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FABRICATION AND CHARACTERIZATION OF ALMOND MILK POWDER SUPPLEMENTED WITH PUMPKIN SEED POWDER FOR PHYSICOCHEMICAL, BIO-FUNCTIONAL, AND ORGANOLEPTIC PROPERTIES

Saria Yousaf[*1], Aleena Faryad[2], Aimen Shabbir[3], Mahmood Khan[4], Aksefatima Yaqoob[5], Iqra Ramzan[6], Ayesha Usman[7], Maham Zulfiaqar[8], Anas Shakoor[9], Mahnoor Tanveer[10]

[1,2,4,7,8,10]*National Institute of Food Science and Technology, University of Agriculture, Faisalabad, Pakistan.*
[3]*NFC- Institute of Engineering and Technology, Multan, Pakistan.*
[5]*Department of Human Nutrition and Dietetics, Government College University, Faisalabad, Pakistan.*
[6]*School of Food and Agricultural Sciences, University of Management and Technology, Lahore, Pakistan.*
[9]*Department of Food Science and Technology, UAF-Constituent College, Burewala, Pakistan.*

[*1]sariayousaf73@gmail.com

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Corresponding Author: *
Saria Yousaf

Abstract
Almond milk is a plant-based dairy alternative widely consumed by individuals with lactose intolerance, offering nutritional benefits such as low saturated fat and cholesterol; however, it lacks sufficient iron content, limiting its role in addressing iron deficiency anemia a condition that affects a significant portion of the global population, particularly women and children. This study aimed to enhance the nutritional profile of almond milk powder by fortifying it with pumpkin seed powder (PSP), a natural source of iron and other essential nutrients. Five formulations were developed using 0%, 20%, 25%, 30%, and 35% PSP and spray-dried to produce fortified almond milk powders. Results showed that proximate composition such as protein, fat, fiber, and ash contents, was significantly increased with increasing PSP levels, indicating improved nutritional quality. Similarly, the incorporation of PSP significantly increased the biofunctional properties (total phenolic content, total flavonoid content, and antioxidant activity) and mineral composition (potassium, magnesium, phosphorus, and iron). Sensory evaluation results showed that T_4 (35% PSP) obtained the highest scores among the treatments. These findings demonstrate that pumpkin seed powder is an effective natural fortificant, and its incorporation through spray drying offers a promising approach for developing iron-rich almond milk powder that could help mitigate iron deficiency anemia through regular dietary use.

INTRODUCTION

Almonds *(Prunus dulcis)* are a nutrient-dense food. It contains 6.27 mg of vitamin E, 76 mg of calcium, 136 mg of phosphorus, 208 mg of potassium, 14.2g total fat, 3.5g dietary fiber, and 6g of protein in one serving (1 ounce/28.4 grams). Phytochemicals found in almonds include phytosterols, phenolic acids, and polyphenolic substances like pro-anthocyanidins and flavonoids, which have been linked to anti-inflammatory and antioxidant qualities. Protein, dietary fiber, unsaturated fatty acids, and micronutrients are abundant in almonds, which are nutrient-dense meals (Dikariyanto *et al.,* 2021). Spray-dried skim milk powders were considered to be non-wettable, slightly dispersible, and moderately soluble, with particle sizes ranging from 14 to 20 mm (O'Neil *et al.,* 2016). Almond milk, soy milk, peanut milk, and other plant-based beverages are starting to gain popularity as healthy non-diary beverage substitutes in Europe and the USA. Those with lactose intolerance and cow milk hypersensitivity particularly favor almond milk. Nutrients such as α-tocopherol, essential fatty acids, dietary fiber, and numerous other phytochemicals are also abundant in almond milk. Almond milk consumption is also associated with a lower risk of coronary heart disease (Ceylan *et al.,* 2022).

Powdered vegetable milks have a longer shelf life, need less space for storage and transit, prevent probiotic growth, and are simple and convenient for customers to use. One widely suggested technique for drying vegetable beverages is spray drying. Food fortification is a method that has a greater and longer-lasting impact on addressing malnutrition. Additionally, fortification could enhance the food and its nutrients (García *et al.,* 2022). Iron (Fe) is a vital element for our bodies. Depending on the growth stage, gender, and nutrition, the human body needs between 5 and 30 milligrams of iron each day (Dehnad *et al.,* 2023).

