eISSN 1981-1829

Ciência e Agrotecnologia
Science and Agrotechnology

Composition and potential utilization strategies of by-products from the Brazilian peach palm industry

Composição e potenciais estratégias de utilização dos subprodutos da agroindústria brasileira de pupunha

Matheus Samponi Tucunduva Arantes[1*], Geovana Silva Marques[1], Fabrício Augusto Hansel[2], Patrícia Raquel Silva Zanoni[2], Washington Luiz Esteves Magalhães[2], Vítor Renan da Silva[1], Cristiane Vieira Helm[2]

ABSTRACT

Peach palm (*Bactris gasipaes*) is a native tree from Brazil widely used for obtaining palm heart. Due to the increasing interest in palm heart, plantations are expanding to the Brazilian South and Southeast regions. Peach palm processing generates high amounts of solid wastes, which are inadequately disposed of and have no consolidated use. Proposing potential utilizations for the valorization of these lignocellulosic matrices requires knowing their chemical composition. This work aimed to determine the chemical composition (at mineral, nutritional, and macromolecular levels) of the three by-products (internal sheath, external sheath, and basal portion) generated during the processing of the peach palm, to characterize their semi-volatile compounds, and to compare them to the edible palm heart. The by-products represent 83.6% (w/w) of the biomass in the peach palm processing and have a high dietary fiber content (59.2 - 68.1%). Internal sheath and basal portion showed high protein content (8.40 - 11.8%) according to Brazilian legislation and several bioactive compounds such as myo-inositol and organic acids (succinic, gallic, and linoleic acids), indicating their nutraceutical properties and potential to be used as food additives or ingredients in food formulation. Besides, the external sheath had high cellulose content (39.6%) that could be extracted and applied in material science. All by-products have compounds of interest to the industry and a high potential to be employed in the development of products with higher added value.

Index terms: Waste; *Bactris gasipaes*; bioactive compound; biorefinery.

RESUMO

A pupunha (*Bactris gasipaes*) é uma planta nativa do Brasil amplamente utilizada na obtenção de palmito nas regiões Sul e Sudeste do Brasil. Seu processamento gera altas quantidades de resíduos sólidos, que são descartados inadequadamente e não têm uso consolidado. Propor potenciais utilizações para a valorização destas matrizes lignocelulósicas requer conhecer a composição química de tais materiais, que não foi amplamente apresentada na literatura. Os objetivos do presente trabalho foram determinar a composição química dos três subprodutos gerados no processamento do palmito de pupunha com relação a suas composições mineral, nutricional e macromolecular, caracterizar os compostos semivoláteis de tais materiais, e compará-los ao palmito, a parte comestível da pupunha. Os subprodutos representam 83.6% (m/m) da biomassa processada na agroindústria de pupunha e apresentam um alto teor de fibras alimentares (59.2 - 68.1%). A Bainha Interna e a Parte Basal apresentaram alto teor de proteína (8.40 - 11.8%) de acordo com a legislação brasileira e vários compostos bioativos como mio-inositol e ácidos succínico, gálico e linoleico, indicando suas propriedades nutracêuticas e potencial para uso como aditivos ou ingredientes na formulação de alimentos devido a sua composição nutricional. Ainda, a Bainha Externa apresentou alto teor de celulose (39.6%), que poderia ser extraída e aplicada na área de ciência dos materiais. Todos os subprodutos têm um teor considerável de compostos de interesse para a indústria e um alto potencial para emprego no desenvolvimento de produtos com alto valor agregado.

Termos para indexação: Resíduos; *Bactris gasipaes*; composto bioativo; biorrefinaria.

Agricultural Sciences

Ciênc. Agrotec., 48:e006224, 2024
http://dx.doi.org/10.1590/1413-7054202448006224

Editor: Renato Paiva

[1]Universidade Federal do Paraná/UFPR, Departamento de Engenharia Química, Curitiba, PR, Brasil
[2]Embrapa Florestas, Colombo, PR, Brasil

Corresponding author: matheussamponi@ufpr.br

Received in March 27, 2024 and approved in July 5, 2024

Introduction

Palm heart (PH) is widely consumed around the world and Brazil stands out as one of the largest producers (Fonseca et al., 2020) with an annual average PH production of 4,580 t between the years of 2010 and 2021 (Instituto Brasileiro de Geografia e Estatística - IBGE, 2022). PH can be extracted from different palm trees, such as the *juçara* palm (*Euterpe edulis*) and king palm (*Archontophoenix cunninghamiana*). However, the peach palm (*Bactris gasipaes*) presents several advantages over them, such as precocity (it can be processed sooner than the others), higher quality, and higher productivity (Monteiro et al., 2002). Peach palm is native to the Amazon region and Brazil is the world's largest producer of peach palm products (Santos et al., 2022), which includes fruits (mostly consumed in the North and Northeast regions of Brazil) and palm heart (mostly consumed in Southern Brazil).

2024 | Lavras | Editora UFLA | www.editora.ufla.br | www.scielo.br/cagro

PH from peach palm is generally commercialized *in natura*, minimally processed, or canned (Galdino & Clemente, 2008). Its nutritional composition varies according to environmental factors (e.g., soil and climate) and genetic factors (e.g., lineage and origin). *In natura* PH usually presents high moisture (88.2 – 91.52%), dietary fibers (20.93%, dry basis), and protein (15.2 – 18.70%, dry basis) contents, considerable amounts of reducing sugars (8.03%, dry basis) and ashes (8.47%, dry basis), and low content of lipids (0.45%, dry basis) (Fonseca et al., 2020; Monteiro et al., 2002).

During the processing of peach palm, the stem is cut on the field, and the leaves are removed and left on the soil to promote nutrient cycling. The commercial stem without its leaves (Figure 1a) is taken to the industry, where it is peeled. The PH (Figure 1b) is cut and canned, while the external sheath (ES), internal sheath (IS), and the basal portion (BP) are discarded or underutilized as animal feed (Cabral et al., 2015).

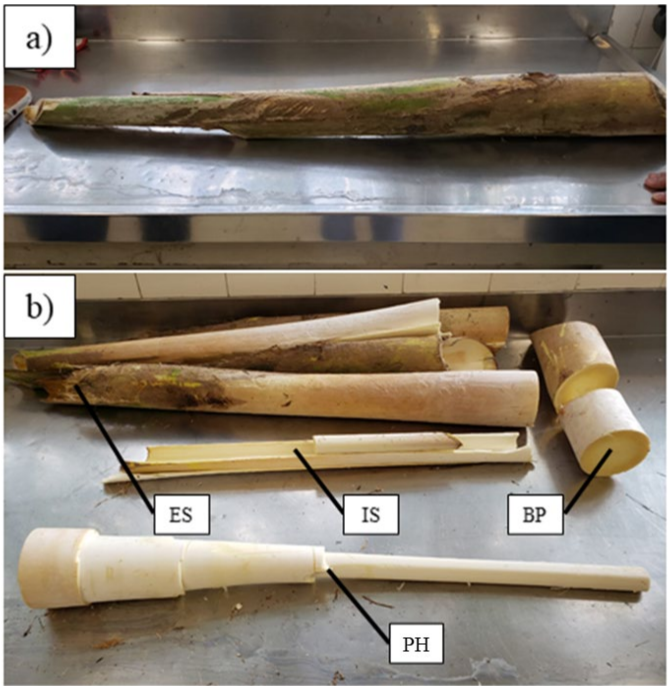

Figure 1: Commercial stem of the peach palm before industrial processing (a); and the processed parts of the peach palm (b): Palm heart (PH), and the by-products external sheath (ES), internal sheath (IS), and basal portion (BP).

