilian ginseng roots (*Pffafia glomerata*) were cultivated in the experimental field of CPQBA (Campinas, Brazil), where they were collected on March 25, 2004, being 3 years old. They were washed and dried in a forced air circulation dryer at 40 °C for 5 days. The dried roots (7.0 % moisture) were then comminuted in a pulse mill (Marconi, model MA 340, Piracicaba, Brazil) for few seconds. Next, the particles of higher size were milled again, this time using a knife mill (Tecnal, model TE 631, Piracicaba, Brazil) for 2 s at 18,000 rpm and finally, they were separated according to their size using sieves (Series Tyler, W.S. Tyler, Wheeling, USA). The milled roots were stored in freezer (Metalfrio, model DA 420, São Paulo, Brazil) at -10 °C.

2.2 Pressurized liquid extraction (PLE)

The pressurized liquid extraction laboratory-scale setup is shown in Figure 1. The solvent was pumped by a HPLC pump (Thermoseparation Products, Model ConstaMetric 3200 P/F, Fremoni, USA) into the extraction cell, which was placed in an electrical heating jacket at a desired temperature, until the required pressure was obtained. All connections within the system were made using stainless steel tubes (1/16” and 1/8”).

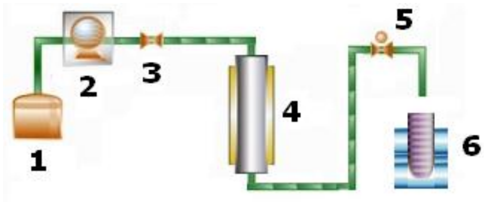

Figure 1: Diagram of the laboratory-scale system used for the pressurized liquid extraction. 1- Solvent reservoir; 2- Solvent pump; 3-Blocking valve; 4- Extraction cell; 5-Back pressure regulator valve; 6-Collecting flask.

Dried pieces of Brazilian ginseng roots (4.5 g) were placed in a 6.57 cm^3 extraction cell (Thar Designs, Pittsburg, USA) containing a sintered metal filter at the bottom and upper parts. The cell containing the sample was heated, filled with extraction solvent (distilled water) and then pressurized. The sample was placed in the heating system for 6 min to ensure that the extraction cell would be at the desired temperature (60 °C) during the filling and pressurization procedure. After pressurization, the sample with pressurized solvent was kept statically at the desired pressure (12 MPa) for the desired time (4 min). Thereafter, the back pressure regulator (BPR) valve (Tescom, 26-1761-24-161, ELK River, USA) was carefully opened, keeping the pressure at an appropriate level for the desired flow (1.4 cm^3/min), to rinse the extraction cell with fresh extracting solvent for 14 min (dynamic extraction time). After PLE, the extracts were rapidly cooled to -5 °C in ice water using glass flasks to prevent extract degradation.

2.3 Drying of aqueous extract

The aqueous extracts obtained by PLE were frozen in and afterwards freeze-dried for 5 days at 60-100 µHg and at -50°C (Liobras, Liotop L101, São Carlos, Brazil).

2.4 Dry extract production simulation

To simulate the production of dry extract from Brazilian ginseng roots (*Pfaffia glomerata*), SuperPro Designer 6.0® was used. This software allows for mass and energy balance estimation for all streams of the process. The PLE process developed in Figure 2 consists of a solvent storage tank (water), pump, two extractors (while one of the vessels is under operation, the other goes through the cleaning and recharging processes) that operate semi-continuously, two heat transfers, a valve, an evaporator and a spray dryer. The extraction procedure consists placing a known mass of Brazilian ginseng roots dried and grinded in contact with pressured water. The PLE process designed was performed with a static extraction step before beginning the dynamic extraction step.

The process was designed to run 7920 h per year, which corresponds to 330 days per year of continuous 24-h-per-day shifts. It was assumed that all of the estimated amount exported from Brazil (360 t per year - moisture content of 67 %, which is changed to 231.79 t per year – moisture content of 7 % after drying and grinding) could be used and that the industrial-scale unit has the same performance as the laboratory-scale unit when the ratio between the mass of solid and solvent and the operating conditions are kept constant.

