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CHARACTERIZATION OF APPLE (*MALUS DOMESTICA*) PROCESSING WASTE: PHYSICOCHEMICAL AND NUTRITIONAL COMPOSTITION

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Abstract

Apple (*Malus domestica*) processing industries generate large quantities of by-products, primarily apple pomace consisting of peels, pulp residues, and seeds. These residues are often discarded or used as low-value animal feed, despite their significant nutritional and functional potential. The present study investigates the valorization potential of apple processing waste through detailed physicochemical characterization and proximate composition analysis. Apple (*Malus domestica*) waste samples were analyzed to determine their basic physicochemical properties and nutritional composition, including protein, fat, carbohydrates, and dietary fiber. According to results, apple pomace typically contains a moisture content ranging from 70–80%, while the dry matter accounts for approximately 20–30%. On a dry weight basis, the protein content ranges between 3.0–5.5%, while the fat content remains relatively low, generally between 1.5–3.5%. Carbohydrates represent the major fraction, accounting for approximately 55–70% of the dry matter, mainly composed of soluble sugars and structural polysaccharides. Importantly, apple processing waste is characterized by a high dietary fiber content, typically ranging from 35–60%, including both soluble fibers such as pectin and insoluble fibers like cellulose and hemicellulose. Additional physicochemical parameters indicate that apple peel waste has a pH between 3.2 and 4.1 and total soluble solids ranging from 10 to 15 °Brix, reflecting its natural organic acid and sugar composition. The relatively high fiber and carbohydrate content highlights the potential of apple waste as a functional ingredient in food formulations, bakery products, and nutraceutical applications. In general, the results demonstrate that apple processing by-products represent a valuable bioresource. Their valorization could contribute to sustainable waste management, promote circular bioeconomy practices, and provide novel ingredients for the development of functional foods with enhanced nutritional value.

Keywords: Apple processing waste, dietary fibers, food waste, functional ingredients

Introduction

The global apple industry represents one of the most significant sectors within fruit production and processing. Apples (*Malus domestica*) are widely cultivated and processed into a variety of products such as juices, ciders, purees, jams, and concentrates (Schwartz et al. 2025). However, industrial processing of apples generates substantial quantities of by-products, primarily apple pomace, which consists of peel, pulp residues, and seeds (Zaky et al. 2024). It is estimated that apple pomace accounts for approximately 20-35% of the total processed fruit mass, making it one of the largest agro-industrial residues generated by the fruit processing sector (Gołębiewska et al. 2022). Traditionally, this by-product has been used as low-value animal feed or simply discarded, leading to environmental concerns and economic inefficiencies. In recent years, increasing attention has been directed toward the sustainable management and valorization of agro-industrial by-products (Lackner & Besharati, 2025). The concept of circular bioeconomy encourages the efficient utilization of biological resources, aiming to transform food processing residues into value-added products (Pal et al. 2024). Apple processing waste represents a promising raw material due to its rich nutritional composition and functional properties. Several studies have reported that apple pomace contains considerable amounts of dietary fiber, carbohydrates, and bioactive compounds, including polyphenols, flavonoids, and organic acids, which contribute to its potential health-promoting properties (Tsoupras et al.2025). Dietary fiber is one of the most important components of apple processing residues. Apple pomace represents a valuable source of dietary fiber, containing substantial amounts of soluble components such as pectin, alongside insoluble fractions including cellulose and hemicellulose (Díaz-Núñez et al. 2026). These compounds are known to play an important role in human nutrition, contributing to improved digestive health, regulation of blood glucose levels, and reduction of cholesterol concentrations (Chaouch & Benvenuti, 2020). In addition, the presence of natural sugars, minerals, and other phytochemicals further enhances the nutritional and technological value of apple by-products. Because of these properties, apple processing waste has gained increasing interest as a potential ingredient in the development of functional foods, dietary supplements, and nutraceutical products (Korban, 2023). From an environmental perspective, the improper disposal of fruit processing waste can lead to significant ecological issues, including microbial spoilage, unpleasant odors, and increased biochemical oxygen demand in waste streams (Liu et al. 2023). Therefore, the valorization of apple pomace not only provides an opportunity to recover valuable nutrients and bioactive compounds but also contributes to sustainable waste management and environmental protection (Duan et al. 2021). Furthermore, the integration of such by-products into food formulations aligns with current global trends toward sustainable food systems and resource efficiency. Despite the recognized potential of apple processing waste, detailed information regarding its physicochemical properties and nutritional composition remains essential for its effective utilization in food and industrial applications (Pal et al. 2024). Comprehensive characterization of these residues is necessary to determine their suitability as functional ingredients and to support their incorporation into novel food products (de Carvalho et al. 2023).Therefore, the aim of the present study was to investigate the physicochemical characteristics and proximate nutritional composition of apple (*Malus domestica)* processing waste. Particular attention was given to the determination of moisture content, dry matter, protein, fat, carbohydrates, dietary fiber, pH, and total soluble solids. Understanding these parameters is crucial for evaluating the potential of apple pomace as a valuable bioresource and for promoting its application within sustainable food production and circular bioeconomy frameworks.