The use of these materials, considered solid wastes, is becoming an important matter to the scientific community to adjust the processing of the peach palm within the circular economy concept. Circular economy prioritizes the integral use of raw materials and reduction of waste generation. The by-products of the peach palm industry can be used for developing food products (Andrade et al., 2015; Giombelli et al., 2023; Helm, Raupp, & Santos, 2013), substrates for the cultivation of mushrooms (Lima et al., 2020a; Vargas-Isla et al., 2013; Zenni, Helm, & Tavares, 2018), biomaterials (Sá et al., 2020), for removing pollutants from industrial effluents (Chicatto et al., 2018), and for extracting nanocellulose (Franco et al., 2019) and xylooligosaccharides (Vieira et al., 2021). Although few studies have investigated the nutritional, mineral, and macromolecular compositions of such materials (Bolanho, Danesi, & Beléia, 2013; Bolanho, Danesi, & Beléia, 2014; Franco et al., 2019), there are no reports on the full chemical composition of the semi-volatile compounds of the by-products of the peach palm agribusiness. They may contain important bioactive compounds and provide insights into biorefinery-like approaches for generating valuable products from such matrices.

Therefore, the objective of this work was to quantify the generation of by-products (ES, IS, and BP) in peach palm processing, determine their chemical composition, and compare them to PH to determine potential uses for these materials in the food industry and to develop new products.

Material and Methods

Sample preparation and determination of by-product yield

The by-products yield was determined after processing 10 commercial stems (Figure 1a). PH and the three by-products (Figure 1b) were separated according to the method used in the agribusiness environment, by removing the ES, BP, and IS consecutively. Each part was weighted (C&F P6-MT, Brazil) separately, and their relative contents were calculated.

The materials were ground separately (Trap TRF 300, Brazil), and divided into two parts. One part was dried in an oven at 60 °C with air circulation (FANEM 315 SE, Brazil) for 48 h. The dried materials were ground again in a commercial coffee grinder (Cadence MDR302-127, Brazil) to generate more homogeneous samples. Samples were stored in plastic bags and kept at room temperature (18 – 25 °C) until further analyses. The other part was used to determine the *in natura* moisture according to the gravimetric methodology. Aliquots (triplicates of 5 g) were heated at 105 °C until constant mass (Association of Official Agricultural Chemists - AOAC, 2016).

Nutritional characterization

Nutritional analyses of the dried samples were performed in triplicate, according to AOAC (2016). Moisture and ashes were determined by gravimetric methods after heating 5 g of samples at 105 and 550 °C, respectively, until constant mass. Lipids were extracted in a Soxhlet system using diethyl ether. Proteins were estimated using the micro-Kjeldahl method, multiplying the N content by 6.25. Dietary fibers were determined using the Megazyme's Total Dietary Fiber Assay Kit and the non-fiber carbohydrate content was estimated by the difference of the values previously determined to 100%.

Mineral and elemental characterization

Mineral composition was determined using atomic absorption spectrometry (Perkin Elmer AA200, England). Calcium (Ca) and magnesium (Mg) were determined according to Sarruge and Haag (1974), whereas copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) were quantified based on AOAC (2016). The content of phosphorus (P) was obtained by a titrimetric method (Silva, 1999), and the content of potassium (K) was determined by flame photometry (Quimis Q398M2, Brazil). The elemental composition was obtained using an elemental analyzer (Elementar Vario Micro Cube, Germany) and the C:N ratio was calculated from the carbon and nitrogen contents.

Macromolecular characterization

Macromolecular characterization was performed on the three by-products of the peach palm agribusiness to determine their cellulose and lignin contents. Aliquots (5 g, in triplicate) were extracted using toluene/ethanol (2:1, v/v) in a Soxhlet system for 5 h according to NBR 14853 (Associação Brasileira de Normas Técnicas - ABNT, 2010a) to determine the content of total extractives.

After the extraction, the residual solids were used to determine the Klason lignin (insoluble lignin) content according to NBR 7989 (ABNT, 2010b). The solids were dried at 105 °C and submitted to a two-step hydrolysis with sulfuric acid (15 mL, 72% H_2SO_4 v/v, 20 °C, 2 h; and 575 mL, 2% H_2SO_4 v/v, 4 h, ebullition temperature with reflux). The suspension was left resting overnight, the decanted lignin was filtrated on a previously tared filter, and weighted after drying (105 °C).

The filtrate was recovered, and part of it was used to determine the soluble lignin content using a UV-vis spectrophotometer (Shimadzu UV1800) at 205 nm (Technical Association of the Pulp and Paper Industry - TAPPI, 1991). The total lignin content was calculated by the sum of Klason lignin and soluble lignin contents.

The structural sugar content was determined after injecting the filtered hydrolyzed solution into an ionic chromatographer (Thermo Fisher Scientific ICS-5000, USA). Monosaccharides were separated in a CarboPac PA 20 (guard: 4 mm x 50 mm; column: 4 mm x 250 mm), 25 µL looping, and a flow rate of 0.5 mL/min at 30 °C. The gradient method used was: 1.5 mmol/L NaOH (20 min), followed by a 3 min ramp to 210 mmol/L NaOH, maintained for 10 min, then a 3 min ramp to the original 1.5 mmol/L NaOH, with a waiting time of 26 min before the next injection. Sugars were detected by a gold electrode and were quantified by external curves. Finally, cellulose and hemicellulose contents were determined by the sum of their corresponding carbohydrates (sum of hexoses and sum of pentoses, respectively), according to Franco et al. (2019).

Profile of semi-volatile compounds

The semi-volatile compounds present in the samples were determined according to a semi-quantitative methodology (Lima et al., 2020b), with minor modifications. Aliquots (50 mg in triplicate) were extracted with toluene/ethanol (2:1, v/v), and the extract was separated into hydrophilic and lipophilic phases by adding water. $^{13}C_6$-sorbitol (0.2 mg/mL) and nonadecanoic acid (2 mg/mL) were used as internal standards for the analyses, and the compounds were separated in a DB-5 column (30 m x 0.25 mm x 0.25 µm). The temperatures of the injector and the transfer line were set to 230 and 250 °C, respectively, and the material was eluted with helium (1.5 mL/min). Chromatography analysis started with its oven (Thermo Fisher Scientific Focus GC, USA) at an isotherm of 1 min at 70 °C, followed by a heating ramp of 8 °C/min to 320 °C, and a final isotherm of 5 min. The mass spectrometer (Thermo Fisher Scientific Polaris Q, USA) was operated with a 70 eV electro-impact ionization in a positive mode, and with an ion source temperature of 200 °C. The compounds were identified via the AMDIS software using the reference collection of the Golm Metabolome Database (Hummel et al., 2010) for hydrophilic compounds and a library built in the AMDIS software with the samples analyzed at Embrapa Florestas for lipophilic compounds. Once all metabolites were identified and quantified, the relative content of each compound was calculated using the total metabolite content as a basis.

Statistical analyses

One-way analysis of variance (ANOVA) followed by a post hoc Tukey test using the software Statistica® was performed to determine significant differences among means ($p \leq 0.05$).

Results and Discussion

By-products yield

The yields of the different parts obtained from processing the commercial stem of the peach palm are shown in Table 1. It is important to notice that the yield of the edible part is only 16.4%, whereas most of the biomass is residual waste.

When considering the previously mentioned average production of PH of 4,580 t/year in Brazil in the last years (2010 – 2021) and the results presented in Table 1, an average of 23,344 t of solid wastes with no consolidated use are generated every year in the Brazilian peach palm industry. This highlights the urgent need for using these alternative materials.

