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Investigaciones en pecán en Sudamérica

Pecan Nut Sustainable Utilization: The Nutritional and Bioactive Potential of Pecan Shell and Meal

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Abstract

The demand for pecan consumption has been increasing, and consequently, the volume of waste generated from shelling and processing for pecan oil extraction has also grown. This study aimed to characterize the residues resulting from the oil extraction process of the Barton cultivar. For this purpose, pecans from commercial orchards were shelled for oil extraction via pressing. The shells and the cake resulting from the oil extraction were collected. Both the shells and cake were evaluated for their proximal composition and bioactive compounds. The cake showed a composition of 18.62% protein and 17.42% lipids, with a fatty acid profile similar to pecan kernels. The shells stood out for their total phenolic content and antioxidant capacity, as well as their fiber content (36.50%). The valorization of these byproducts is essential as they have potential for use in the food industry and for the development of new products. This study contributes to a more sustainable and economically viable production chain while encouraging the exploration of pecan byproducts, which have an excellent nutritional profile and high added value, expanding market opportunities.

Keywords: pecan byproducts, nutritional composition, bioactive compounds, cake, shell

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Aprovechamiento sostenible: El potencial nutricional y bioactivo de la cáscara y torta de nuez pecán

Resumen

La demanda por el consumo de nuez pecán ha ido en aumento y, con ello, también ha crecido el volumen de residuos derivados del descascarillado y del procesamiento para la obtención de aceite de nuez pecán. Este estudio tuvo como objetivo caracterizar los residuos resultantes del procesamiento del aceite de nuez pecán de la variedad Barton. Para ello se descascararon las nueces procedentes de huertos comerciales para la extracción del aceite mediante prensado. Se recolectaron las cáscaras y la torta resultante de la extracción del aceite. Tanto en las cáscaras como en la torta se evaluaron la composición proximal y los compuestos bioactivos. La torta presentó una composición de 18,62% de proteínas y 17,42% de lípidos, con un perfil de ácidos grasos similar al del fruto de la nuez pecán. Las cáscaras, por su parte, se destacan por su contenido de fenoles totales y su capacidad antioxidante, así como por su porcentaje de fibras (36,50%). Por lo tanto, la valorización de estos subproductos es fundamental, ya que presentan un potencial para su uso en la industria alimentaria y en el desarrollo de nuevos productos. Este estudio contribuye a una cadena productiva más sostenible y económica, además de fomentar la explotación de los subproductos de la nuez pecán, que poseen un excelente perfil nutricional y alto valor añadido, lo que amplía las posibilidades de exploración en el mercado.

Palabras clave: subproductos de nuez pecán, composición nutricional, compuestos bioactivos, torta, cáscara

Aproveitamento sustentável: O potencial nutricional e bioativo da casca e torta de noz-pecã

Resumo

A demanda pelo consumo de noz-pecã vem aumentando, e, com isso, cresce o volume de resíduos provenientes do descascamento e do processamento para obtenção de óleo de noz-pecã. Esse estudo objetivou caracterizar os resíduos resultantes do processamento do óleo de noz-pecã da cultivar Barton. Para isso, as nozes provenientes de pomares comerciais foram descascadas para extração do óleo por prensagem. As cascas e a torta resultante da extração do óleo foram coletadas. Na casca e torta, foram avaliados a composição centesimal e compostos bioativos. A torta apresentou uma composição de 18,62% de proteínas e 17,42% de lipídios, com perfil de ácidos graxos semelhantes ao fruto de noz-pecã. Já a casca destaca-se pelo teor de fenólicos totais e capacidade antioxidante, bem como seu percentual de fibras (36,50%). Diante disso, a valorização desses subprodutos torna-se fundamental, já que apresentam potencial para utilização na indústria alimentícia e no desenvolvimento de novos produtos. Este estudo contribui para uma cadeia produtiva mais sustentável e econômica, além de encorajar a exploração dos subprodutos da noz-pecã, que possuem excelente perfil nutricional e alto valor agregado, ampliando as possibilidades de exploração no mercado.

Palavras-chave: subprodutos da noz-pecã, composição nutricional, compostos bioativos, torta, casca

1. Introduction

The human population has been continuously increasing, leading to a growing demand for food production and, consequently, a staggered rise in agro-industrial waste generation (Naik et al., 2023). This makes it essential to seek technological solutions for utilizing these wastes in order to minimize environmental damage and improve the use of natural resources. The pecan tree has been widely cultivated in recent years in southern Brazil, especially due to its good adaptation to the environmental conditions of temperate and subtropical highland climates, which are favorable for its development (Raseira, 1990; Martins et al., 2017, 2018).