Pumpkin seeds are high in protein (37–45%), fat (25–37%), dietary fiber (16–24%), and minerals (4.59%) making them a viable substitute for nutritional enrichment or fortification of food products. Apart from vital nutrients like protein, carbs, and fats, the body also needs minerals like calcium, magnesium, iron, and zinc. The human body's basic physiological processes and enzymatic activity depend on minerals (Zlateva *et al.,* 2022). Globally, iron deficiency anemia (IDA) is a nutritional condition that is particularly problematic in underdeveloped nations. Pumpkin seeds are thought to help treat iron insufficiency because of their greater iron concentration. Iron is essential for carrying oxygen in both the blood's hemoglobin and the muscles' myoglobin. Pumpkin seeds of different varieties had an iron content in the range of 6.66–13.66 mg/100 g (Singh *et al.,* 2024).

The optimal input air temperature for this product under spray drying conditions was found to be 180 °C. Almond milk was delivered to the spray dryer by a peristaltic pump with speed10 rpm and a flow rate of 25 mL min^{-1}, after it had been sterilized for 30 minutes at 200°C air temperature. After that, the milk was sprayed through an atomizer with a nozzle having a diameter of 0.7 mm and a chamber air pressure of roughly 8 bar. During the feeding process, the powder was collected in a stainless-steel container and stored in polyethylene vacuum bags for further analysis (Lipan *et al.,* 2020).

Spray-dried almond milk powder fortified with pumpkin seed powder as an iron source offers immense commercialization potential. The product offers a plant-based, iron fortified option for individuals wishing to enrich their diets. Being in p owder form, the product offers long shelf life, easy storage, and easy preparation, thus making it user-friendly. It can be consumed in smoothies, coffee, baking, or as a dairy-free milk alternative. With the increasing demand for healthy, plant-based, and functional foods, this fortified almond milk powder can appeal to health-conscious consumers, vegans, and individuals with iron deficiencies. Its nutritional value and versatility make it a worthwhile addition to the functional food market. The present study aimed to develop almond milk powder supplemented with various concentrations of pumpkin seeds. Subsequently, investigate the effect of varying concentrations of pumpkin seed powder on the physicochemical, phytochemical, mineral profile, and sensory evaluation of fortified almond milk powder.

MATERIALS AND METHODS

Procurement of raw materials

All the raw materials were procured from the local market of Faisalabad. All chemicals and reagents were used of analytical grade (Merck, Germany).

Product Development

The product was developed using almond milk with the incorporation of varying concentrations of pumpkin seed powder as outlined in the treatments:

T_0 (100% almond milk powder, plain), T_1 (80% almond milk powder with 20% pumpkin seed powder), T_2 (75% almond milk powder with 25% pumpkin seed powder), T_3 (70% almond milk powder with 30% pumpkin seed powder), and T_4 (65% almond milk powder with 35% pumpkin seed powder). The preparation of iron-fortified almond milk began with the careful selection of clean, dirt-free almonds, which were thoroughly washed under flowing water and manually inspected to remove damaged kernels. One kilogram of selected almonds was then soaked in distilled water at a 1:3 (w/w) almond-to-water ratio for 14 hours at 37°C, followed by peeling. The soaked almonds were ground for two to three minutes using a high-speed grinder with a 1:7 water volume to obtain a fine slurry. This slurry was filtered through muslin cloth to separate the okara, yielding raw almond milk, which was subsequently pasteurized by heating at 80–85°C for 15 minutes to ensure microbial safety and product quality, and then allowed to cool gradually.

The pasteurized almond milk was converted into almond milk powder using spray drying technology, which involved atomizing the liquid milk into fine droplets and exposing them to a stream of hot air under controlled conditions. Standard spray drying protocols were followed, including the regulation of inlet and outlet air temperatures, feed flow rate, and atomization pressure to ensure efficient moisture removal while preserving nutritional and sensory quality. Typically, a high inlet temperature was used to enable rapid drying while maintaining a suitable outlet temperature to prevent thermal degradation of heat-sensitive components. The resulting fine powder was collected and stored under hygienic conditions. For iron fortification, pumpkin seed powder, a natural source of iron, was incorporated into the almond milk powder at the specified treatment levels to enhance its nutritional value.