Nutritional characterization

The peach palm products have a high *in natura* moisture (82.3 – 90.4%), requiring a fast processing after harvest. The centesimal composition (Table 2) corroborates previous data on the characterization of PH and its by-products. Monteiro et al. (2002) and Fonseca et al. (2020) reported similar *in natura* moisture content of PH (90.1 - 91.5% and 88.2%, respectively). However, levels of protein (12.8 - 18.7%) and total fibers (20.9 - 28.0%) were slightly lower than the ones observed here (Monteiro et al., 2002). Bolanho, Danesi and Beléia (2013), who have focused on the nutritional composition of the peach palm's by-products, reported similar levels of *in natura* moisture (81.3 - 90.7%) and proteins (3.9 - 24.9%), but a slightly higher content of total dietary fibers (48.2 - 82.6%) than the ones reported in this paper. These minor differences may be associated with edaphoclimatic factors.

Table 1: Yield of palm heart and by-products of peach palm processing.

Fraction	Average mass (kg/stem)	Relative content (%)
Commercial stem	3.03 ± 0.70	100
Palm heart	0.50 ± 0.16	16.4 ± 3.3
Internal sheath	0.78 ± 0.36	24.8 ± 8.9
External sheath	1.38 ± 0.43	45.4 ± 9.0
Basal portion	0.38 ± 0.17	13.4 ± 7.1
By-products	2.53 ± 0.58	83.6 ± 3.3

Data are means ± standard deviation (n=10).

PH showed the highest level of protein content, followed by IS, BP, and ES. According to Agência Nacional de Vigilância Sanitária, ANVISA (2012), PH, IS, and BP can be possible sources of proteins (protein contents higher than 6%). Thus, IS and BP can be considered as food ingredients for vegetarian or vegan diets.

All four products had high levels of total dietary fibers (48.3 – 68.1%), responsible for several beneficial effects on human health, such as holding water molecules and assisting and regulating the gastrointestinal system (Elleuch et al., 2011; Gaharwar et al., 2023). The consumption of dietary fibers by humans is also associated with benefits to the metabolism, assisting in digestion and in decreasing blood cholesterol levels, and reducing risks of occurrence of non-transmissible chronic diseases (Helm, Raupp, & Santos, 2013).

The content of dietary fibers in the by-products of the peach palm industryis higher than in several by-products of the food industry used as dietary fibers supplement, such as apple peel (45.4%, dry basis), rice husk (27.0%, dry basis), peach dietary fiber concentrate (30.7%, dry basis), Nori algae (34.7%, dry basis), and passion fruit peel (57.3%, dry basis) (Bettanin et al., 2020; Elleuch et al., 2011; Gaharwar et al., 2023). When added to food formulations, flours rich in dietary fibers increase the water and oil binding, facilitating the integration of the ingredients and improving qualities such as texture and flavor retention (Bolanho, Danesi, & Beléia, 2014; Rayan, Swailam, & Hamed, 2023).

PH, IS, and ES can be considered products with low content of lipids (2.59, 0.93, and 0.84%, respectively) according to ANVISA (2012). This characteristic is interesting when using these materials as ingredients for developing functional foods, especially for low-fat or weight-loss diets, because low levels of lipids result in low caloric value. Differences in lipids content among the by-products have already been reported, with BP having the highest content, followed by IS and ES (Bolanho, Danesi, & Beléia, 2013), corroborating the results observed in the present work.

Non-fiber carbohydrate content was higher in ES and BP (18.5 and 15.7%, dry basis, respectively), followed by IS and PH (8.77 and 6.49%, dry basis, respectively). These results can be associated with the phloems, conductive tubes responsible for the translocation of carbohydrates through the plants and located mainly in the most external parts of the plants (Taiz & Zeiger, 2013). Such carbohydrates are also known as simple carbohydrates and can have small sugars, vitamins, phenolic compounds, and other compounds in their composition (Damodaran, Parkin, & Fennema, 2010), which have applications in food and pharmaceutical industries.

Table 2: Centesimal composition of PH and by-products of the peach palm industry (% w/w, g/100 g).

Fraction	IS	ES	BP	PH
In natura moisture^1	82.3 ± 1.9^b	82.3 ± 0.8^b	88.3 ± 0.9^a	90.4 ± 1.4^a
Moisture^2	7.12 ± 0.08^b	5.96 ± 0.31^c	7.67 ± 0.61^b	8.87 ± 0.38^a
Protein^2	11.8 ± 0.5^b	4.53 ± 0.30^d	8.40 ± 0.52^c	25.6 ± 0.1^a
Total dietary fibers^2	65.9 ± 1.1^a	68.1 ± 1.2^a	59.2 ± 1.8^b	48.3 ± 1.4^c
Ashes^2	5.51 ± 0.05^b	2.10 ± 0.04^c	5.21 ± 0.34^b	8.11 ± 0.89^a
Lipids^2	0.93 ± 0.06^c	0.84 ± 0.29^c	3.88 ± 0.51^a	2.59 ± 0.24^b
Non-fiber carbohydrates^2	8.77 ± 1.74^b	18.5 ± 2.2^a	15.7 ± 3.8^a	6.49 ± 2.93^b

Data are means ± standard deviation (n=3). Significant differences (one-way ANOVA followed by Tukey's test, $p \leq 0.05$) of the evaluated parameters among fractions are shown by letters. *In natura* composition (1), and dry basis composition (2). Internal sheath (IS). External sheath (ES). Basal portion (BP). Palm heart (PH).

Mineral and elemental characterization

Minerals are translocated through the plants in the xylems, conductive tubes located mostly in the internal parts of the plants (Taiz & Zeiger, 2013). Xylem location can be associated with the difference in the concentration of minerals (Table 3) in the different parts of the peach palm. As expected, the internal parts, such as HPH and IS, had a higher content of minerals than BP and ES.

Macro elements represent the minerals that are most required by human metabolism, and considerable contents of phosphorus, potassium, calcium, and magnesium were observed in *B. gasipaes* parts, corroborating previous results reported by Bolanho, Danesi and Beléia (2014). Such minerals are responsible for promoting numerous functions in the human body (e.g., bone formation, synthesis of cells, synthesis of DNA and RNA, enzyme cofactors) (Damodaran, Parkin, & Fennema, 2010). Regarding the micro elements, appreciable contents of copper, iron, manganese, and zinc were observed, which are essential for human health and play several fundamental roles in human metabolism (e.g., oxygen transportation, energetic metabolism, DNA and enzyme synthesis, antioxidant) (Damodaran, Parkin, & Fennema, 2010).

The carbon/nitrogen ratio (Table 3) has been reported as an important parameter in evaluating the potential of biomass in the development of substrates for the cultivation of mushrooms (Lima et al., 2020a; Vargas-Isla et al., 2013). The required C:N content varies according to the mushroom species of interest. ES, for instance, might be an alternative in the formulation of substrates for mushrooms requiring higher C:N contents (up to 40.6), while IS might be used in substrates for the growth of mushrooms requiring lower levels of C:N (up to 11.6).

Additionally, the C:N ratio is an important parameter in evaluating the potential of utilizing biomasses to produce biogas in biodigesters. Martin and Hadiyanto (2018) have reported that, for rice husk, biogas production was the highest at the optimal C:N ratio of 35, a value close to the one observed in ES, which indicates a potential application for this part.

Macromolecular characterization

The macromolecular composition of the by-products (Table 4) indicates that these materials are rich in cellulose (estimated by the sum of the hexoses), hemicellulose (estimated by the sum of the pentoses), and extractives.

The profile of structural sugars is mostly represented by glucose and xylose (35.1 – 39.1% and 18.9 – 22.9%, dry basis, respectively), similar to results obtained by Bolanho, Danesi and Beléia (2015). High glucose contents are expected as cellulose chains, which represent up to one-third of plant dietary fibers (Bolanho, Danesi, & Beléia, 2015), are composed of glucose monomers. Cellulose contents were high in all by-products (39.6 – 43.6%, dry basis). Besides having several benefits to human health, cellulose fibers can be extracted from biomasses and employed in the material science and pharmaceutical industry (e.g., biosorbents, biofilms, drug delivery). High xylose contents are also expected as the peach palm by-products are rich in xylooligosaccharides composed of xyloses (Vieira et al., 2021).