In May 2021, the Brazilian Agricultural Research Corporation (Embrapa) signed an agreement with the Brazilian Institute of Pecan Culture (IBPecan) to advance pecan cultivation, launching the “Pecan 2030” project to raise resources and develop strategies for the sustainable growth of the sector. The goal is to achieve 25,000 to 30,000 hectares of cultivated land by 2030. This is driven by the nut's nutritional profile (>52.70% lipids, especially unsaturated fatty acids) (Siebeneichler et al., 2023), sensory qualities, and its potential to diversify farmers' income through the sale of fresh nuts or processed products (Atanasov et al., 2018; Martins et al., 2018; Ribeiro, Klein et al., 2020; Ribeiro, Ribeiro et al., 2020; Salvador et al., 2016).

In recent years, there has been an increase in both demand and interest in obtaining pecan oil. One method of processing pecans is oil extraction, where processing residues like the shell –which accounts for 40 to 50% of the fruit's weight (Prado, 2013)– and the meal –which can yield 50 to 60% from oil extraction (Polmann et al., 2022)– are often discarded or used for animal feed (Maciel, 2021; Salvador et al., 2016). Salvador et al. (2016) reported that pecan oil extraction residue (meal) is rich in lipids (36-59 g/100 g), carbohydrates (13-22 g/100 g), protein (10-19 g/100 g), fiber (9-14 g/100 g), and ash (1.96-3.55 g/100 g), and also contains phenolic compounds with antioxidant capacity.

Thus, encouraging the full utilization of pecans is becoming increasingly necessary, as it not only benefits farmers by offering an opportunity to diversify their income through value-added products like meal and shells but also reduces waste, which benefits the environment. The use of these by-products by farmers can provide economic diversification (Salvador et al., 2016), while also contributing to the United Nations' Sustainable Development Goals (SDGs), such as zero hunger and sustainable agriculture, industry innovation and infrastructure, and responsible consumption and production (Teigiserova et al., 2019).

Considering that these residues from pecan oil processing have the potential to become ingredients in the food or pharmaceutical industries, it is essential to research their chemical composition to develop appropriate technologies that allow for their safe and efficient use in human consumption products. In this regard, the aim of this study was to characterize the shell and meal, residues from pecan oil processing.

2. Materials and Methods

2.1 Samples

The pecan nut samples of the Barton cultivar were obtained from a commercial orchard operated by Prosperato, located in Barra do Ribeiro – RS, Brazil. The nuts were dried, shelled, and manually separated from the shells. The shells were ground directly, and the nuts were used for oil extraction by cold mechanical pressing machine (IMP-02TC, Imperium) on a laboratory scale, yielding a 27% residue (cake). After extraction, the ground shells and the cake were sent for analysis at the Technological Institute in Food for Health (Itt Nutrifor) located on the São Leopoldo Campus of the University of Vale do Rio dos Sinos (UNISINOS).

For the analyses, the cake was ground into a fine flour in a food processor (OMPR850 Oster®). Both samples were stored under refrigeration until analysis.

2.2 Analyses

2.2.1 Proximate Composition and Calculation of the Energy Value of the Residues

The moisture, protein, carbohydrate, lipid, fiber, and ash contents were determined following the protocols of the Adolfo Lutz Institute (Zenebon et al., 2008). Moisture was measured by direct oven drying at 130 °C for 2 hours or until constant weight. Ash content was determined by incineration in a muffle furnace at 550 °C for 18 hours. Lipid content was measured by the Soxhlet method, and protein content by the Kjeldahl method. Total fiber content was determined by acid and alkaline digestion, while carbohydrate content was determined by difference, i.e., 100 g of product minus the sum of protein, lipid, ash, and moisture. Results were expressed as a percentage.

The total energy value per 100 g of the sample was calculated using Atwater conversion factors, where the amounts of carbohydrates and proteins found in the analysis were multiplied by four, and lipids by nine. The total was expressed in kilocalories (kcal) per 100 g of the flour derived from pecan nut oil processing residue.

2.2.2 Quality of the Residual Oil in the Cake

For oil quality analysis, the cake was subjected to the Soxhlet method using petroleum ether for 8 hours.

