**Nutritional Profile and Functional Attributes of Almond Press Cake as a Sustainable Food Source**

**ABSTRACT**

**Aims:** The rising demand for sustainable and nutrient-rich foods has intensified interest in using agro-industrial byproducts, particularly oilseed press cakes, as functional food ingredients. This study investigates the functional and proximate composition of almond press cake (APC), a byproduct of cold-pressed almond oil extraction.

**Place and duration of study:** The present research work was done in the Department of Home Science, Kurukshetra University, Kurukshetra, between April 2024 to April 2025.

**Methodology:** The almond press cake was procured from Multan Oil Kolhu, New Delhi, on the day of extraction. The almond press cake was defatted and evaluated for changes in bulk density, water and oil absorption capacity, swelling capacity. Effect of defatting was also assessed on the proximate composition of almond press cake.

**Results:** Results indicated that defatting significantly(p≤0.05) improved the functional properties of the flour, increasing the bulk density (38.18%), tapped bulk density (4.88%) and water absorption capacity (8.69%). Proximate analysis revealed that the protein content significantly (p≤0.05) increased from 43.63% to 48.86%, while the fat content decreased from 5.28% to 0.92% significantly (p≤0.01). Additionally, the defatted APC showed improved levels of dietary fiber and ash, confirming its potential as an effective functional ingredient in food formulations.

**Conclusion:** These findings underscore the potential of defatted almond press cake as a valuable plant-based resource aligned with sustainable food system goals.

*Keywords: sustainable, almond press cake, defatting, functional properties, proximate analysis.*

**1. INTRODUCTION**

The current global landscape is confronted with two major issues: food insecurity and malnutrition, which are exacerbated by climate change, population growth, and unequal access to nutrition. According to the Food and Agriculture Organization (FAO, 2023), approximately 820 million people experience chronic hunger, while over 2 billion suffer from hidden hunger or micronutrient deficiencies, which often go undetected but have serious long-term health consequences. The growing global population, which is predicted to reach 10 billion by 2050, is creating an urgent demand for affordable, sustainable plant-based protein,

and nutritious food sources. In this context, the utilization of agro-industrial waste presents a viable strategy to meet the rising demand for plant-derived proteins, which also promotes environmental sustainability (Hadidi et al., 2024). The valorisation of agro-industrial by-products, such as oil press cakes, emerges as a viable and sustainable solution. These residual materials, traditionally considered waste, can be repurposed to enhance food security and reduce environmental impact, aligning with the principles of circular economy and sustainable food production systems (Hadidi et al., 2025).

Oilseed press cakes, by-products of oil extraction, are recognized for their high-quality protein, dietary fiber, and bioactive compound content, offering substantial potential for functional food development (Garcia-Perez et al., 2021). Oil extraction is typically carried out using two conventional methods: mechanical pressing and solvent extraction. In mechanical pressing, oilseeds are heated to approximately 100 °C and then pressed using a screw press while cold pressing keeps the temperature between 50–60 °C to retain the oil’s natural properties. Solvent extraction, meanwhile, is more efficient in recovering oil, making it a preferred method for achieving higher yields (Ancuța & Sonia, 2020). Cold-pressing techniques are regarded as the ideal method for preserving the rich aromatic profile and essential macro-and micronutrients, along with other valuable bioactive compounds of oil extraction with lower energy consumption (Miljanić et al.,2021). Consequently, cold-pressed oilseed cakes are increasingly viewed as promising ingredients for human nutrition, moving beyond their conventional uses as livestock feed, plant fertilizers, or soil conditioners (Radočaj et al., 2012).

Among oilseeds, almonds (*Prunus dulcis*) are not only delicious but also the healthiest nuts due to their high nutritional value, including high levels of healthy fats, vitamin E, fiber, and antioxidants. The rising global demand for almond oil, especially in the cosmetic and pharmaceutical sectors, has resulted in a surplus of almond press cake (APC), a nutrient-dense by-product often referred to as almond meal (Hadidi et al., 2024; Houmy et al., 2021). Recent compositional analyses have demonstrated that defatted almond press cake retains substantial nutritional value, comprising approximately 27.83% protein, 16.12% dietary fiber, and 30.15% carbohydrates, as well as significant amounts of minerals, vitamins, and bioactive compounds (Naseer et al., 2021). Moreover, almond press cake is naturally gluten-free and has a visually appealing color, making it an ideal ingredient for incorporation into functional foods, such as high-protein flours, snacks, and bakery products (Houmy et al., 2023).