Proximate Analysis of Product

The proximate composition (moisture, fat, protein, fiber, ash, and carbohydrate contents) of supplemented almond milk powder was determined according to the AOAC (2023) as reported in literature (Asif et al., 2023).

Physicochemical Analysis of Product

pH

The pH of the supplemented powder was measured using the AOAC (2023) protocol with a digital pH meter. 30 grams of the sample were dissolved in distilled water and transferred into a clean beaker. The electrode was immersed in the solution, and the pH was recorded. This measurement was repeated three times to ensure accuracy and reproducibility

Bulk Density

Bulk Density (BD) was calculated according to the procedure described by Singh *et al.* (2021). It is the mass of powder divided by the bulk volume.

$$BD = \frac{mass\ of\ sample}{volume\ of\ sample}$$

Tapped Density

It is the ratio of the powder's mass to the volume after mechanical tapping until a constant volume is achieved. Tapped Density (TD) was determined by following Padma *et al.* (2010).

$$TD\ (\frac{g}{mL}) = \frac{m}{V_f}$$

Here, m = mass of the powder, V_f = final tapped volume

Flowability and cohesiveness

The flowability and cohesiveness of the spray-dried almond milk powder were assessed by determining its bulk and tapped densities. Approximately 2 g of the powder sample was gently filled into a 10 mL graduated cylinder, and the initial volume was recorded to calculate the bulk density. The same cylinder was then tapped 50 times on a smooth, padded surface to obtain a constant final volume, which was used to calculate the tapped density. Bulk and tapped densities were expressed as the ratio of sample mass to the corresponding volume. The Carr Index (CI) and Hausner Ratio (HR) were subsequently calculated from these density values to evaluate the powder's flow characteristics, packing behavior, and cohesiveness. These indices are widely used indicators of powder flowability and compressibility (Singh *et al.*, 2022).

$$\text{Carr Index} = \frac{Tap\ desnity - bulk\ density}{tap\ density}$$

$$\text{Hausner Ratio} = \frac{Tap\ desnity}{bulk\ density}$$

Bio-functional Characterization

Total phenolic Contents (TPC)

TPC in supplemented almond powder was determined using the suggested method (lipan *et al.*, 2020). Briefly, an extract of supplemented almond powder was prepared by dissolving 2g of the sample in 20 mL of ethanol and keeping it at room temperature for 2 hours, and filtering through Whatman Filter No. 2. After that extract and FC reagent (1:1) were mixed, followed by the addition of sodium carbonate (3mL). Furthermore, this solution was placed at room temperature for 90 minutes. Then the absorbance was measured at 725nm using Spectrophotometer 752D (UV Visible, China). The standard curve of gallic acid was used as a reference sample; values were shown in terms of mg GAE/g.

Total flavonoid content (TFC)

TFC in supplemented almond milk powder was measured using the prescribed method by (Khaleel *et al.*, 2022) using quercetin as a reference. In this method, one milliliter of sample extract was added in three milliliter solution of methanol containing aluminum chloride and potassium acetate. Afterwards, the solution was diluted with distilled water (5.6 mL) and kept at room temperature for 30 min. Then, sample absorbance was observed at 415 nm wavelength using the spectrophotometer 752D (UV Visible, China). The quercetin was used as a standard, and results are shown in terms of mg QE/g.

Antioxidant activity

The antioxidant activity of the *sample* was determined using the DPPH (1,1-diphenyl-2-picrylhydrazyl) assay following AOAC (2023) guidelines. A 0.1 mM DPPH solution was prepared by dissolving 1.94 mg of DPPH in ethanol and making up the volume to 100 ml. After that, 2 mL of DPPH solution was mixed with 1mL extract and placed it at dark place for 30 minutes, and absorbance was measured at 517 nm using a spectrophotometer. The percentage of DPPH radical scavenging was calculated using the formula:

$$\text{Scavenging activity} = 1 - \frac{A_f}{A_0} \times 100$$

Where, A_o and A_f are the absorbance values of the blank and sample, respectively

Mineral Analysis

The mineral contents were determined by using an atomic absorption spectrophotometer (Model AA240 Varian K, Australia) according to the prescribed method (Barbosa-Pereira et al., 2021; Fatima et al., 2025). 0.5g dried sample was added with 5 mL ($HClO_4$) and 10 mL (HNO_3) in a digestion flask and heated on a hot plate until the contents became clear. After that, the digested sample was filtered and transferred to a 100 mL volumetric flask to prepare a 100 mL volume using double distilled water. Afterward, samples were run for each mineral on an atomic absorption spectrophotometer.