2.2.3 Fatty Acid Profile

The fatty acid profile was determined by gas chromatography-mass spectrometry (GC-MS) following the method described by The International Olive Council (2015). Results were expressed as a percentage.

2.2.4 Free Fatty Acids

Acidity was determined by titration according to the Adolfo Lutz Institute (Zenebon et al., 2008), with results expressed in mg KOH/g (milligrams of KOH per gram).

2.2.5 Specific Extinction Coefficients (K232 and K270)

The specific extinction coefficients (K232 and K270) were determined by spectrophotometer absorbance readings, according to the method proposed by the American Oil Chemists' Society (2012).

2.2.6 Tocopherols

The content of tocopherols (α-, γ-, and δ-) was determined by high-performance liquid chromatography (HPLC) with a fluorescence detector, using a CLC-ODS reverse-phase column (3.9 cm × 150 mm × 4 μm) after dilution in isopropanol (1:5). Results were expressed in mg/100 g.

2.3 Total Phenolic Compounds and Flavonoids in Defatted Cake and Ground Shells

2.3.1 Extraction

In a Falcon tube, 1.25 g of defatted cake and ground shells were weighed, and 5 mL of 80% methanol was added. The samples were subjected to 15 minutes of ultrasonic treatment, then centrifuged at 4000 rpm for 5 minutes at 4 °C. The supernatant was collected, and the process was repeated once. The combined supernatants were used for quantifying phenolic compounds and flavonoids.

2.3.2 Total Phenolics

Total phenolic content was determined using the Folin-Ciocalteu method (Swain & Hillis, 1959), with results expressed in milligrams of gallic acid equivalents per gram (mg GAE/g).

2.3.3 Total Flavonoids

Total flavonoid content was assessed by a colorimetric assay, which involved the addition of aluminum chloride ($AlCl_2$) and sodium nitrite ($NaNO_2$) to form a flavonoid-aluminum complex (Zhishen et al., 1999). Results were expressed in milligrams of catechin equivalents per gram (mg CAE/g).

2.3.4 Data Analysis

Results were expressed as mean ± standard deviation (n=3).

3. Results

3.1 Proximal Composition of Pecan Residues

The centesimal analysis of the byproducts from pecan oil processing revealed that the meal contained 8.81% moisture, 4.47% ash, 17.42% lipids, 18.62% protein, 8.99% crude fiber, and 51.04% carbohydrates, with an energy value of 433.96 kcal/100 g. The yield of the meal after oil extraction was 27%, indicating that 27% of the initial weight of the nuts was converted into residual meal (Table 1).

For the pecan shell, the composition was as follows: 20.25% moisture, 1.61% ash, 1.91% lipids, 2.19% protein, 36.50% crude fiber, and 76.23% total carbohydrates, with an energy value of 330.87 kcal/100 g (Table 1).

Table 1. Proximate composition of the pecan oil processing residues of the cultivar

Evaluated Parameters	Cake (g/100g)	Shell (g/100g)
Moisture	8.81 ± 0.15	20.25 ± 0.00
Ash	4.47 ± 0.06	1.61 ± 0.02
Lipids	17.42 ± 1.98	1.91 ± 0.00
Proteins	18.62 ± 0.17	2.19 ± 0.35
Crude Fiber	8.99 ± 0.00	36.50 ± 4.09
Carbohydrates	41.69 ± 2.24	37.57 ± 0.00
Energy Value	433.96 kcal/100 g	330.87 kcal/100 g

3.2 Quality of the Residual Oil from the Meal

The fatty acid profile of the meal indicated that 67% of the fatty acids were unsaturated, predominantly oleic acid (40.14%), followed by linoleic acid (23.01%). Saturated fatty acids accounted for approximately 33% of the lipid profile, mainly palmitic acid (22.84%) and stearic acid (9.07%) (Table 2).

The tocopherol content was measured at 17.66 mg/100 g for γ-tocopherol, 7.23 mg/100 g for α-tocopherol, and 0.20 mg/100 g for δ-tocopherol (Table 2).