In the present study, defatting of almond press cake was employed to further improve its nutritional and techno-functional properties. Functional properties define the behavior of ingredients during food preparation and cooking as well as affect the appearance, texture, and taste of the final food products (Awuchi et al., 2019). The oil press cake that was obtained from expeller underwent an additional solvent de-oiling process to reduces residual oil content, thereby enhancing protein concentration and improving properties such as water absorption, oil-holding capacity, and bulk density, which are key attributes for food formulation. Such modifications are crucial for integrating APC into high-protein, functional food products aimed at health-conscious and plant-based consumers.

Therefore, this study aimed to de-fat the raw almond press cake and to evaluate the proximate composition and functional properties of both raw and defatted almond press cake, with the goal of establishing its potential as a sustainable and functional ingredient in the development of value-added food products. These outcomes are expected to contribute to nutritional enhancement, innovative product development in the functional food sector and waste reduction.

**2. MATERIALS AND METHOD**

The study was conducted on almond press cake (APC), which was obtained by extracting oil from almonds (*Prunus dulcis*), using a screw press. Almond press cake was procured from a local oil expeller in Delhi on the same day of extraction. The chemicals used for analytical procedures were of analytical grade and sourced from Sigma-Aldrich (Japan).

**2.1 Preparation of APC flour**

The APC was carefully cleaned to eliminate foreign particles. The samples were then dried at 60°C for 60 min before milling to ensure they passed through a 40-mesh sieve. The samples were packed into airtight containers and stored at refrigerated condition 4℃ for further analysis.

**2.2 Defatting of APC**

For defatting of raw almond press cake, remaining oil was removed according to the method described by Manamperi et al. (2007) with slight modifications. The oil press cake was mixed with n-hexane and stirred at 150 rpm for 1 h at room temperature (25°C). The solvent was then decanted. This process was repeated thrice. Residual hexane was removed by drying in a forced air oven at 60°C for 1 h, after which it was left for 24 h under a fume hood to eliminate the remaining solvent. The resultant defatted cake was ground to pass through 40 mesh sieves. The sample was stored at -20°C.

**2.3 Functional Properties of APC**

**2.3.1 Bulk density (BD) and tapped bulk density (TBD)**

The bulk density and tapped bulk density were determined using the method described by M. Kaur & Singh, 2007 with slight modification. A known quantity of flour sample (10 g) (M) was placed in a dry measuring cylinder, and the volume (V) was recorded for the loose bulk density. For the tapped bulk density, the cylinder was tapped 100 times on the bench top to remove voids and note the tapped volume (V2). BD and TBD were calculated using the following equation:

$$Bulk density (g/cm3)=\frac{M}{V1}$$

$$Tapped bulk density(g/cm3)=\frac{M}{V2}$$

Where M is the mass of flour and V1 and V2 are volumes for bulk and tapped bulk density respectively.

**2.3.2 Water absorption capacity (WAC)**

The method described by Onwuka, 2005 was used for the determination of WAC. One gram of flour (S) sample was added to 10 ml distilled water in a pre-weighted centrifuge tube(T). The tube was agitated on a vortex mixer for 2 min and centrifuged at 4000 rpm for 20 min. The clear supernatant was decanted and discarded. The tube was weighed (T2).

$$WAC/OAC \left(\frac{ml}{100g}\right)=(T2-\frac{\left(S+T\right)}{S})$$

where S is the sample weight, and T and T2 are the initial and final weight of centrifuge tube.

**2.3.3 Oil absorption capacity (OAC)**

The oil absorption capacity was determined using the method described by Onwuka, 2005. One gram of flour sample was mixed with 10 ml refined ground nut oil in a weighted centrifuge tube and allowed to stand at ambient temperature for 30 min. The tube was then centrifuged at 3000 rpm for 30 min. The oil was decanted properly, and the tube was weighed.

**2.3.4 Swelling capacity (SC)**

The swelling capacity was measured using the method described by Subramanian et al. (1986). One gram sample was mixed with 10 ml of distilled water in a weighted centrifuge tube. The tube was then placed in a water bath at 85℃ for 15 min and centrifuged at 2000 rpm for 30 min. The clear supernatant was decanted and discarded. Tube was weighed. The swelling power of the flour was calculated as the ratio of the final weight to the initial weight, multiplied by 100.

**2.4 Proximate analysis**

Proximate analysis was performed to determine the moisture, ash, fat, fiber, and protein content of all samples using the method described by the Association of Official Analytical Chemists (AOAC, 2010).