Sensory Evaluation

Sensory evaluation was carried out by a trained panel of judges using a 9-point hedonic scale to assess various attributes, including color, flavor, texture, and overall acceptability (Jun *et al.*, 2019; Asif et al., 2025b)

Statistical Analysis

All the experiments were carried out in triplicates and the results are presented as mean ± SD at 5% level of significance. Tukey's HSD test was used to check the extent of difference between treatments (Asif *et al.*, 2024; Asif *et al.*, 2025a).

Results and discussion

Proximate analysis

The proximate composition, such as moisture, crude fat, crude fiber, crude protein, ash, and nitrogen free extract (NFE) of supplemented almond milk powder was determined, and results are presented in Table 1. The incorporation of pumpkin seed powder (PSP) at different concentrations significantly influenced the proximate composition of almond milk powder. Moisture content increased progressively with PSP addition, ranging from 3.01% in the control (T_0) to 4.15% in T_4, indicating enhanced moisture retention due to PSP Similarly, crude fat content showed a significant rise from 23.00% in T_0 to 30.15% in T_4, attributed to the higher lipid content of pumpkin seeds, in agreement with Moraes *et al.* (2021). Fiber content also increased significantly with PSP supplementation, from 4.95% in the control to 6.76% in T_4, reflecting the naturally high soluble and insoluble fiber fractions of pumpkin seeds. Protein and ash contents were markedly enhanced with increasing PSP levels, demonstrating the nutritional enrichment of the formulation. Protein content increased from 12.60% in T_0 to 29.30% in T_4 due to the higher protein density and favorable amino acid profile of pumpkin seeds, aligning with observations by Adelerin *et al.* (2021). Ash content, indicative of total mineral matter, rose significantly from 1.99% in the control to 3.40% in T_4, reflecting improved mineral density. Conversely, nitrogen-free extract (NFE) content declined steadily from 53.89% in T_0 to 26.24% in T_4 as PSP concentration increased, indicating a shift from carbohydrate-rich components toward higher protein, fat, and mineral fractions. These results are consistent with Arshad *et al.* (2025).

Table 1. Proximate composition of almond milk supplemented with Pumpkin seed powder

Treatments	Moisture	Fat	Fiber	Protein	Ash	NFE
T_0	3.01±0.0	23.00±0.02	4.95±0.01	12.60±0.02	2.55±0.02	53.89±0.01
T_1	3.55±0.04	26.95±0.05	5.96±0.03	22.08±0.04	3.05±0.04	38.41±0.03
T_2	3.8±0.01	27.05±0.03	6.21±0.02	24.45±0.05	3.14±0.01	35.35±0.04
T_3	3.95±0.05	28.25±0.04	6.46±0.05	26.82±0.0	3.32±0.05	31.20±0.05
T_4	4.15±0.03	30.15±0.01	6.76±0.03	29.30±0.08	3.40±0.03	26.24±0.03

Mineral composition

Mineral Compositions of fortified almond milk powder are determined, and results are presented in Table 2. Results showed that the incorporation of pumpkin seed powder in almond milk powder significantly increased ($p<0.05$) the mineral composition. The addition of 20% PSP significantly increased potassium in fortified powder up to 188.00 mg/g, compared to 35.00 mg/g in the control. The maximum potassium content was observed in T4 (302.75 mg/g). It may be due to the supplementation of the highest (35%) concentrations of pumpkin seed powder in almond milk. These results align with prior reported literature (O'Neil *et al.*, 2016; Chakraborty *et al.*, 2023).