Extractives are chemical compounds with low molecular weight and are responsible for the aroma, color, and flavor of the material. They represent all the compounds extracted with toluene and ethanol, such as proteins, ashes, lipids, and simple carbohydrates. BP presented the highest content of total extractives (35.3%, dry basis), followed by the IS and ES (27.2 and 21.6%, respectively). The values are slightly lower than the 39.8% obtained by Franco et al. (2019), which might be related to differences in factors such as cultivation conditions.

Table 3: Mineral and elemental compositions of the PH and by-products of the peach palm industry (dry basis, w/w).

Fraction	IS	ES	BP	PH
P (g/kg)	4.83 ± 0.15^{b}	1.34 ± 0.16^{d}	3.21 ± 0.04^{c}	9.51 ± 0.23^{a}
K (g/kg)	10.1 ± 1.0^{b}	4.12 ± 0.41^{c}	8.68 ± 1.04^{b}	35.1 ± 1.6^{a}
Ca (g/kg)	2.70 ± 0.40^{b}	1.00 ± 0.29^{c}	0.93 ± 0.09^{c}	5.01 ± 1.11^{a}
Mg (g/kg)	1.98 ± 0.13^{b}	1.05 ± 0.10^{d}	1.72 ± 0.09^{c}	2.80 ± 0.32^{a}
Cu (mg/kg)	15.3 ± 3.3^{ab}	15.0 ± 2.3^{ab}	14.3 ± 1.7^{b}	20.3 ± 3.3^{a}
Fe (mg/kg)	65.7 ± 2.4^{b}	41.7 ± 8.6^{c}	51.0 ± 6.0^{c}	96.7 ± 17.0^{a}
Mn (mg/kg)	30.3 ± 3.5^{b}	22.0 ± 0.0^{c}	13.3 ± 1.7^{d}	49.0 ± 0.0^{a}
Zn (mg/kg)	38.7 ± 0.7^{b}	7.00 ± 1.13^{d}	36.3 ± 0.7^{c}	148 ± 2^{a}
C (%)	43.2 ± 0.1^{b}	44.4 ± 0.1^{a}	43.1 ± 0.1^{b}	37.7 ± 0.4^{c}
N (%)	3.73 ± 0.07^{b}	1.10 ± 0.10^{d}	1.74 ± 0.07^{c}	5.61 ± 0.18^{a}
H (%)	7.84 ± 0.44^{b}	7.88 ± 0.14^{b}	8.05 ± 0.03^{b}	9.97 ± 0.24^{a}
S (%)	0.34 ± 0.05^{a}	0.17 ± 0.02^{c}	0.20 ± 0.01^{c}	0.25 ± 0.02^{b}
C:N	11.6 ± 0.2^{c}	40.6 ± 3.8^{a}	24.8 ± 1.0^{b}	6.74 ± 0.28^{d}

Data are means ± standard deviation (n=3). Significant differences (one-way ANOVA followed by Tukey's test ($p \leq 0.05$) of the evaluated parameters among fractions are shown by letters. Internal sheath (IS). External sheath (ES). Basal portion (BP). Palm heart (PH).

Table 4: Profile of structural sugars and macromolecular composition of the by-products in the peach palm industry (dry basis % w/w, g/100 g).

Fraction	IS	ES	BP
Arabinose[1]	4.23 ± 0.04^{b}	3.86 ± 0.33^{b}	6.24 ± 0.99^{a}
Xylose[1]	20.8 ± 0.2^{a}	18.9 ± 0.6^{a}	22.9 ± 4.0^{a}
Hemicellulose	25.0 ± 0.2^{ab}	22.7 ± 0.9^{b}	29.2 ± 5.0^{a}
Galactose[2]	3.44 ± 0.04^{a}	3.71 ± 1.11^{a}	3.90 ± 0.98^{a}
Glucose[2]	37.0 ± 0.3^{a}	35.1 ± 1.6^{a}	39.1 ± 5.8^{a}
Mannose[2]	0.79 ± 0.02^{a}	0.75 ± 0.12^{ab}	0.64 ± 0.04^{b}
Cellulose	41.2 ± 0.3^{a}	39.6 ± 2.8^{a}	43.6 ± 6.8^{a}
Total extractives	27.2 ± 2.9^{b}	21.6 ± 2.9^{b}	35.3 ± 2.0^{a}
Klason lignin	5.97 ± 0.65^{b}	12.4 ± 0.6^{a}	4.34 ± 1.04^{b}
Soluble lignin	1.73 ± 0.23^{a}	0.76 ± 0.12^{b}	1.53 ± 0.40^{a}
Total lignin	7.70 ± 0.88^{b}	13.1 ± 0.7^{a}	5.87 ± 1.44^{b}

Data are means ± standard deviation (n=3). Significant differences (one-way ANOVA followed by Tukey's test ($p \leq 0.05$) of the evaluated parameters among fractions are shown by letters. Pentoses (1), and Hexoses (2). Internal sheath (IS). External sheath (ES). Basal portion (BP).

Lignin is a macromolecule responsible for stiffness and water permeability in plant tissues (Carvalho et al., 2010), which justifies the higher lignin content in the most external parts. As expected, the lignin content in the ES (13.1%, dry basis) was the highest, followed by the IS and BP (7.70 and 5.87%, dry basis, respectively). High lignin content in the ES is a negative attribute for its use as an ingredient in food formulation since it might confer undesirable characteristics to the products, increasing its stiffness. On the other hand, the lignin present in the ES could be extracted and employed in the material science field as a precursor to surfactants and adhesives or as an antioxidant for plastics and rubbers (Tabasso et al., 2016).

When compared to the main wood biomasses used for obtaining cellulose pulp and lignin in Brazil such as *Eucalyptus sp.* (Pereira et al., 2013) and *Pinus sp.* (Gulsoy & Ozturk, 2015), the peach palm by-products have considerably lower contents of cellulose and lignin, but a higher content of extractives. Such results highlight the importance of knowing the profile of the semi-volatile compounds in *B. gasipaes* parts and proposing utilization strategies for these matrices considering the extraction of these compounds.

Profile of semi-volatile compounds

We have identified 79 hydrophilic and 25 lipophilic compounds (Table 5) in the peach palm products by gas chromatography coupled to mass spectrometry, which were attributed to 19 classes. All samples presented a higher relative content of hydrophilic compounds (77.6 – 95.5%) than lipophilic compounds, associated with the low levels of lipids observed (Table 2). The relative content of the compounds presented in Table 5, obtained via a semi-quantitative methodology, can be associated with the contents determined via quantitative essays, such as the levels of lipids and total extractives.

The relative content of sugars, the class with the highest relative content, presented a similar behavior to the one observed in the estimated content of non-fiber carbohydrates (Table 2): the highest content was found in the ES and BP (65.4 and 71.9%, respectively) and the lowest content in the IS and PH (53.9 and 48.5%, respectively). Specifically, expressing contents of fructose (23.1 – 30.6%), glucose (6.01 – 14.9%), and sucrose (8.21 – 34.5%) were observed. High levels of free sugars, alongside the high *in natura* moisture of the samples, are responsible for the material's high degradability, which implies on the necessity of processing them within a few days after the harvest to avoid the proliferation of microorganisms.

Samples showed a high relative content of sugar alcohols (5.12 – 20.2%), widely present in vegetables and used as additives in the food industry to achieve optimal texture, water activity, and flavor of products (Damodaran, Parkin, & Fennema, 2010). A significant content of myo-inositol was observed (2.69 – 3.54%), a compound related to several biological activities (e.g., facilitating insulin signaling, glucose metabolism, and signal transductions to various hormones) and industrially obtained by chemical or enzymatic synthesis from glucose or starch (Joardar, Duarah, & Purkait, 2023).