**2.4.1 Moisture content**

Five-gram sample was dried in a hot air oven for 3 h at 105 °C. The sample was cooled in a desiccator and weighed to determine the loss of moisture. Moisture content was calculated using the following formula:

$$Moisture \left(\%\right)=\frac{Loss in weight\left(g\right)}{weight of sample (g)}$$

**2.4.2 Ash content**

A dried sample was ignited until no charred particles remained in the crucible, and then the crucible was placed in a muffle furnace at 550°C for 6 h or until white ash was obtained. Following formula was used to calculate ash content:

$$Ash \left(\%\right)=\frac{weight of ash\left(g\right)}{weight of sample (g)}$$

**2.4.3 Crude fat content**

A moisture free sample was added to a thimble and placed in the extraction unit. Petroleum ether (approximately 150 ml) was used as the solvent. The extraction was carried out in a Soxhlet apparatus for 8 h at 80°C. The extracted fat was weighed after cooling in a desiccator employing following formua:

$$Fat \left(\%\right)=\frac{weight of fat (g)}{weightof sample\left(g\right)}$$

**2.4.4 Crude protein content**

The protein content was determined using the micro Kjeldahl method according to the standard AOAC (2000). A 0.2 g moisture-free sample was digested in a heating block at 420°C for approximately one hour 40 min. The digested sample was cooled and distilled using CLASSIC-DX. The distilled sample was titrated against 0.1 N HCL until a light pink color was obtained. A conversion factor of 6.25 was applied to convert the nitrogen content to protein content. The protein content was determined using the following formula:

$$Crude protein \left(\%\right)=0.0014×titrate volume\left(S-B\right)× Normality × F 1000 ×sample weight$$

where S= volume of HCL used in titration of sample

B= volume of HCL used in titration of blank

F= factor for converting N to protein

**2.4.5 Crude fibre content**

One gram of the fat-free sample was transferred into a crucible and inserted into the FIBRA PLUS unit. The sample was subjected to acid and alkali washes. After washing, the samples were dried in a hot air oven and weighed. The residue was ignited in a muffle furnace at 500℃ for 1-2 hours. The crucible was cooled in a desiccator and reweighed. The crude fiber content was determined by the loss in weight due to ignition using the formula:

$$Crude fibre\left(\%\right)=\frac{weight of residue-weight of ash after ignition}{weightof sample taken }$$

**2.4.6 Carbohydrate content**

The carbohydrate content was calculated using the following formula:

$$Carbohydrate \left(\%\right)=100- (Moisture+ Fat+ Protein+ Ash+ Fibre) \% $$

**2.4.7 Energy (kcal) content**

The energy content was calculated using the factorial method:

$$Energy\left(Kcal\right)=\left(4×protein\right)+\left(9×Fat\right)+(4×Carbohydrates)$$

**3. RESULTS AND DISCUSSION**

**3.1 Functional properties of APC**

The functional properties of almond press cake, in both raw and defatted, were evaluated. The parameters analysed include bulk density (BD), tapped bulk density (TBD), water absorption capacity (WAC), oil absorption capacity (OAC) and swelling capacity (SC). The findings for functional characteristics of oil press cake are displayed in table 1. The values are presented as mean value of triplicate readings ± standard deviation (SD) and were statistically analyse.

**Table 1. Functional properties of Almond press cake**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Almond press cake  | BD(g/cm3) | TBD (g/cm3) | WAC (ml/100g) | OAC (ml/100g) | SC (%) |
| Raw  | 0.55±0.05 | 0.82±0.004 | 336.8±1.90 | 156.7±4.80 | 85.84±0.44 |
| Defatted  | 0.76±0.04 | 0.86±0.01 | 366.1±4.31 | 162.2±0.96 | 78.2±0.57 |
| Percentage change  | (+38.18) | (+4.88) | (+8.69) | (+3.51) | (-8.9) |
| p value  | 0.0045\*\* | 0.0184\* | 0.0025\*\* | 0.1799 | 0.0001\*\* |

Values are represented as the mean value of triplicate readings± standard deviation (SD).

 \*Significant at p≤0.05, \*\* significant at p≤0.01

**3.1.1 Bulk and tapped bulk density**

The bulk density and tapped bulk density of flour, which include its weight and particle size, are crucial for determining optimal food packaging, processing, and handling requirements (Oladele & Aina, 2007). In this study, defatting increased both BD and TBD in almond press cake. The bulk density of APC increased from 0.55 g/ cm3 to 0.76 g/ cm3 and TBD from 0.82 to 0.86 g/ cm3, represent 38.18% and 4.88% increases in defatted samples as compared to raw samples, respectively. Defatting significantly (P≤0.05) improved the BD (P= 0.0045) and TBD (P= 0.0184) of almond press cake. This increases could be due to lipid separation, which reduces particle porosity and improves packing efficiency. Bulk density variations in foods are often influenced by starch content, with higher starch levels typically leading to increased density. Other contributing factors include particle size, shape, surface properties, and compaction methods. A high bulk density indicates that the flour is well-suited for various food applications (Iwe et al., 2016).