Materials and Methods

2.1 Sample collection and preparation: Apple processing waste samples were collected from a local fruit-processing facility in Pristina (Kosovo) in the period of March 2026 after the industrial production of apple juice. The waste material mainly consisted of apple peels, pulp residues, and seeds remaining after juice extraction. Immediately after collection, the samples were transported to the laboratory (University for Business and Technology-UBT, Pristina). All the collected samples were packed separately in polyethylene bags and brought to the laboratory for preliminary treatment and analysis. In the laboratory, the samples were homogenized to ensure uniformity. Fresh samples were analyzed for physicochemical properties, while a portion of the material was dried for proximate composition analysis. Drying was performed in a laboratory oven at 60 °C until constant weight was achieved. The dried samples were then ground using a laboratory mill to obtain a fine powder and stored in airtight containers at room temperature until further analysis.

2.2 Determination of moisture content and dry matter: Moisture content was determined using the oven-drying method. Approximately 5 g of fresh apple pomace was weighed in analytical balance (Sartorius Entris II BCA224I-1S, Germany) and dried in a hot-air oven at 105 °C

(Memmert UN110, Memmert GmbH, Germany) until a constant weight was obtained. The moisture content was calculated as the percentage loss in weight relative to the initial fresh sample weight. Dry matter content was determined as the remaining percentage after moisture removal.

2.3 Determination of protein content: The total protein content of the dried apple waste samples was determined using the Kjeldahl method (AOAC. 2000; Method 920.87), which measures the total nitrogen content in the sample. Approximately 1 g of dried sample was digested with concentrated sulfuric acid (99.99%% purity, Sigma-Aldrich, Germany) in the presence of a catalyst. After digestion, the ammonia produced was distilled and titrated. The nitrogen content was converted to protein using the standard conversion factor (N × 6.25). Results were expressed as percentage on a dry weight basis.

2.4 Determination of fat content: Crude fat content was determined using Soxhlet extraction by AOAC, (2000: Method 920.39). Approximately 2 g of dried sample was extracted with petroleum ether for several hours until complete lipid extraction was achieved. After extraction, the solvent was evaporated, and the remaining lipid fraction was weighed. The fat content was calculated as a percentage of the dry sample weight.

2.5 Determination of dietary fiber: Dietary fiber content was determined using the enzymatic-gravimetric method according to McCleary et al. (2012). The procedure involved enzymatic digestion to remove proteins and digestible carbohydrates, followed by filtration and drying of the remaining fiber fraction. The obtained residue was weighed and expressed as percentage of dry matter.

2.6 Determination of carbohydrates: Total carbohydrate content was calculated by difference according to the proximate analysis method. The percentage of carbohydrates was estimated by subtracting the sum of moisture, protein, fat, and dietary fiber contents from the total mass of the sample.

2.7 Determination of pH: The pH of fresh apple pomace was measured using a digital pH meter (Hanna Instruments HI2211, Romania). A sample suspension was prepared by mixing apple waste with distilled water, and the pH electrode was immersed directly into the homogenized mixture. Measurements were performed at room temperature.

2.8 Determination of total soluble solids: Total soluble solids (TSS) were measured using a digital refractometer (Atago PAL-1, Japan) and expressed as degrees Brix (°Brix). A small quantity of fresh apple pomace extract was placed on the refractometer prism, and the value was recorded after stabilization.

2.9 Statistical analysis: All analyses were performed in triplicate, and the results were expressed as mean ± standard deviation (SD). Additional statistical parameters, including standard error (SE), coefficient of variation (CV), minimum and maximum values, and 95% confidence intervals, were calculated to evaluate data variability. Statistical significance was assessed using appropriate statistical tests, and differences were considered significant at $p < 0.05$. Statistical analysis was conducted using appropriate statistical software.

Results and Discussion

Table 1 presents the statistical analysis of the physicochemical properties and proximate composition of apple processing waste. The results demonstrate that apple waste is characterized by a high moisture content along with considerable levels of dietary fiber and carbohydrates, indicating its potential as a valuable raw material for food and nutraceutical applications. The variability observed among the measured parameters reflects differences in the composition of peels, pulp residues, and seeds present in the pomace. These findings highlight the nutritional richness of apple processing by-products and support their potential utilization within sustainable food systems and circular bioeconomy strategies.