We observed considerable relative contents of organic acids in all four samples (3.63 – 5.58%), with particular attention to the succinic acid (1.12 – 2.36%), This compound can be industrially synthesized from petrochemicals or obtained from lignocellulosic biomass and has several industrial applications (e.g., precursor for biodegradable plastics, tetrahydrofuran, aliphatic esters, and food flavoring) (Akhtar et al., 2014; Damodaran, Parkin, & Fennema, 2010). BP and ES presented a significant relative content of lactic acid (1.80 and 1.72%, respectively), which could be extracted and utilized as a precursor for the production of the bioplastic PLA (Swetha et al., 2023). HP and IS presented a significant relative content of shikimic acid (1.22 and 1.26%, respectively), an important metabolic intermediate in the biosynthesis of aromatic amino acids (e.g., phenylalanine) in plants (Damodaran, Parkin, & Fennema, 2010), with uses in the pharmaceutical industry (precursor on anti-influenza drug synthesis), and industrially obtained from the seeds of *Ilicium verum* (Rawat, Tripathi, & Saxena, 2013).

A significant relative content of phenols was observed in the BP and HP (3.37 and 4.13%, respectively), mainly gallic acid, which has several bioactivities (e.g., antioxidant, anti-inflammatory, anti-cancer) (Fernandes & Salgado, 2016; Giombelli et al., 2020) and potential application as an additive in foods or food coats for increasing food shelf-life (Sharma et al., 2022).

Table 5: Relative content of the main hydrophilic and lipophilic semi-volatile compounds identified on PH and by-products of the peach palm industry by GC-MS.

RI	Identity	m/z (1)	m/z (2)	m/z (3)	IS	ES	BP	PH
	Total hydrophilic compounds				78.31	95.49	92.86	77.57
	Amine				3.69	0.58	0.67	0.96
1108.0	Hydroxylamine	249	146	133	0.00	0.01	0.15	0.16
1260.2	Ethanolamine	262	174	100	0.47	0.03	0.22	0.35
1524.2	4-Amino-butanoic acid	304	216	174	3.22	0.54	0.30	0.45
	Amine sugar				0.00	0.00	0.03	0.03
1941.7	2-Amino-2-deoxy-glucose	293	217	203	0.00	0.00	0.03	0.03
	Amino acid				2.76	0.55	5.19	6.28
1265.3	Leucine	232	158	102	0.00	0.00	0.58	0.57
1287.0	Isoleucine	232	218	158	0.32	0.01	0.32	0.36
1292.2	Proline	216	142	73	0.08	0.00	1.26	1.28
1299.6	Glycine	276	248	174	0.13	0.02	0.18	0.23
1352.7	Alanine	290	262	188	0.49	0.29	1.11	1.03
1353.7	Serine	306	218	204	0.05	0.00	0.19	0.21
1378.3	Threonine	320	292	219	0.11	0.00	0.08	0.10
1397.6	Alanine [+CO2]	262	190	160	0.02	0.02	0.00	0.00
1422.2	β-Alanine	290	248	174	0.06	0.01	0.01	0.02
1443.6	Homoserine	292	218	128	0.00	0.00	0.04	0.06
1516.5	Pyroglutamic acid	258	230	156	0.74	0.08	0.27	0.89
1519.6	Cis-4-hydroxy-proline	304	230	156	0.00	0.00	0.01	0.03
1578.1	Proline [+CO2]	288	216	186	0.27	0.09	0.06	0.07
1614.3	Glutamic acid	348	246	230	0.00	0.00	0.10	0.06
1620.7	Phenylalanine	266	218	192	0.00	0.00	0.13	0.34
1663.6	Asparagine	258	231	188	0.00	0.00	0.07	0.11
1766.9	Glutamine	156	203	245	0.00	0.00	0.01	0.05
1933.5	Tyrosine	354	280	218	0.00	0.00	0.06	0.25
1209.7	Valine	218	144	100	0.49	0.03	0.71	0.62
	Aromatic				0.56	0.02	0.05	0.06
1153.0	Benzylalcohol	180	165	135	0.55	0.02	0.05	0.06
1248.7	Benzoic acid	179	135	105	0.01	0.00	0.00	0.00
	Cyclic nitrogen				0.65	0.00	0.62	0.41
1295.0	Nicotinic acid	180	136	106	0.04	0.00	0.03	0.06
1333.1	Uracil	255	241	99	0.48	0.00	0.45	0.34

Continue...

Table 5: Continuation.

RI	Identity	m/z (1)	m/z (2)	m/z (3)	IS	ES	BP	PH
1395.2	Thymine	270	255	239	0.03	0.00	0.14	0.01
2015.7	Xanthine	368	353	294	0.10	0.00	0.00	0.00
	Organic acid				5.55	5.58	3.88	3.63
1053.1	Lactic acid	219	191	147	0.58	1.72	1.80	0.28
1071.2	Glycolic acid	205	177	147	0.08	0.22	0.07	0.06
1140.2	3-Hydroxypropanoic acid	219	177	147	0.16	0.13	0.05	0.13
1310.7	Succinic acid	247	172	147	2.36	1.12	1.36	1.49
1347.8	Fumaric acid	245	217	147	0.16	0.04	0.10	0.15
1482.1	Malic acid	335	245	233	0.77	1.57	0.39	0.25
1566.7	2-Isopropyl-malic acid	377	275	259	0.00	0.01	0.00	0.00
1569.7	2-Hydroxy-glutaric acid	349	247	203	0.10	0.05	0.01	0.02
1595.6	3-Hydroxy-3-methyl-glutaric acid	363	273	247	0.02	0.04	0.00	0.03
1804.8	Shikimic acid	372	282	204	1.26	0.25	0.10	1.22
1811.9	Citric acid	375	273	257	0.04	0.28	0.00	0.00
1987.0	D-Pantothenic-acid	291	247	201	0.02	0.15	0.00	0.00
	Organic nitrogen				0.00	0.00	0.10	0.02
1359.5	2-Piperidinecarboxylic acid	230	156	147	0.00	0.00	0.10	0.02
	Phenol				0.84	0.35	3.37	4.14
1533.6	1,2,3-Triol-benzene	342	239	211	0.00	0.00	0.03	0.03
1545.5	Trans-cinnamic acid	220	205	161	0.00	0.00	0.02	0.05
1624.7	4-Hydroxy-benzoic acid	267	223	193	0.82	0.32	0.06	0.04
1762.0	Vanilic acid	312	297	282	0.02	0.02	0.00	0.00
1948.7	Gallic acid	458	443	281	0.00	0.00	3.26	4.02
1998.5	Guaiacyl glycerol	297	223	209	0.00	0.01	0.00	0.00
	Phosphate				0.39	0.04	1.21	0.22
1265.8	Phosphoric acid	314	299	283	0.39	0.04	1.21	0.22
	Sugar				53.84	65.35	71.87	48.52
1645.6	Xylose	307	277	217	0.02	0.27	0.00	0.00
1651.6	Arabinose	307	277	217	0.08	2.18	0.00	0.00
1654.6	Ribose	307	227	217	0.00	0.00	0.01	0.01
1666.2	Ribulose	263	205	173	0.07	1.87	0.00	0.00
1871.8	Fructose[b]	364	307	217	29.54	30.61	23.10	23.13
1879.0	Galactose	319	217	205	0.86	2.87	0.00	0.00
1902.9	Glucose[b]	319	217	205	12.82	14.92	14.23	6.01
1966.0	D-Glucopyranose	219	205	192	0.00	0.00	0.01	0.01
2623.0	Sucrose	437	361	217	9.98	8.21	34.52	19.36
2714.0	Maltose	361	217	204	0.11	3.17	0.00	0.00
2725.9	D-α,α-trehalose	361	271	217	0.03	1.17	0.00	0.00
3347.0	Raffinose	437	361	217	0.33	0.08	0.00	0.00

Continue...