**3.1.2 Water and oil absorption capacity**

Defatting led to a significant (P≤0.05) increase in the water absorption capacity of almond press cake. The WAC of almond press cake increased from 336.02 ml/100g (raw) to 366.1(defatted) ml/100g. Duarte et al. (2024) previously reported the water absorption capacity (WAC) of almond press cake as 4.5g/g. In the present study, the WAC of raw almond press cake was found to be lower than the value reported by Duarte et al. 2024. Water absorption capacity is an essential functional property in foods, especially in those that involve dough handling (Iwe et al., 2016). The water absorption capacity measures the ability of a protein matrix to retain moisture under certain conditions (Tarahi et al., 2024). This property is vital for enhancing the texture and flavour of meats, soups, gravies, and baked goods. It plays a critical role in determining the texture and overall quality of the final product**.**

Almond press cake also showed significant (P≤0.05) increase in oil absorption capacity from 156.7 mg/100g to 162.2 ml/100g. In the previous study, Duarte et al. (2024) reported the OAC of APC (2.3g/g) that was higher than the present result of raw almond press cake. The observed effect can be attributed to the increased exposure of nonpolar protein sites in the defatted sample, which actively bind to hydrocarbon oil units (Rodríguez‐Miranda et al., 2012). High oil absorption capacity is beneficial for improving the organoleptic qualities of meals by improving the flavour, moisture, and fat content of food products (Sreerama et al., 2007; Suresh and Samsher, 2013)

**Fig.1. Percent change in functional properties of defatted Almond press cake**

**3.1.3 Swelling capacity**

The swelling capacity of the almond press cake decreased from 85.84±0.44% to 78.2±0.57% after defatting, that was highly significant (P<0.0001), indicating better hydration and matrix expansion. Similar trends were observed by Moure et al. (2001), who reported that the swelling capacity of press cakes from oilseeds often decreases after defatting due to changes in microstructure and loss of matrix integrity. Similarly, Zhang et al.,2018 found that defatting flaxseed cake significantly reduced swelling capacity, as oil removal resulted in a denser structure with lower water uptake. Low swelling capacity improves the texture and elasticity of noodle and pasta products; for instance, wheat starch with reduced swelling enhances the elasticity of noodles. (Kaur et al., 2023)

**3.2 Proximate composition**

The proximate composition of raw and defatted almond press cake flours is shown in Table 2. The obtained results indicated that almond press cake containing appreciable amount of protein, ash, crude fibre and carbohydrate.

**3.2.1 Moisture**

Moisture content of almond press cake exhibited a marginal, non-significant increase from 7.39% to 7.46% following defatting. This slight elevation may be attributed to increased water-binding capacity due to structural modifications in the defatted matrix. Moisture content of flours could be very important for storage stability. Roncero et al. (2021) reported the moisture content of almond press cake 9.70% with screw press and 8.36% with hydraulic press of almond that was higher than the present findings. Naseer et al. (2021) also reported 8.95% moisture content of defatted almond flour (DAF), higher than studied defatted APC (7.46%).

**3.2.2 Protein**

Almond press cake flour was noticed with a very high amount of protein ie. 43.63% which further increased to 48.86%. Defatting significantly (P≤0.05) improved the protein content (P= 0.0221\*) of almond press cake. This enhancement can be attributed to the removal of lipids, which increases the relative concentration of protein per unit weight of the sample. Previous study by Hallouch et al. (2024) reported 32.56% protein content in raw APC that was lower than present findings. The disparity could be due to differences in almond varieties, oil extraction methods, growing conditions, or post-harvest processing techniques. Moreover, the high protein content in defatted APC indicates its suitability as a plant-based protein source, especially in the context of rising consumer demand for functional, non-dairy protein alternatives and to combat protein energy malnutrition.

**3.2.3 Ash**

Present study shows that the ash content increased from 7.01% in raw almond press cake to 7.39% after defatting. Defatting significantly (P≤0.05) improved the ash content (P= 0.0488\*) of almond press cake. This increase could be attributed to the concentration effect following fat removal. In line with the present findings, Roncero et al. (2021) also observed similar ash content of APC (screw press) 7.39%. The ash content serves as an indirect indicator of the total mineral composition of the sample, which includes important micronutrients like calcium, magnesium, potassium, and phosphorus (Mansour et al., 1993). Therefore, defatted APC can be considered as a valuable source of minerals, enhancing its suitability for use in functional food products and nutritionally enriched food products.