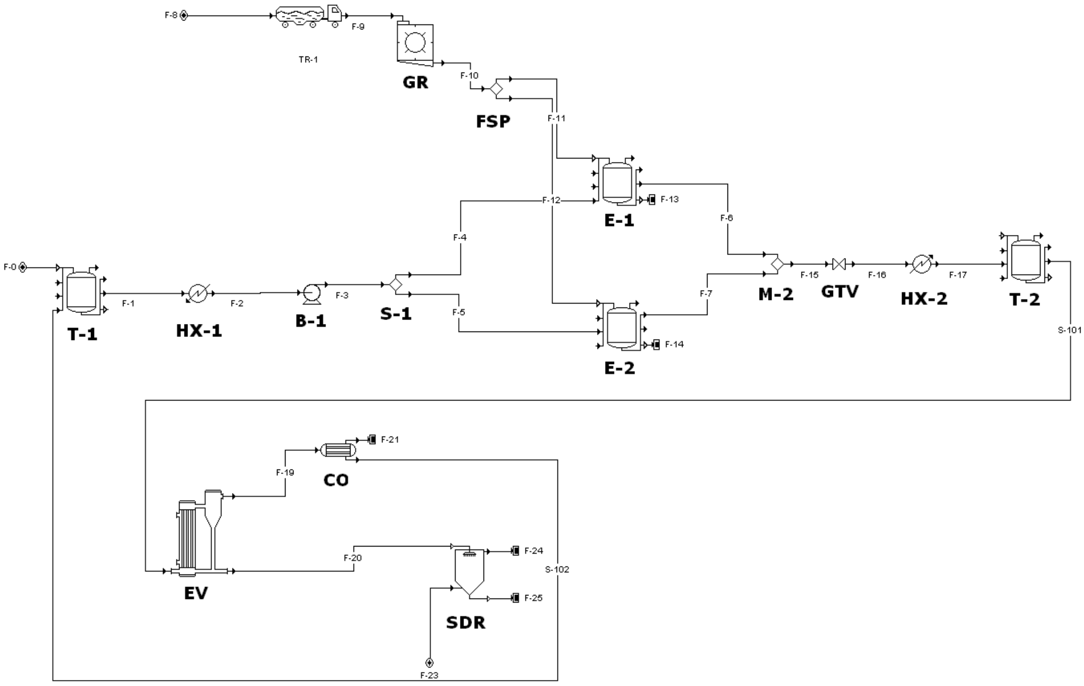

Figure 2: Scheme for the production of dry Brazilian ginseng roots extract developed in SuperPro Designer®.T-1- Receiver Tank; E-1- Receiver Tank; E-2- Receiver Tank; B-1- Centrifugal Pump; S-1- Flow Splitter; M-2- Mixer; T-2- Receiver Tank; SDR- Spray Dryer; EV - Evaporator; CO- Condenser; GR- Grinder; FSP- Flow Splitter; HX-1- Heat Exchanger; GTV- Gate Valve; HX-2- Heat Exchanger.

A double effect forward feed evaporator to concentrate the aqueous extract prior to the spray dryer was placed due two reasons: i) to the reduction of volume in the Brazilian ginseng roots aqueous extract and consequently to the reduction of the process time for the spray drying operation; ii) to the easiness of reuse in the following batch the water from evaporator condensate compared to that originated from spray dryer output.

Evaporator is used to increase the concentration of the extract, by removing 80 % of the water on an evaporator tower, which are reused in the extraction process. Ambient air is heated to 170 °C before it is fed into the spray dryer as the drying medium. Hot air and evaporated water vapor is emitted from the top stream of equipment while Brazilian ginseng roots extract powder at the bottom stream at 70 °C. It is assumed that 1 % of the extract is lost together with the emitted air. The water eliminated by spray drying was considered as water lost during the process.