Table 5: Continuation.

RI	Identity	m/z (1)	m/z (2)	m/z (3)	IS	ES	BP	PH
	Sugar acid				0.16	2.79	0.14	0.13
1323.3	Glyceric acid	292	205	189	0.11	0.12	0.09	0.11
1533.8	Erythronic acid	319	292	220	0.01	0.01	0.05	0.02
1551.1	Threonic acid	319	292	220	0.03	0.03	0.00	0.00
1988.7	Gluconic acid	333	292	204	0.01	2.63	0.00	0.00
	Sugar alcohol				9.87	20.23	5.12	6.49
1267.2	Glycerol	218	205	191	6.00	5.82	0.00	0.00
1498.4	Erythriol	307	217	147	0.13	0.24	0.03	0.07
1693.9	Xylitol	319	217	204	0.09	0.06	0.07	0.10
1708.1	Arabitol	319	307	217	0.32	8.89	0.03	0.04
1713.2	Ribitol	319	307	217	0.18	0.00	0.05	0.08
1915.3	Mannitol	421	319	217	0.09	2.39	1.40	3.51
2080.4	Myo-inositol	318	305	217	3.06	2.83	3.54	2.69
	Unknown hydrophilic				0.00	0.00	0.61	6.68
1409.5	U#01[a]	234	189	144	0.00	0.00	0.00	0.40
1463.7	U#02[a]	334	232	70	0.00	0.00	0.03	0.02
1476.0	U#03[a]	271	199	133	0.00	0.00	0.01	0.01
1501.2	U#04[a]	306	216	102	0.00	0.00	0.11	5.97
1743.3	U#05[a]	231	142	133	0.00	0.00	0.34	0.20
2018.5	U#06[a]	319	217	204	0.00	0.00	0.11	0.05
2488.6	U#07[a]	446	186	217	0.00	0.00	0.01	0.03
	Lipophilic compounds				21.65	4.48	7.16	22.42
	Alcohol				0.07	0.12	0.00	0.00
1958.7	Hexadecanol	299	111	97	0.07	0.12	0.00	0.00
	Carboxylic acid				14.59	2.57	3.32	11.96
1726.8	Tetradecanoic acid	242	199	143	0.44	0.29	0.08	0.15
1901.4	9-(Z)-hexadecenoic acid	268	236	194	0.00	0.00	0.03	0.03
2018.6	Heptadecanoic acid	284	199	143	0.00	0.00	0.05	0.14
2097.7	n-9,12-(Z,Z)-octadecadienoic acid (linoleic acid)	294	262	220	6.15	0.14	1.90	8.32
2104.2	n-9-(Z)-octadecenoic acid (oleic acid)	296	264	222	4.99	0.31	0.93	2.76
2329.8	Eicosanoic acid	326	199	143	0.26	0.18	0.05	0.08
2533.0	Docosanoic acid	354	199	143	0.36	0.18	0.06	0.12
2632.4	Tricosanoic acid	368	199	143	0.32	0.14	0.03	0.06
2731.8	Tetracosanoic acid	382	199	143	1.78	1.09	0.19	0.30
2835.0	Pentacosanoic acid	396	199	143	0.09	0.08	0.00	0.00
2934.8	Hexacosanoic acid	410	199	143	0.20	0.16	0.00	0.00
	Sterol				3.46	0.37	3.39	8.88
3228.1	24-Methyl-cholest-5-en-3β-ol (Campesterol)	382	367	343	0.36	0.05	0.32	0.54
3249.4	24-Ethyl-cholest-5,22-dien-3β-ol (Stigmasterol)	451	394	255	0.22	0.10	0.11	0.20

Continue...

Table 5: Continuation.

RI	Identity	m/z (1)	m/z (2)	m/z (3)	IS	ES	BP	PH
3308.3	24-Ethylcholest-5-en-3β-ol (β-sitosterol)	396	381	357	2.88	0.22	2.96	8.14
	α-Hydroxy acid				3.36	1.25	0.25	0.97
2121.4	2-Hydroxyhexadecanoic acid	343	299	111	0.41	0.12	0.00	0.00
2315.2	2-Hydroxyoctadecanoic acid	371	327	159	0.59	0.18	0.06	0.30
2513.1	2-Hydroxyeicosanoic acid	399	355	159	0.87	0.27	0.06	0.32
2706.1	2-Hydroxydocosanoic acid	427	383	159	0.29	0.10	0.02	0.10
2804.6	2-Hydroxytricosanoic acid	441	397	159	0.00	0.00	0.01	0.02
2905.0	2-Hydroxytetracosanoic acid	455	411	159	1.05	0.47	0.09	0.22
3000.2	2-Hydroxypentacosanoic acid	469	425	159	0.08	0.07	0.01	0.01
3093.5	2-Hydrohexacosanoic acid	483	439	159	0.07	0.04	0.00	0.00
	ω-Hydroxy acid				0.17	0.17	0.00	0.00
3067.0	24-Hydroxytetracosanoic acid	455	423	75	0.17	0.17	0.00	0.00
	Unknown lipophilic				0.00	0.00	0.20	0.61
2837.3	U#08[a]	515	325	263	0.00	0.00	0.20	0.61

Unknown compounds (a), and sum of isomers (b). Retention index (RI). Internal sheath (IS). External sheath (ES). Basal portion (BP). Palm heart (PH).

PH had the highest relative content of amino acids, followed by BP, IS, and ES (6.27, 5.19, 2.75, and 0.56%, respectively). HP and BP presented significant relative content of proline (1.28 and 1.26%, respectively) and alanine (1.03 and 1.11%, respectively), with traces of the essential amino acids valine (0.62 and 0.71%, respectively), leucine (0.57 and 0.58%, respectively), isoleucine (0.36 and 0.32%, respectively), phenylalanine (0.34 and 0.13%, respectively), and threonine (0.10 and 0.08%, respectively). Such results endorse previously conclusions that BP is a suitable food ingredient for use in vegan and vegetarian diets.

Lipophilic metabolites observed in the four parts of the peach palm (4.49 – 22.4%) are mostly represented by carboxylic acids (2.58 – 14.6%), which include the n-9,12-(Z,Z)-octadecadienoic acid (0.14 – 8.32%) known as linoleic acid and having antioxidant activity (Tian et al., 2018); the n-9-(Z)-octadecenoic acid (0.31 – 4.99%) known as oleic acid and presenting several benefits to human health (e.g, decreasing the risk of the development of Alzheimer's disease, heart diseases, and obesity) (Arsic, Stojanovic, & Mikic, 2019); and the tetracosanoic acid (0.19 – 1.78%). We observed a significant content of sterols (0.37 – 8.88%), especially β-sitosterol (0.22 – 8.14%), a phytochemical that supports the regulation of the blood cholesterol levels (Nguyen, 1999); and alsoα-hydroxy acids on the IS (3.36%), with a high relative content of 2-hydroxytetracosanoic acid (1.05%). Considering their benefits to human metabolism, the lipophilic compounds reported could be extracted and employed as antioxidants in cooking oils or in the formulation of pharmaceuticals.

Utilization strategies for the by-products from Brazilian peach palm

As previously mentioned, the IS and BP represent 24.8 and 13.4% of the mass on the *Bactris gasipaes*' commercial steam, respectively. Their composition (high contents of proteins and dietary fibers, and the presence of several bioactive compounds) is interesting for their utilization in the food industry. We formulated two potential utilization strategies for these materials, summarized in Figure 2. The strategies are based on previous works that provided biorefinery perspectives for different by-products obtained from biomasses (e.g., coffee, palm oil, and orange) (Mariana, Alzate, & Ariel 2021; Mora-Villalobos et al., 2023). IS and BP fractions could be dried and ground, resulting in non-gluten flours with bioactive compounds that could be used on special diets for the vegan, vegetarian, or celiac population (Flour A).