Table 2. Fatty acid and tocopherol profile of the residual oil from Barton cultivar pecan cake

Fatty Acids	%
Myristic (C14:0)	0.24
Palmitic (C16:0)	22.84
Palmitoleic (C16:1)	0.19
Margaric (C17:0)	0.22
Stearic (C18:0)	9.07
Oleic (C18:1)	40.14
Linoleic (C18:2)	23.01
Arachidic (C20:0)	0.50
Eicosenoic (C20:1)	0.42
Linolenic (C18:3)	3.14
Total Saturated Fatty Acids	32.97
Total Polyunsaturated Fatty Acids	26.15
Total Monounsaturated Fatty Acids	40.87
Tocopherols	(mg/100 g)
α-tocopherol	7.23 ± 2.00
δ-tocopherol	0.20 ± 0.09
γ-tocopherol	17.66 ± 2.04

α: Alpha; δ: Delta; γ: Gamma

3.3 Specific Extinction Coefficient (k232 and k270) and Oil Acidity

The acidity of the oil was measured at 0.19 mg of KOH/g of sample, and the extinction coefficients K_{232} and K_{270} were 0.03 and 0.04, respectively (Table 3).

Table 3. Acidity content and extinction coefficient of the pecan oil processing residue

Evaluated Parameters	
Acidity (mg KOH/g)	0.19 ± 0.14
Extinction Coefficient	
K_{232}	0.03 ± 0.02
K_{270}	0.04 ± 0.02

KOH: Potassium hydroxide

3.4 Total Phenolic Compounds Content and Total Flavonoids

The levels of total phenolic compounds and flavonoids in the pecan residues are presented in Table 4. The meal contained 479.46 mg of GAE/g of total phenolic compounds and 1.70 mg of CAE/g of flavonoids. The shell exhibited higher values, with 562.53 mg of GAE/g for phenolics and 4.65 mg of CAE/g for flavonoids (Table 4).

Table 4. Total phenolic compounds and total flavonoids content in pecan residues

Evaluated Parameters	Cake	Shell
Phenolics (mg GAE/g)	479.46 ± 2.83	562.53 ± 13.73
Flavonoids (mg CAE/g)	1.70 ± 0.08	4.65 ± 0.10

GAE: Gallic acid equivalent; CAE: Catechin equivalent

4. Discussion

4.1 Proximal Composition of Pecan Residues

The oil extraction process from Barton cultivar pecans yields two main byproducts: the cake and the shell (Figure 1). The cake yield obtained after oil extraction from Barton cultivar nuts was 27%. This value is considered satisfactory within the context of cold mechanical extraction, as techniques like cold pressing typically achieve lower yields than other extraction methods, such as solvent extraction. However, the advantage of this method lies in preserving the quality of bioactive compounds, which are sensitive to heat and chemicals. This outcome closely aligns with a similar study that reported a yield of 26.77% (Maciel et al., 2020), reflecting the oil extraction efficiency and the amount of residual material available for potential applications.

The nutritional composition of the cake suggests it is a rich source of proteins, fibers, and carbohydrates, enhancing its value as a functional ingredient across various products. The proximate analysis of pecan processing residues, including cake and shell, reveals substantial potential for their use as functional and nutraceutical ingredients, with unique nutritional profiles suitable for specific applications. The cake, with its high protein (18.62%) and fiber (8.99%) content, presents a promising opportunity for protein supplementation and fiber-rich formulations, although it shows lower levels than other studies, with values of 13.01% (Maciel, 2021) and 13.7% (Salvador et al., 2016). Carbohydrates, the primary energy source for the human body, account for more than half of the cake composition (51.04%) and include both soluble and insoluble fibers. The protein concentration, nearly three times higher than in raw pecans (Maciel et al., 2020; Ribeiro, Klein et al., 2020), indicates that the cake could enhance food preparations and improve the nutritional profile of bakery, confectionery, and even protein-rich products tailored to athletes and vegans.