2.5 Cogeneration plant simulation

Since residue is produced simultaneously to the extract, the utilization of this waste was studied as a fuel for the production of electricity and steam to fulfill the energetic requirements of the dry extract production process proposed. Certain quantity of the solvent (water) is absorbed in the discharged solid and this is taken as process losses. The assumed moisture content of this solid residue was 15 %. The low heating value (LHV) of this residue considered in this analysis was measured experimentally using a bomb isoperibolic calorimeter.

The cogeneration system studied operates as a steam cycle-based with a conventional steam generator. A back-pressure steam turbine connects the steam generator to the industrial process, supplying saturated steam at 0.7 MPa and producing electricity. The cogeneration system will be used to supply energy to the production of dry Brazilian ginseng roots extract. In accordance to the amount of raw material input adopted, the electricity consumption of the extraction plant was estimated using the software SuperPro Designer 6.0®.

The energetic analysis of the cogeneration process was conducted using the modeling proposed by Albarelli et al. (2011) using an electronic spreadsheet, because the unit operations required are not yet available in the simulator’s database. The main equipment efficiencies were assumed to be 85 % for the steam generator, 95 % for the electric generator and 80 % for the pump. The economic analysis was undertaken to evaluate the pay-back period (k) obtained for the installation of a cogeneration plant to fulfill the energetic requirements of the dry extract production process proposed.

3. Results and discussion

Pfaffia extracts used in pharmacological studies are obtained, most of the times, by polar solvent extraction. Methanol, although being a toxic solvent, is the most used one for recovering extracts from Brazilian Ginseng (*Pfaffia glomerata*), as is reported on literature (Shiobara et al., 1993).

Our research group has focused in the development of environmentally friendly processes for extract production from different plant materials, including *Pfaffia glomerata*. An extraction process employing a mixture of carbon dioxide and ethanol under pressure was developed successfully to produce an extract with high concentration of β-ecdysone (Alexandre et al., 2010; Leal et al., 2010). Despite this advantage, the extract production employing this technique is very low since the extraction yield is 0.52 % wet basis, w.b. (77.82-fold lower than that obtained in this study employing pressurized water).

β-ecdysone has been characterized as the principal constituent from the *Pfaffia glomerata* roots, however, recent studies have demonstrated that in this raw material there are more than 10 constituents, which can have even higher biological activity than β-ecdysone (Nakamura et al., 2010). Thus the production of extracts also rich in these other compounds, which can be achieved employing less selective solvents such as water, might be interesting. Since the use of pressurized solvents can improve the efficiency of traditional processes resulting in shorter extraction time and lower solvent consumption (Veggi et al., 2011; Santos et al., 2012), it seems irrefutable the necessity of the use of water under pressure for the production of extract from Brazilian ginseng roots.

Based on the annual operating time of 7920 h and minimum cycle time of 36 min the annual production for the process model was calculated as 13200 batches (in one batch while one of the vessels is under operation, the other goes through the cleaning and recharging processes). This corresponds to 92.08 t of dry Brazilian ginseng roots extract produced per year (overall product yield of 25.58 % employing the experimental extraction yield obtained of 40.53 % w.b.) and to 124.71 t of residue employing 360 t of fresh raw material (the estimated amount exported from Brazil annually). Extraction yield represents the amount of dry extract that was recovered from the processed raw material (dried and milled) at a given extraction operating condition, while overall product yield takes into account the amount of dry extract recovered from the fresh raw material. Table 1 shows the main specifications of the equipments excerpted from the software SuperPro Designer 6.0®, for the proposed dry extract production

(Extraction temperature = 60 °C; Extraction pressure = 12 MPa; Static extraction time = 4 min; Dynamic extraction time = 14 min; Ratio between the mass of solid and solvent = 1:4.44).