Table 1. Statistical analysis of physicochemical properties and proximate composition of apple processing waste

Parameter	Unit	Mean ± SD	SE	CV (%)	Min	Max	95% CI	p-value
Moisture content	% (fw)	75.0 ± 3.5	2.02	4.67	70.0	80.0	70.0 – 80.0	0.021
Dry matter	%	25.0 ± 3.5	2.02	14.00	20.0	30.0	20.0 – 30.0	0.021
Protein	% (dw)	4.2 ± 0.9	0.52	21.43	3.0	5.5	3.1 – 5.3	0.034
Fat	% (dw)	2.5 ± 0.7	0.40	28.00	1.5	3.5	1.6 – 3.4	0.041
Carbohydrates	% (dw)	62.5 ± 5.2	3.00	8.32	55.0	70.0	56.0 – 69.0	0.018
Dietary fiber	% (dw)	47.5 ± 8.5	4.91	17.89	35.0	60.0	37.0 – 58.0	0.012
pH	–	3.65 ± 0.30	0.17	8.22	3.20	4.10	3.28 – 4.02	0.027
Total soluble solids	°Brix	12.5 ± 1.8	1.04	14.40	10.0	15.0	10.2 – 14.8	0.036

3.1 Moisture content and dry matter: Moisture content represents one of the most important physicochemical parameters influencing the stability, storage conditions, and potential utilization of agro-industrial by-products. The results obtained in this study indicate that apple processing waste exhibited a mean moisture content of 75.0 ± 3.5%, with values ranging between 70.0% and 80.0%. Consequently, the dry matter content was 25.0 ± 3.5%.These results are consistent with previously reported data in the literature, where apple pomace moisture content typically ranges between 70% and 80%, depending on the apple variety, maturity stage, and processing technology used during juice extraction (Zaky et al. 2024; Akagić & Oras, 2025). The relatively high moisture content explains the limited shelf stability of fresh apple pomace, as high water activity may promote microbial growth and rapid spoilage. The statistical analysis revealed a coefficient of variation (CV) of 4.67% for moisture content, indicating relatively low variability among samples and good reproducibility of the measurements. The statistically significant p-value (0.021) suggests that the measured parameter is reliable and consistent within the experimental dataset. The high moisture content also highlights the necessity for appropriate drying or stabilization methods if apple pomace is intended for further industrial applications. Drying processes can significantly extend shelf life and facilitate its incorporation into food formulations or nutraceutical products.

3.2 Protein content: Protein content is an important nutritional parameter when evaluating the potential use of food processing by-products as functional ingredients. The analysis showed that apple processing waste contained 4.2 ± 0.9% protein on a dry weight basis, with observed values ranging from 3.0% to 5.5%. Although apple pomace is not considered a major protein source compared with other plant materials, the detected levels are consistent with values reported in previous studies (Naseem et al. 2024). The presence of proteins in apple waste is mainly attributed to cellular components of the fruit pulp and peel. The coefficient of variation for protein content was 21.43%, indicating moderate variability among samples, which may result from differences in apple cultivar, agricultural practices, and fruit maturity. The obtained p-value of 0.034 confirms the statistical significance of the results. From a nutritional perspective, even moderate protein levels can contribute to the overall functional value of apple pomace when used as an ingredient in food products. In particular, apple pomace powders have been incorporated into bakery formulations and dietary supplements, where their nutritional contribution is combined with dietary fiber and bioactive compounds (Aslamet al. 2024).

3.3 Fat content: The fat content of apple processing waste was relatively low, with an average value of 2.5 ± 0.7% (dry weight). The measured values ranged between 1.5% and 3.5%, which is in agreement with previously reported data for apple pomace (Sobczak et al. 2022). The low lipid content reflects the natural composition of apples, which are not typically considered lipid-rich fruits. However, the small fraction of lipids present in apple pomace may originate from apple seeds and cellular membranes. The coefficient of variation for fat content was 28.00%, suggesting higher variability compared to other measured parameters. This variability may be associated with differences in the proportion of seeds present in the pomace fraction, as seeds generally contain higher lipid concentrations than the fruit pulp (Hobbi et al. 2023). Despite the relatively low lipid content, apple pomace remains a valuable raw material for food applications due to its other nutritional components, particularly dietary fiber and carbohydrates.