Similarly, when PSP was incorporated into almond milk powder, magnesium content was significantly increased. Adding 20% of PSP (T_1) resulted in a substantial increase in magnesium, reflecting the high concentration typically found in pumpkin seeds (550-650 mg per 100 g). Further additions of PSP at 25 % (T_2), 30 % (T_3), and 35 % (T_4) produced proportional gains in magnesium content. This trend can be attributed to the uniform dispersion of pumpkin seed minerals during homogenization and spray drying, ensuring that even minor fortification levels yield noticeable enhancements. These findings are consistent with Hussain *et al.* (2023), who reported a 25-30 % increase in magnesium when 10-15 % pumpkin seed flour was used in biscuit formulations, and Marinelli *et al.* (2022) observed a roughly 28 % rise in magnesium content for oat-based beverages fortified with 20 % PSP, with approximately 7-8 % additional gains for every five % increase. Likewise, the incorporation of pumpkin seed powder in almond milk powder significantly ($p<0.05$) increases the phosphorus and iron contents.

Table 2. Mineral Composition of almond milk supplemented with Pumpkin seed powder

Treatments	K (mg/g)	Mg (mg/g)	P (mg/g)	Fe (mg/g)
T_0	35.0±0.01	10.0±0.05	20.0±0.03	4.0±0.01
T_1	188.0±0.07	108.0±0.09	256.0±0.04	10.0±0.02
T_2	226.25±0.03	132.5±0.03	315.0±0.02	12.25±0.06
T_3	264.5±0.04	157.0±0.01	376.0±0.05	15.0±0.04
T_4	302.75±0.02	181.5±0.06	434.0±0.07	17.5±0.03

Biofunctional characterization

Total Phenolic Content (TPC) is a critical quality attribute in food products because phenolic compounds contribute antioxidant capacity, influence flavor stability, and can extend shelf life by scavenging free radicals. In this study, different concentrations of PSP were incorporated into almond milk powder to develop iron-fortified almond milk powder. Results showed that TPC significantly increased with the incorporation of PSP (Table 3). The minimum TPC content (3.0 mg GAE/g) was measured in T_0 (control sample), and the maximum TPC content was observed in T_4 (8.25 mg GAE/g). Increasing the concentrations of PSP in almond milk powder increased the TPC contents. The total phenolic content increases with the addition of pumpkin seed powder because pumpkin seeds are naturally rich in polyphenols, which are transferred into the final almond milk powder blend. Hussain *et al.* (2023) used different concentrations of pumpkin powder in biscuits and showed that among the different treatment biscuits highest amount of total phenolics was found in the treatment with 15% addition of powder, showing a positive effect of the PSP fortification.

Flavonoids are polyphenolic compounds known for their antioxidant activity, contribution to color, and role in modulating health-related pathways such as anti-inflammatory and cardioprotective effects. In this study, different concentrations of PSP were incorporated into almond milk powder for the development of fortified almond milk powder. The mean values of total flavonoid contents of different treatments of iron fortified milk powder are presented in Table 3. The minimum TFC content (2.15 mg QE/g) was measured in T_0 (control sample), and the maximum TFC content was observed in T_4 (10.14 mg QE/g). Results showed that increasing the supplementation of PSP in almond milk significantly increased the TFC. The increase in total flavonoid content with the addition of pumpkin seed powder to almond milk powder is primarily due to the bioactive compounds naturally present in pumpkin seeds. Pumpkin seeds are rich in various phenolic compounds, especially flavonoids such as quercetin, kaempferol, and apigenin. As the proportion of pumpkin seed powder increases, it contributes more of these compounds, thereby increasing the total flavonoid content in the blend. Hussain *et al.* (2023) also showed that increasing the concentration of pumpkin powder resulted in significant flavonoid content.

The antioxidant activity of fortified almond milk powder is presented in Table 3. The minimum DPPH radical scavenging activity (35.02%) was measured in T_0 (control sample), and the maximum DPPH radical scavenging activity was observed in T_4 (40.26%). Results showed that PSP incorporation into almond milk powder resulted in increased radical-scavenging activity. It may be due to pumpkin seeds, which are rich in phenolic compounds (such as flavonoids and phenolic acids), which are powerful antioxidants. These compounds donate hydrogen atoms to DPPH free radicals, neutralizing them and increasing scavenging activity. Patel *et al.* (2023) reported that adding 20-40 % pumpkin seed flour to rice-based beverages increased DPPH inhibition.