Table 1: Equipment specifications for the production of dry Brazilian ginseng roots extract developed in SuperPro Designer®.

Tag ID	Type	Size (Capacity)
T-1	Receiver Tank	24.38 dm^3
E-1	Receiver Tank	15.08 dm^3
E-2	Receiver Tank	15.08 dm^3
B-1	Centrifugal Pump	0.18 kW
S-1	Flow Splitter	36.47 kg/h
M-2	Mixer	36.47 kg/h
T-2	Receiver Tank	26.37 dm^3
SDR	Spray Dryer	72.70 dm^3
EV	Evaporator	0.07 m^2
CO	Condenser	1.26 m^2
GR	Grinder	7.77 kg/h
FSP	Flow Splitter	7.77 kg/h
HX-1	Heat Exchanger	0.01 m^2
GTV	Gate Valve	0.01 cm
HX-2	Heat Exchanger	0.03 m^2

An energy analysis was performed to evaluate the possibility of using the solid residue from the proposed extraction process as a fuel to electricity and steam production in a cogeneration system. The global efficiency obtained was around 85 %, demonstrating the high efficiency of this cogeneration cycle. It was produced more thermal energy than electricity due to the fact that the steam cycle operates chiefly to attend the thermal demand. Even though, analyzing the total energy produced by this system in one year, considering 24 h of work per day and 300 days of work per year, the total electricity produced is 64,471.76 kW.h, employing in the simulation the experimentally measured low heating value (LHV) of 12,500 kJ/kg.

With the recycling of the residue from the extraction process for electricity and steam production in the cogeneration system used the needs of the proposed dry extract production plant could be fulfilled by 59.54 % of total amount of electricity produced. The other 41.5 % surplus electricity might be sold to the local concessionary or to local community. On the other hand, 2.75-fold more steam (1,120.56 t) is necessary to attend the thermal demand requirements.

Since the utilization of the residue from extraction (roots previously extracted) by itself showed not to be attractive, the use of the aerial parts also as fuel was also evaluated. Considering a LHV of 14,900 kJ/kg the estimated amount of aerial parts to fulfill the thermal demand requirements was 292.01 t, which is 49.3 % of the total amount left in the field during the harvest of the roots necessary for the proposed extract production.

Similarly for sugarcane biorefinery, several studies demonstrated that the amount of energy produced by the sugarcane processing plant also is increased significantly when an additional biomass (generally sugarcane trash) is used (Dias et al., 2011, Dias et al., 2012). Sugarcane trash and aerial parts of Brazilian ginseng are not yet transported from the field in Brazil, otherwise this alternative seems promising. On the other hand, some part of these vegetable materials must be left in the field in order to provide weed and diseases control as well as nutrient recycling. Since that, up to 50 % of the sugarcane trash is the recommended amount that must be left in the field (Hassuani et al., 2005), the amount of 51.7 % of aerial parts of *Pfaffia glomerata* not necessary for energy production should also be left in the field.

Indeed, the utilization of the roots previously extracted by PLE with water as solvent along with the unused aerial parts of Brazilian ginseng as fuel showed to be a sustainable attractive option an economic analysis was done. A moderate pay-back time of 3 years and 9 months to recover the cost of investment (US$ 117,694.44) was obtained for the installation of a cogeneration plant to fulfill the energetic requirements of the dry extract production process proposed.

4. Conclusions

An integrated sustainable extract production from Brazilian ginseng roots with a cogeneration plant that uses the residue from extraction (roots previously extracted) along with the unused aerial parts of Brazilian ginseng as fuel was successfully designed. It was estimated that an amount of 49.3 % of the total amount of aerial parts left in the field during the harvest of the roots is necessary to fulfill the energetic requirements of the dry extract production process proposed, which includes pressurized liquid extraction using water as environmentally friendly solvent followed concentration and spray drying steps. Future studies will be done focused on the optimization of all steps during dry extract production.