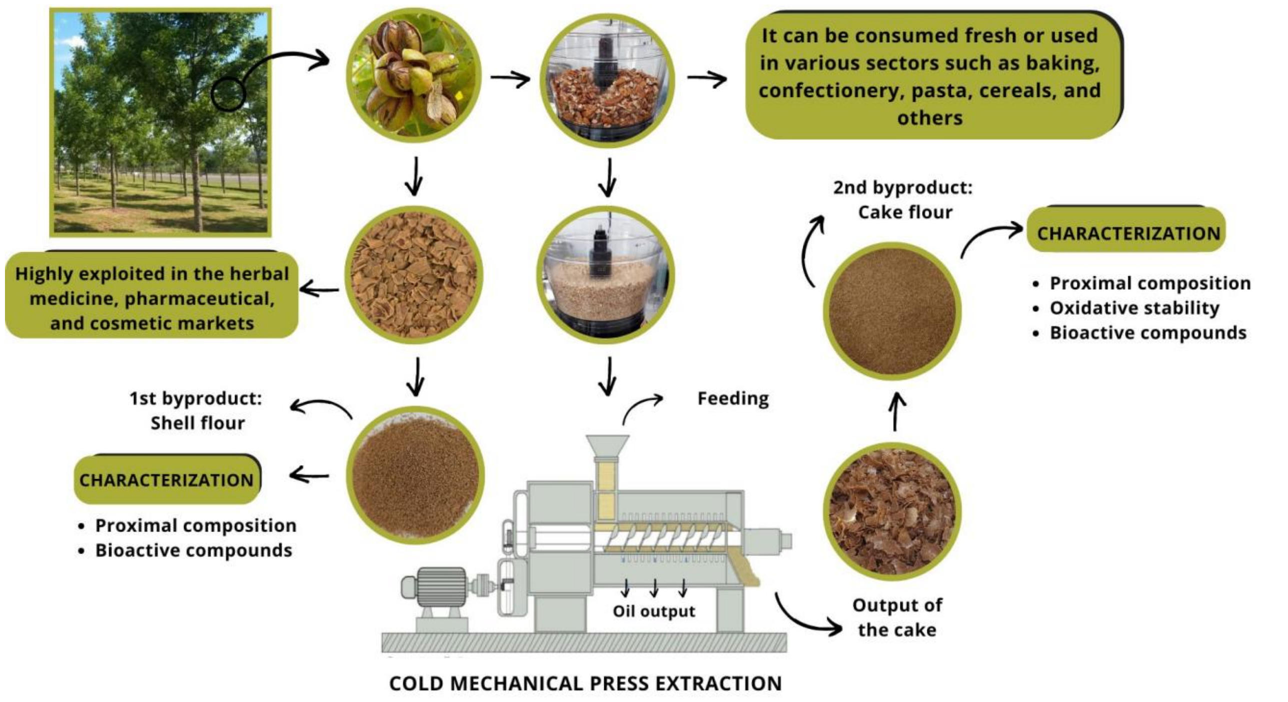

Figure 1. Diagram illustrating the cold mechanical press extraction process of pecan oil and the generation of byproducts

The process begins with whole pecans, which are shelled to produce the first byproduct, shell flour, characterized for its proximal composition and bioactive compounds. The shelled pecans are then ground and fed into the mechanical press, where the oil is extracted. The second byproduct, the pressed cake (cake flour), is also characterized for its proximal composition, oxidative stability, and bioactive compounds.

Pecan shells, in turn, exhibited a high fiber content (36.50%) (Table 1), comparable to other plant-based fiber sources sold for human consumption, such as chia (34-40%) (Maciel et al., 2020) and coconut flour (40%) (Freitas & Naves, 2010). This attribute positions the shell as a potential raw material for fiber supplements or fiber-rich ingredients that may aid in gut health management and the development of health-focused products. Additionally, the shell has high total carbohydrate levels and a low lipid content (1.91%). In comparison, shells from three different batches in Rio Grande do Sul, consisting of various cultivars harvested in 2006, demonstrated a composition predominantly of total fibers (48.6%), followed by carbohydrates (29.6%), moisture (16.8%), proteins (2.2%), ash (1.4%), and lipids (1.1%), with a total caloric value of 331.6 kcal/100 g (Prado, 2008). Another study analyzed the shell composition from an industrial producer, finding 53.3% carbohydrates, 28.15% total fibers, 14.2% moisture, 2.16% protein, 1.78% ash, 0.41% lipids, and a caloric value of 225.53 kcal/100 g (Basso & Richards, 2023), values close to those found by Prado (2008). These results show a similarity between findings in the literature and the current research, while variations may relate to genetic factors, cultivar, environmental conditions, and agronomic management.

The ash content (4.47%) found in the cake was higher than the results reported by Salvador et al. (2016), with 1.96 to 3.55%, and Polmann et al. (2022), with 1.65%. Mineral analysis reported a prevalence of magnesium (416.74 mg/100 g-1), manganese (23.21 mg/100 g-1), and cobalt (59.00 mg/100 g-1) in the pecan cake (Maciel et al., 2020), suggesting that 100 g of pecan cake could suffice to meet the daily intake recommendations for adults according to the Dietary Reference Intakes (DRI) (Padovani et al., 2023).