Table 3. Biofunctional Characterization of almond milk powder supplemented with Pumpkin seed powder

Treatments	TPC	TFC	DPPH (%)
T_0	3.0 ±0.01	2.15±0.02	35.02±0.01
T_1	6.01±0.03	6.72±0.01	38.01±0.03
T_2	6.75±0.02	7.86±0.04	38.76±0.02
T_3	7.50±0.05	9.01±0.05	39.50±0.05
T_4	8.25±0.03	10.14±0.03	40.26±0.03

Physicochemical properties

pH is a critical parameter that reflects acidity or alkalinity and influences microbial stability, protein solubility, and overall sensory perception in food products. Almond milk typically exhibits a mildly acidic to near-neutral pH, and ingredients with neutral or slightly acidic pH values are unlikely to cause drastic shifts in acidity. The pH of fortified almond milk powder in different samples was determined, and the results are shown in Table 4. The minimum pH was observed in the control sample (6.55), and the maximum pH was observed in T_4 (6.71). These findings are in line with a previous study by Pourmohammadi *et al.* (2020) studied that the highest pH was observed in powdered drinks fortified with pumpkin seed, which was 6.4. Nasir *et al.* (2021) similarly reported that adding protein- and fiber-rich ingredients to plant-based milk analogues produced a pH of 6.6.

Flowability refers to the ability of a powder to flow freely and consistently under gravity or applied force. It is a critical property in the handling, processing, packaging, and storage of powdered food products. Different concentrations of PSP were added to almond milk powder to develop iron-fortified almond milk powder. Mean values of flowability of fortified almond milk powder are presented in Table 4. Maximum Flowability was recorded in T_0 (22.05 g/s) and minimum in T_4 (13.25 g/s). Results revealed that increasing the concentration of PSP in almond milk powder significant decrease in flowability. These findings are correlated with previous research reported by Nyam *et al.* (2013), which showed that the addition of pumpkin seed powder to milk powder decreased the flowability of the resulting powder blend.

Bulk density, measured as mass per unit volume (g/cm³), is a critical functional property in food powder due to its direct impact on packaging efficiency, storage requirements, and reconstitution behavior. In this study, different concentrations of PSP were incorporated into almond milk powder to develop iron-fortified almond milk powder. The bulk density of iron fortified almond milk powder samples is presented in Table 4. The minimum bulk density was observed in T_0 (0.50 g/cm³) and the maximum bulk density was measured in T_4 (0.57 g/cm³). It may be due to the addition of PSP, which are rich in proteins and fats, which are denser than carbohydrates typically found in almond milk powder. Their incorporation increases the overall solid mass per unit volume, leading to increased bulk density. These results are in line with a previous study reported by Apostol *et al.* (2020), which showed the highest bulk density was found in samples of 0.83 g/cm³, whereas the lowest bulk density was 0.80 g/cm³ in the drinks fortified with pumpkin powder.

Tapped density, measured as the consolidated mass per unit volume (g/cm³) after mechanical compaction, is a critical indicator of powder packing efficiency and flow characteristics in food processing. In this study, different concentrations of PSP were incorporated into almond milk powder to develop iron-fortified almond milk powder. The mean values of tapped density are mentioned in Table 4. The maximum tapped density was observed in the control sample (0.60 g/cm³), and the minimum tapped density was measured in T_4 (0.50 g/cm³). Results revealed that the incorporation of PSP into the almond milk powder tapped density was significantly decreased. The decrease in tapped density with increasing levels of pumpkin seed powder is due to the combined effects of lower particle density, irregular morphology, higher porosity, and increased cohesiveness. These outcomes are correlated with a previous study reported by Rodríguez- Pourmohammadi *et al.* (2020), which investigated a similar decline of 0.015-0.025 g/cm³ per 10% seed addition in almond blends due to enhanced porosity.