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References

Albarelli J.Q., Santos D.T., Holanda M.R., 2011, Energetic and economic evaluation of waste glycerol cogeneration in Brazil, Brazilian Journal of Chemical Engineering, 28, 691 – 698, DOI: 10.1590/S0104-66322011000400014.

Alexandre F.C., Meireles M.A.A., Kfouri M.B., Leal P.F., 2010, Processo de extração de substâncias ativas a partir do ginseng brasileiro, PI0900551-0 A2.

Dias M.O.S., Cunha M.P., Jesus C.D.F., Rocha G.J.M., Pradella J.G.C., Rossell C.E.V., Filho R.M., Bonomi A., 2011, Second generation ethanol in Brazil: Can it compete with electricity production?, Bioresource Technology, 102, 8964-8971, DOI: 10.1016/j.biortech.2011.06.098.

Dias M.O.S., Junqueira T.L., Cavalett O., Cunha M.P., Jesus C.D.F., Rossell C.E.V., Filho R.M., Bonomi A., 2012, Integrated versus stand-alone second generation ethanol production from sugarcane bagasse and trash, Bioresource Technology, 103, 152-161, DOI: 10.1016/j.biortech.2011.09.120.

Gomes A.C.M.M., Carneiro R.M.D.G., Ciroto P.A., Cordeiro C.M.T., Mattos J.C., 2006, Resistência de Acessos de *Pfaffia glomerata* a Meloidogyne incógnita Raça 1, Nematologia Brasileira, 30, 189-194.

Guçlu-Ustundag O., Mazza G., 2007, Saponins: properties, applications and processing, Critical Reviews in Food Science and Nutrition, 47, 231-258, DOI: 10.1080/10408390600698197.

Hassuani, S.J., Leal, M.R.L.V., Macedo, I.C. Eds, 2005, Biomass Power Generation – Sugarcane Bagasse and Trash. PNUD-CTC, Piracicaba, Brazil.

Leal P.F., Kfouri M.B., Alexandre F.C., Fagundes F.H.R., Prado J.M., Toyama M.H., Meireles M.A.A., 2010, Brazilian Ginseng extraction via LPSE and SFE: Global yields, extraction kinetics, chemical composition and antioxidant activity, Journal of Supercritical Fluids, 54, 38-45, DOI: 10.1016/j.supflu.2010.03.007.

Petersson, E.V., Liu J., Sjöberg P.J.R., Danielsson R., Turner C., 2010, Pressurized hot water extraction of anthocyanins from red onion: a study on extraction and degradation rates, Analytica Chimica Acta, 663, 27-32, DOI: 10.1016/j.aca.2010.01.023.

Santos D.T., Veggi P.C., Meireles M.A.A., 2012, Optimization and economic evaluation of pressurized liquid extraction of phenolic compounds from jabuticaba skins, Journal of Food Engineering, 108 , 444–452, DOI: 10.1016/j.jfoodeng.2011.08.022.

Shiobara Y., Inoue S.S., Kato K., Nishiguchi Y., Oishi Y., Nishimoto N., Oliveira F., Akisue G., Akisue M.K., Hashimoto G., 1993, A nortriterpenoid, triterpenoids and ecdystereoids from *Pfaffia glomerata*, Phytochemistry ,32, 1527-1530, DOI: 10.1016/0031-9422(93)85172-N.

Veggi P.C., Santos D.T., Meireles M.A.A., 2011, Anthocyanin extraction from Jabuticaba (*Myrciaria cauliflora*) skins by different techniques: economic evaluation, Procedia Food Science, 1 (2011) 1725 – 1731, DOI: 10.1016/j.profoo.2011.09.254.

Zimmer A.R., Bruxel F., Bassani V.L., Gosmann G., 2006, HPLC method for the determination of ecdysterone in extractive solution from *Pfaffia glomerata*, Journal of Pharmaceutical and Biomedical Analysis, 40, 450-453, DOI: 10.1016/j.jpba.2005.07.016.