The mechanical pressing method used for sample collection in this study is only one of the available industrial methods for oil extraction, although it typically results in greater residual oil loss, which is less desirable for producers. However, it remains a cost-effective option that better preserves oil quality (Polmann et al., 2022). Thus, there is a considerable amount of residual oil present in the cake, constituting approximately 17.42% of its composition. Maciel (2021) reported a similar value to this study, with 16.64% lipids in the cake, while Salvador et al. (2016), despite using the same extraction method, reported lipid content between 36 and 59% in the cake, and Polmann et al. (2022) reported a value of 29.55%, differing from the current findings. These differences may relate to the characteristics of the nuts used for extraction, including cultivar and environmental factors (Siebeneichler et al., 2023).

4.2 Residual Oil Quality in Pecan Cake

The residual oil content can be utilized to obtain bioactive compounds, such as tocopherols, which act as natural antioxidants in the body. The presence of these compounds can be leveraged for the development of functional products, given that the tocopherols, especially γ-tocopherol (17.66 mg/100 g), provide health-promoting properties, such as combating oxidative stress (Guinazi et al., 2009). Moreover, the residual oil in the cake offers an economical alternative for formulating high-value foods by using an industry byproduct as a functional raw material.

In terms of the lipid quality of the residual oil, the unsaturated fatty acid profile, including oleic acid (40.14%) and linoleic acid (23.01%), contributes cardiovascular and antioxidant benefits, adding value to the use of pecan cake as an ingredient rich in beneficial fatty acids. The lipid profile of Brazilian pecans varies significantly in the literature, with oleic acid ranging from 62% to 72% and linoleic acid from 17% to 25% in different regions of Brazil (Salvador et al., 2016). A more recent study on pecans (Polmann et al., 2022) from the same region examined in this research reported a lipid profile consisting of 91.5% unsaturated fatty acids and 8.3% saturated fatty acids, with 69.7% oleic acid and 20.9% linoleic acid, findings that closely align with those of the present study. However, discrepancies between studies may be related to the quality of pecans influenced by cultivar, location, management, post-harvest storage, and environmental factors (Siebeneichler et al., 2023, 2024).

The residual oil in the cake imparts a characteristic nutty aroma to the product; however, it also accelerates the oxidation process. It is well known that the more unsaturated the lipids, the more susceptible they are to oxidation. Thus, oleic acid, found in greater amounts in the cake, has only one double bond, making it less prone to oxidation compared to linoleic acid, which has two double bonds and, despite its instability, is essential in the diet since it cannot be synthesized biochemically in the human body (Oro, 2007).

Comparing the data, the values found for the cake differ significantly from those found in raw pecans, as the concentration of proteins, minerals, fibers, and carbohydrates increases, while the energy value of the cake decreases by approximately 38.2% due to its lower lipid percentage. Thus, this pecan byproduct presents interesting technological characteristics for use in the food industry, particularly in culinary applications such as baking, confectionery, pasta, and even yogurts and cheeses (Maciel et al., 2020).

The presence of polyunsaturated fatty acids and tocopherols suggests that pecan cake may be used in food and cosmetic formulations aimed at providing antioxidant and protective health benefits. Tocopherols are part of the compounds known as "Vitamin E" and can be found as α-, β-, γ-, and δ-isomers (alpha, beta, gamma, and delta), with vegetable oils like pecan oil being an excellent source of these compounds (Guinazi et al., 2009). They act as antioxidants in the body, inhibiting lipid oxidation of unsaturated fatty acids and defending against oxidative stress caused by free radicals (Freitas & Naves, 2010).

Literature on pecan oil reports 168.5 mg/100 g of γ-tocopherol and 12.2 mg/100 g of α-tocopherol (Ryan et al., 2006). Thus, it is observed that after oil extraction, about 11% of γ-tocopherol and 56% of α-tocopherol remain in the cake. Consequently, the health benefits related to these bioactive compounds are also present in the cake, albeit in smaller quantities.

4.3 Specific Extinction Coefficient (k232 and k270) and Oil Acidity

Enzymatic browning and lipid oxidation are the main oxidation reactions in foods. Due to its high lipid content, pecan is particularly susceptible to lipid oxidation, which can lead to rancid flavors and aromas. Therefore, analyses indicating oxidation are essential, especially in product development, where the quality and safety of raw materials are critical (Prado, 2008).