Alternatively, these materials could be fractionated following a biorefinery-like process: a water extraction similar to the one reported by Giombelli et al. (2020) for the hydrophilic compounds, such as the sugars, sugar alcohols, organic acids, and phenols observed in the profile of semi-volatile compounds (Table 5). The resulting solid phase, which is represented by the non-soluble compounds on the matrices, would have increased concentrations of dietary fibers, and could be commercialized as non-gluten flours for the supplementation of dietary fibers (Flour B), similar to the fiber concentrate developed by Giombelli et al. (2023).

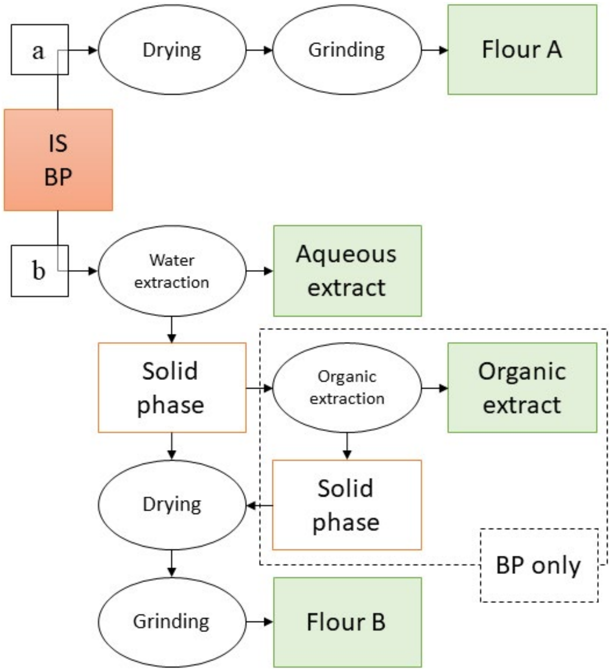

Figure 2: Potential utilization strategies for the internal sheath (IS) and basal portion (BP) from the Brazilian peach palm.

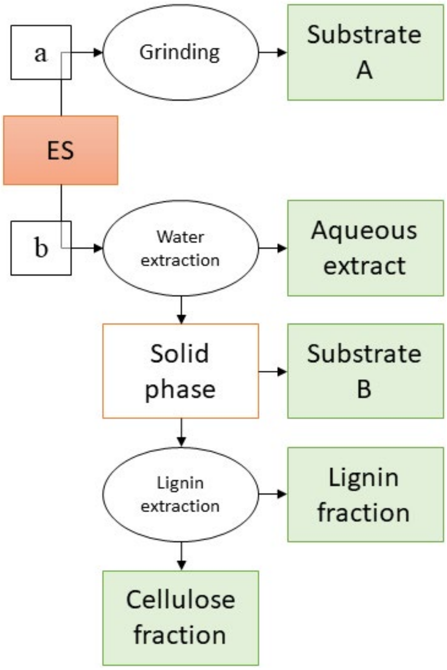

Figure 3: Potential utilization strategies for the external sheath (ES) from the Brazilian peach palm.

Considering its content of lipids (3.88%), an additional organic extraction (using ethyl lactate or ethyl acetate for example) could be performed in the BP. This would enrich lipophilic compounds, such as the carboxylic acids and sterols observed in the profile of semi-volatile compounds.

ES is the material with the highest yield on the *Bactris gasipaes* commercial steam (45.4%), it presents a wood-like appearance and the highest total lignin content (13.1%), being the stiffest material when compared to the IS, BP, and PH. Unlike the other parts, ES is not suitable for use in the food industry after minimal processing, however, it presents potential applications (Figure 3). ES could be employed in the development of substrates for mushroom cultivation due to its high C:N ratio, following methodologies of (Lima et al., 2020a; Vargas-Isla et al., 2013), or, similarly to the IS and BP, a biorefinery-like system can be considered on the use of ES, with an initial hydrophilic compounds extraction, resulting in an aqueous extract rich in sugars, sugar alcohols and organic acids. The resulting solid phase could be employed in developing substrates for the cultivation of mushrooms, or it could be submitted to a lignin extraction methodology (Tabasso et al., 2016) for obtaining lignin-rich and cellulose-rich fractions.

Separation and purification studies on the aqueous and organic extracts obtained in the strategies presented in Figure 2 and 3 should be considered for the development of purified extracts of each major class, which could be commercialized for industrial applications.

Conclusions

The by-products generated during the processing of the peach palm to obtain palm heart represent a large fraction of the commercial steam and have no proper use. These materials have a high content of dietary fibers and cellulose, and several bioactive compounds of commercial interest (e.g., succinic acid and myo-inositol). Therefore, these compounds can be integrally used in biorefinery-like systems, generating products for several industries, reducing solid waste generation and increasing the profit of the peach palm industry.

Author Contribution

Conceptual idea: Arantes, M.S.T.; Silva, V.R.; Helm, C.V.; Methodology design: Hansel, F.A.; Zanoni, P.R.S.; Magalhães, W.L.E., Data collection: Arantes, M.S.T.; Marques, G.S., Data analysis and interpretation: Arantes, M.S.T.; Marques, G.S.; Hansel, F.A., and Writing and editing: Arantes, M.S.T.; Marques, G.S.; Silva, V.R; Helm, C.V.

References

Akhtar, J. et al. (2014). Recent advances in production of succinic acid from lignocellulosic biomass. *Applied Microbiology and Biotechnology*, *98*:987-1000.

Andrade, D. R. M. et al. (2015). Assessment of nano cellulose from peach palm residue as potential food additive: Part II: Preliminary studies. *Journal of Food Science and Technology*, *52*:5641-5650.

Association of Official Agricultural Chemists - AOAC. (2016). *Official Methods of Analysis of AOAC International*. 20ed. Gaithersburg, United States: AOAC. 3750p.

Arsic, A., Stojanovic, A., & Mikic, M. (2019). Oleic acid - Health benefits and status in plasma phospholipids in the Serbian population. *Serbian Journal of Experimental and Clinical Research*, *20*:3-8.

Bettanin, L. L. et al. (2020). Reaproveitamento de resíduos vegetais na indústria de alimentos. *Revista Observatorio de la Economía Latinoamericana*, *18*:1-16.

Bolanho, B. C., Danesi, E. D. G., & Beléia, A. P. (2013). Peach palm (*Bactris gasipaes* kunth) characterization and the potential of by-products flour processing. *Food Science and Technology Research*, *19*:1061-1069.

Bolanho, B. C., Danesi, E. D. G., & Beléia, A. P. (2014). Characterization of flours made from peach palm (*Bactris gasipaes* Kunth) by-products as a new food ingredient. *Journal of Food and Nutrition Research*, *53*.

Bolanho, B. C., Danesi, E. D. G., & Beléia, A. P. (2015). Carbohydrate composition of peach palm (*Bactris gasipaes* Kunth) by-products flours. *Carbohydrate Polymers*, *124*:196-200.

Agência Nacional de Vigilância Sanitária - ANVISA. (2012). *RDC n.54* – Provides for the Technical Regulation on Supplementary Nutritional Information.

Associação Brasileira de Normas Técnicas - ABNT. (2010a). *NBR 14853*: *Madeira - Determinação do material solúvel em etanol-tolueno e em diclorometano e em acetone*. Wood - Determination of soluble matter in ethanol-toluene and in dichloromethane and in acetone. 3p.

Associação Brasileira de Normas Técnicas - ABNT. (2010b). *NBR 7989*: *Pasta celulósica e madeira - Determinação de lignina insolúvel em ácido*. Pulp and wood - Determination of acid-insoluble lignin.

Instituto Brasileiro de Geografia e Estatística - IBGE. (2022). *Produção da Extração Vegetal e da Silvicultura*. Available in: <https://sidra.ibge.gov.br/tabela/289>.