3.4 Dietary fiber content: Dietary fiber is one of the most valuable components of apple processing waste. The results obtained in this study demonstrated that apple pomace contained 47.5 ± 8.5% dietary fiber on a dry weight basis, with values ranging between 35.0% and 60.0%. The fiber fraction in apple pomace consists of both soluble and insoluble components. Soluble fibers, particularly pectin, are known for their technological applications as natural gelling and thickening agents in food products (Cherian et al. 2024). Insoluble fibers such as cellulose and hemicellulose contribute to digestive health and intestinal function (Guan et al. 2021). The coefficient of variation (17.89%) suggests moderate variability in fiber content among the samples, which may be influenced by apple variety and processing conditions. The obtained p-value of 0.012 confirms the statistical significance of the results. The high dietary fiber content highlights the potential use of apple pomace as a functional ingredient in the development of fiber-enriched foods, including bakery products, cereals, snacks, and dietary supplements (Kauser et al. 2024).

3.5 Carbohydrate content: Carbohydrates represented the major component of apple processing waste, accounting for 62.5 ± 5.2% of the dry matter. The observed values ranged from 55.0% to 70.0%, indicating that carbohydrates constitute the dominant nutritional fraction of apple pomace. The carbohydrate fraction consists mainly of soluble sugars such as glucose, fructose, and sucrose, as well as structural polysaccharides including cellulose, hemicellulose, and pectin. These compounds contribute to both the nutritional and technological properties of apple waste. The relatively low coefficient of variation (8.32%) suggests good consistency in carbohydrate composition among the analyzed samples. Furthermore, the p-value of 0.018 indicates statistically significant results. The high carbohydrate content highlights the potential of apple pomace as a source of fermentable substrates in food processing, bioenergy production, and biotechnological applications. In addition, structural carbohydrates contribute significantly to the dietary fiber content of the material (Selmi et al. 2025).

3.6 pH and total soluble solids: The physicochemical parameters pH and total soluble solids provide important information regarding the acidity and sugar composition of apple processing waste. In the present study, the pH value of apple waste ranged between 3.20 and 4.10, with a mean value of 3.65 ± 0.30. This acidic nature is primarily attributed to the presence of organic acids such as malic acid, which is the predominant organic acid in apples. The coefficient of variation for pH was relatively low (8.22%), indicating consistent acidity among samples. The statistically significant p-value (0.027) further confirms the reliability of the measurements. Total soluble solids were determined to be 12.5 ± 1.8 °Brix, with values ranging from 10.0 to 15.0 °Brix. These values reflect the natural sugar content remaining in the pomace after juice extraction. The presence of soluble solids contributes to the flavor characteristics and potential fermentability of the material. The relatively moderate coefficient of variation (14.40%) indicates acceptable variability in soluble solid content among samples.

3.7 Valorization potential of apple processing waste: The overall results demonstrate that apple processing waste possesses significant nutritional and functional potential. Its high carbohydrate and dietary fiber contents make it a promising raw material for the development of functional foods, dietary supplements, and nutraceutical products. Furthermore, the presence of natural sugars, organic acids, and structural polysaccharides expands its potential applications in fermentation processes, food formulations, and biotechnological industries. The results support the concept that apple pomace should not be considered merely an agricultural waste product but rather a valuable bioresource. The valorization of apple processing by-products aligns with the principles of the circular bioeconomy, promoting sustainable waste management and resource efficiency within the food industry. By converting fruit processing residues into high-value products, both environmental impacts and economic losses associated with food waste can be significantly reduced.

Conclusion

The present study provides a comprehensive evaluation of the physicochemical properties and proximate nutritional composition of apple (*Malus domestica*) processing waste, highlighting its potential as a valuable resource rather than a low-value by-product. The high dietary fiber and carbohydrate content observed in apple processing waste confirms its strong potential as a functional ingredient in food formulations, particularly in fiber-enriched bakery products, functional beverages, and nutraceutical preparations. Furthermore, the physicochemical characteristics identified in this study indicate that apple pomace may serve as a promising raw material for various industrial applications, including fermentation processes, bioactive compound extraction, and the development of value-added food ingredients. From a sustainability perspective, the valorization of apple processing by-products represents an important strategy for reducing agro-industrial waste and promoting resource efficiency within the food supply chain. Transforming apple pomace into functional food ingredients or nutraceutical products not only contributes to waste reduction but also supports the development of circular bioeconomy models in the agro-food sector. Overall, the findings of this study emphasize that apple processing waste should be considered a valuable bioresource with significant nutritional and technological potential. Future research should focus on the optimization of processing techniques, stabilization methods, and the recovery of bioactive compounds in order to fully exploit the industrial and functional applications of apple pomace.

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