The titratable acidity of the oil in the cake in the present study (0.19 mg KOH/g) is lower than that reported by Salvador et al. (2016), who found values ranging from 0.93 to 2.18 mg KOH/g. The acidity of pecan cake oil complies with the standards set by the Brazilian Health Surveillance Agency (ANVISA) for cold-pressed, unrefined oils, which establishes a maximum acidity value of 4.00 mg KOH/g (Agência Nacional de Vigilância Sanitária, 2005). This difference may be related to the quality of the pecans used in extraction, cultivar, location, and factors such as light exposure and higher temperatures (Guinazi et al., 2009; Ribeiro, Klein et al., 2020; Ribeiro, Ribeiro et al., 2020; Siebeneichler et al., 2023).

Lipid oxidation involves several factors, such as exposure to light, heat, the presence of pro-oxidant or antioxidant agents, and chemical structure aspects, such as the amount of unsaturation in the chain (Prado, 2008). The extinction coefficient K_{232} nm indicates conjugated compounds such as peroxides, which are associated with primary oxidation (also known as autoxidation), while K_{270} nm indicates the formation of carbonyl compounds, such as ketones, alcohols, and aldehydes, which are secondary oxidation products (Maldonade et al., 2021; Oro, 2007).

No studies were found in databases that analyze the extinction coefficient of pecan byproducts. However, the results for pecan cake are similar to and even lower than those for freshly extracted nut oil. For example, Oro (2007) evaluated the bioactive compounds and shelf life of pecan and cold-pressed oil at the initial time and after 150 days of storage, finding 0.833 at 232 nm and 0.033 at 270 nm at the initial time. These results suggest good stability of the pecan oil processing residue, comparable to fresh nut oils.

4.4 Phenolic Compounds and Flavonoids

Phenolic compounds, such as flavonoids, tannins, and phenolic acids, play a role as hydrogen atom donors in neutralizing free radicals, preventing the acceleration of lipid oxidation processes. Additionally, in metabolism, these compounds have important functions, such as reducing the incidence of chronic and degenerative diseases (Villarreal-Lozoya et al., 2007).

The total phenolic content in pecan meal varies widely in the literature, ranging from 71 to 100 mg GAE/g (Salvador et al., 2016), while another study reported a range from 172.43 to 2744.24 mg GAE/g (Maciel et al., 2020), and in our study, it was 479.46 mg GAE/g. Regarding flavonoids in the meal, one study indicated that only 24.15% remain after oil extraction (Yang et al., 2009).

Pecan shells are particularly rich in phenolic compounds. Chlorogenic, gallic, and p-hydroxybenzoic acids have been shown to be the main phenols in pecan shells, along with epigallocatechin, epigallocatechin-3-gallate, and procyanidin (Morales-de la Peña et al., 2023). In the present study, we found a total phenolic content of 562.53 mg GAE/g and a total flavonoid content of 4.65 mg CAE/g, values comparable to those found in different harvests and varieties of pecan shell, which ranged from 94.04 mg GAE/g to 590.78 mg GAE/g (Prado, 2013). Interestingly, it has been reported that the shell contains 18 times more tannins than the nut (Villarreal-Lozoya et al., 2007). This composition is responsible for the astringent organoleptic characteristics and high antioxidant activity of shell extracts. Thus, pecan shells represent a promising byproduct for exploration and application in pharmaceutical or food product lines (Martins et al., 2017).

5. Conclusions

The characterization of pecan cake reveals a rich composition, comprising 17.42% lipids and a favorable fatty acid profile, with high levels of monounsaturated fatty acids (40.87%) and polyunsaturated fatty acids (26.15%), along with a significant protein content of 18.62%. The shell stands out due to its total phenolic content of 562.53 mg GAE/g and its corresponding crude fiber content of 36.50%. These results demonstrate the potential of the cake for utilization in both human and animal nutrition, as it can serve as a source of lipids and proteins for food enrichment and the development of new products. This study provides a solid foundation for future research that may expand the utilization of these residues in the creation of new food product lines. The valorization of pecan waste represents a beneficial strategy to promote a circular economy, reduce waste in the industry, and explore the full potential of these by-products.

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Transparency of Data

Data not available: The data set that supports the results of this study is not publicly available.

Author Contribution Statement

	SCF	TDS	TJS	RLC	CRM	VZ	CDF	JFH
Conceptualization					X			X
Funding acquisition								X
Investigation	X	X						
Writing – original draft	X							
Writing – review and editing			X	X	X	X	X	X

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