Cabral, Í. S. et al. (2015). Silage or fresh by-product of peach palm as roughage in the feeding of lambs. *Tropical Animal Health and Production*, *47*:525-531.

Carvalho, A. M. et al. (2010). Lignin, hemiceluloses and celulose concentrations of cover plants with potential use in no-tillage systems in Cerrado. *Embrapa Cerrado*, 290:1-15.

Chicatto, J. A. et al. (2018). Decolorization of textile industry wastewater in solid state fermentation with Peach-Palm (*Bactris gasipaes*) residue. *Brazilian Journal of Biology*, *78*(4):718-727.

Damodaran, S., Parkin, K. L., & Fennema, O. R. (2010). *Química de alimentos fennema*. 4ed. Porto Alegre, Brasil: Artmed. 900p.

Elleuch, M. et al. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry*, *124*(2):411-421.

Fernandes, F. H. A., & Salgado, H. R. N. (2016). Gallic acid: Review of the methods of determination and quantification. *Critical Reviews in Analytical Chemistry*, *46*(3):257-265.

Fonseca, G. V. M. et al. (2020). Osmotic dehydration of pupunha palm heart followed by drying as na income alternative for small producers. *Brazilian Journal of Development*, *6*(3):12590-12601.

Franco, T. S. et al. (2019). Nanocellulose obtained from residues of peach palm extraction (*Bactris gasipaes*). *Carbohydrate Polymers*, *218*:8-19.

Gaharwar, S. S. et al. (2023). Valorization of Malus domestica L. (Apple) peels: A case study of circular bioeconomy. *Sustainable Chemistry and Pharmacy*, *36*:101301.

Galdino, N. O., & Clemente, E. (2008). Palmito de pupunha (*Bactris gasipaes* Kunth.) composição mineral e cinética de enzimas oxidativas. *Ciência e Tecnologia de Alimentos*, *28*(3):540-544.

Giombelli, C. et al. (2020). Valorization of peach palm by-product through subcritical water extraction of soluble sugars and phenolic compounds. *The Journal of Supercritical Fluids*, *165*:104985.

Giombelli, C. et al. (2023). Chemical composition and functional properties of dietary fiber concentrates obtained from peach palm by-product. *Journal of the Brazilian Chemical Society*, *34*:927-936.

Gulsoy, S. K., & Ozturk, F. (2015). Kraft pulping properties of European black pine cone. *Maderas. Ciencia y tecnología*, *17*(4):875-882.

Helm, C. V., Raupp, D. D. S., & Santos, Á. F. (2013). Development of peach palm fibrous flour from the waste generated by the heart of palm agribusiness. *Acta Scientiarum. Technology*, *36*(1):171-177.

Hummel, J. et al. (2010). Decision tree supported substructure prediction of metabolites from GC-MS profiles. *Metabolomics*, *6*:322-333.

Joardar, S., Duarah, P., & Purkait, M. K. (2023). Recent advances in myo-inositol recovery and purification from agricultural sources as potential dietary supplements: A review. *Sustainable Chemistry and Pharmacy*, *36*:101331.

Lima, G. G. et al. (2020a). Enzymatic activities and analysis of a mycelium-based composite formation using peach palm (*Bactris gasipaes*) residues on Lentinula edodes. *Bioresources and Bioprocessing*, *7*:58.

Lima, G. G. et al. (2020b). Characterisation and *in vivo* evaluation of *Araucaria angustifolia* pinhão seed coat nanosuspension as a functional food source. *Food & Function*, *11*:9820-9832.

Mariana, O. S., Alzate, C., & Ariel, C. (2021). Comparative environmental life cycle assessment of orange peel waste in present productive chains. *Journal of Cleaner Production*, *322*:128814.

Martin, H. H. A., & Hadiyanto, H. (2018). The influence of microbial consortium and c/n ratio to biogas production from rice husk waste by using solid state anaerobic digestion (SS-AD). *E3S Web of Conferences 73:*01018.

Monteiro, M. A. M. et al. (2002). Chemical study of formulated foods based on dehydrated *Bactris gasipaes* H.B.K. (pupunha). *Food Science and Technology*, *22*(3):211-215.

Mora-Villalobos, J. A. et al. (2023). Tropical agroindustrial biowaste revalorization through integrative biorefineries - review part I: Coffee and palm oil by-products. *Biomass Conversion and Biorefinery*, *13*:1469-1487.

Nguyen, T. T. (1999). The cholesterol-lowering action of plant stanol esters. *The Journal of Nutrition*, *129*(12):2109-2112.

Pereira, B. L. C. et al. (2013). Influence of chemical composition of *Eucalyptus wood* on gravimetric yield and charcoal properties. *BioResource*, *8*(3):4574-4592.

Rawat, G., Tripathi, P., & Saxena, R. K. (2013). Expanding horizons of shikimic acid. *Applied Microbiology and Biotechnology*, *97*:4277-4287.

Rayan, A. M., Swailam, H. M., & Hamed, Y. S. (2023). Composition, structure, and techno-functional characteristics of the flour, protein concentrate, and protein isolate from purslane (*Portulaca oleracea* L.) seeds. *Plant Foods for Human Nutrition*, *78*:117-123.

Sá, F. P. et al. (2020). Peach palm residue compost as substrate for *Bactris gasipaes* self- sustaining seedlings production. *International Journal of Recycling Organic Waste in Agriculture*, *9*:183-192.

Santos, O. V. et al. (2022). White peach palm (*pupunha*) a new *Bactris gasipaes* kunt variety from the Amazon: Nutritional composition, bioactive lipid profile, thermogravimetric and morphological characteristics. *Journal of Food Composition and Analysis*, *112*:104684.

Sarruge, J. R., & Haag, H. P. (1974). *Chemical analysis in plants*. ESALQ, Piracicaba.

Sharma, S. et al. (2022). Active packaging film based on poly lactide-poly (Butylene Adipate-Co-Terephthalate) blends incorporated with tannic acid and gallic acid for the prolonged shelf life of cherry tomato. *Coatings*, *12*(12):1902.

Silva, F. C. (1999). *Manual de análises químicas de solos, plantas e fertilizantes*. Embrapa Informação Tecnológica, Brasília. 320p.

Swetha, T. A. et al. (2023). A review on biodegradable polylactic acid (PLA) production from fermentative food waste - Its applications and degradation. *International Journal of Biological Macromolecules*, *234*:123703.

Tabasso, S. et al. (2016). Microwave-assisted γ-valerolactone production for biomass lignin extraction: a cascade protocol. *Molecules*, *21*(4):413.

Taiz, L., & Zeiger, E. (2013). *Fisiologia vegetal*. 5ed. Porto Alegre, Brasil: Artemed. 954p.

Technical Association of the Pulp and Paper Industry - TAPPI. (1991). *TAPPI UM 250*: Acid-soluble lignin in wood and pulp. Atlanta.

Tian, C. et al. (2018). Chemical compositions, extraction technology, and antioxidant activity of petroleum ether extract from *Abutilon theophrasti* Medic. leaves. *International Journal of Food Properties*, *21*(1):1789-1799.

Vargas-Isla, R. et al. (2013). Production of *Panus strigellus* spawn using the internal sheath of peach palm (*Bactris gasipaes*) as a substrate. *Interciência*, 38(10):733-736.

Vieira, T. F. et al. (2021). Valorization of Peach Palm (*Bactris gasipaes* Kunth) waste: Production of antioxidant xylooligosaccharides. *Waste and Biomass Valorization*, *12*:6727-6740.

Zenni, R. D. S., Helm, C. V., & Tavares, L. B. B. (2018). Cascas do processamento de palmito para uso na alimentação humana: Uma abordagem socioambiental. *Revista Gestão & Sustentabilidade Ambiental, 7*(2):276-299.