**Table 2. Proximate composition of almond press cake**

|  |  |  |  |
| --- | --- | --- | --- |
| Constituents | Almond press cake | Percent change | P value  |
| Raw | Defatted |  |  |
| Moisture (%) | 7.39±0.031 | 7.46±0.29 | (+0.95) | 0.7234 |
| Crude protein (%) | 43.63±0.56 | 48.86±0.90 | (+11.98) | 0.0221\* |
| Crude fat (%) | 5.28±0.06 | 0.92±0.06 | (-82.58) | 0.0001\*\* |
| Ash (%) | 7.01±0.16 | 7.39±0.05 | (+5.42) | 0.0488\* |
| Crude fibre (%) | 7.80±0.20 | 8.63±0.03 | (+10.64) | 0.0161\* |
| Carbohydrate (%) | 28.90±1.80 | 26.75±1.15 | (-7.44) | 0.1705 |
| Energy value (kcal/100g) | 337.6±0.29 | 310.7±1.343 | (-7.97) | 0.0005\*\* |

Values are represented as the mean value of triplicate readings± standard deviation (SD). \*Significant at p≤0.05, \*\*significant at p≤0.01

**Fig. 2. Percent change in Proximate composition of defatted almond press cake**

**3.2.4 Crude Fat**

The crude fat content decreased from 5.28% to 0.92% followed by defatting that was statistically significant (p=<0.0001). This substantial reduction confirms the effectiveness of the solvent extraction method used (*n*-hexane), which removed most of the residual lipids left after cold pressing. The defatting process enhances the stability of the flour by reducing the susceptibility to oxidative rancidity, thus improving shelf life and storage quality. Roncero et al. (2021) observed comparatively high fat content (8.63%) in raw APC which may be due to differences in oil extraction method (e.g. screw press or hydraulic press), almond varieties, or post-harvestprocessing. Lower fat content in defatted APC flour makes it suitable for developing low-fat, high-protein food formulations, particularly in baked goods, energy bars, and health-focused snacks.

**3.2.5 Crude Fibre**

The crude fibre content for defatted almond press cake was observed to increase significantly (p=0.0161). Raw APC was noticed with 7.80% crude fibre, which increased to 8.63% after defatting. Roncero et al. (2021) reported 3.86% crude fibre content for APC that was comparatively lower than the present findings. The high fibre content of APC, especially after defatting, adds nutritional and functional value. Defatted APC may serve as a valuable fibre source in functional food formulations as dietary fibre enhances gastrointestinal health, supports weight management, and aids in the regulation of blood glucose and lipid levels (Slavin, 2013).

**3.2.6 Carbohydrates**

A reduction in carbohydrate content was observed (-7.44%), but the change was not statistically significant (p=0.1705). Raw almond press cake flour has 28.90% of carbohydrate which decreased to 26.90% after defatting. Roncero et al. (2021) also observed the similar carbohydrate content in raw APC (28.10%), while, Hallouch et al. (2024) observed 34.15% carbohydrate content in APC that was higher than the present results. While APC is not a carbohydrate-rich source, its moderate carbohydrate content, combined with high protein and fibre, makes it suitable for incorporation into functional foods, and dietary formulations where controlled carbohydrate intake is preferred. Additionally, the low glycaemic potential of nut-based flours supports their use in diabetic- and weight-management diets (Wang et al.,2021).

**3.2.7 Energy**

The energy content of raw and defatted almond press cake (APC) was recorded as 337.34 kcal and 310.7 kcal, respectively, indicating a highly significant (P<0.05) reduction (7.97%) following defatting. This reduction aligns with known principles of food composition, where lipids contribute approximately 9 kcal/g, making them the most energy-dense macronutrient (FAO, 2023). In previous study, Roncero et al. (2021) and Naseer et al. (2021) reported slightly higher energy values for APC, documenting 380.50 kcal and 380.44 kcal, respectively, than that observed in the raw APC of the present study.

**4. CONCLUSION**

This study represents the promising potential of almond press cake, an agro-industrial by-product, as a nutrient-rich and functional food ingredient. The defatting process notably enhances its functional characteristics, including bulk density, water absorption capacity as well as oil absorption capacity, which are essential for effective food processing and formulation. Furthermore, the defatting process improves its nutritional profile by increasing protein and fibre content while decreasing fat and energy levels. The high protein content, combined with its gluten-free nature and the presence of beneficial bioactive compounds, positions defatted almond press cake as a sustainable, cost-effective, and health-promoting ingredient. Its application in the development of plant-based functional foods resonates well with current initiatives aimed at reducing food waste and fostering circular economy practices.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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