Table 4. Physicochemical properties of almond milk powder supplemented with pumpkin seed powder				
Treatments	pH	Flowability(g/s)	Bulk Density (g/cm^3)	Tapped Density
T_0	6.55±0.03	20.05±0.03	0.50±0.01	0.60±0.03
T_1	6.64±0.01	18.35±0.01	0.52±0.03	0.57±0.06
T_2	6.66±0.02	17.25±0.02	0.54±0.02	0.55±0.04
T_3	6.68±0.03	16.01±0.06	0.56±0.05	0.53±0.05
T_4	6.71±0.05	13.25±0.01	0.57±0.03	0.50±0.01

Sensory Evaluation

Sensory parameter was checked, such as color, texture, flavor, and overall acceptability. Sensory parameters of fortified almond milk powder were analyzed using a 9-hedonic scale by trained judges. The color score of almond milk powder supplemented with pumpkin seed powder was measured, and the results are presented in Figure 1. The minimum color score was observed in the control sample (7.12), and T_4 obtained the maximum color score (8.05). Increasing the concentration of SPS in almond milk powder significantly increased. The results of the present findings are correlated with a previous study reported b Asaduzzaman *et al.* (2025), which investigated that plant-based milks fortified with 15 % pumpkin seed flour exhibited higher consumer color preference scores. Flavor refers to the combined sensory impression of food or other substances, primarily determined by taste, smell (aroma), and sometimes texture, temperature, and chemical sensations present in food. The minimum flavor score was observed in the control sample (6.82), and T_4 obtained the maximum color score (7.23). The mean values of the texture score of iron fortified almond milk powder are presented in Figure 1. The maximum texture score was observed in the control sample (7.21), and T_4 obtained the minimum texture score (5.62). Increasing the concentration of SPS in almond milk powder significantly decreased the texture score. The sensory texture of almond milk powder formulations was found to decrease with the increasing addition of pumpkin seed powder. pumpkin seed powder possesses lower solubility and dispersibility compared to almond powder, contributing to a gritty or sandy mouthfeel upon reconstitution (Ungureanu *et al.,* 2025). Overall acceptability is defined as the comprehensive sensory evaluation of a food product, reflecting the combined perception of its color, aroma, flavor, texture, and taste**,** as judged by the consumer or sensory panel. Results showed a highly significant difference among the treatments, indicating that PSP addition significantly influences the acceptability score of iron fortified almond milk powder.

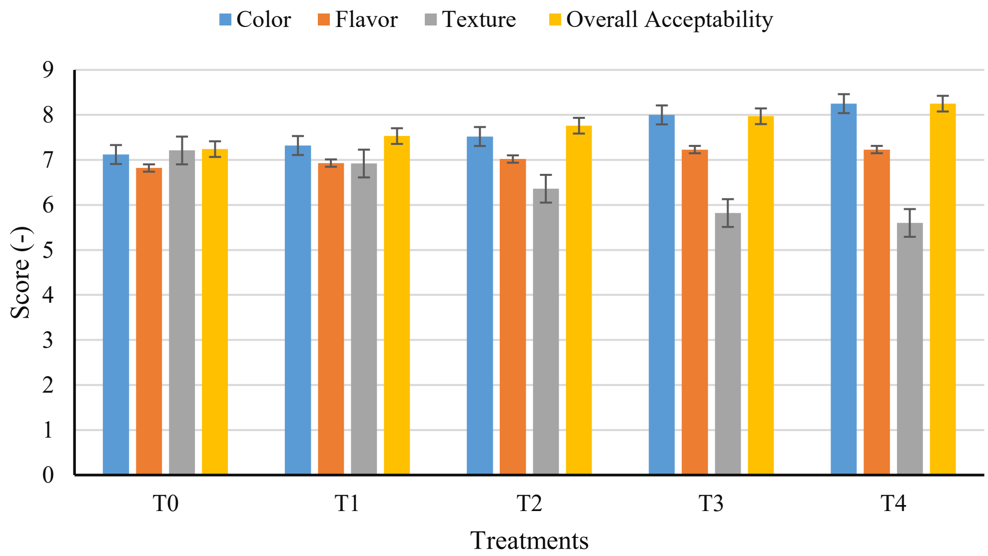

Figure 1. Graphical representation of sensory evaluation of almond milk powder supplemented with pumpkin seed powder

Conclusion

This study aimed to develop almond milk powder supplemented with varying concentrations of pumpkin seed powder using spray-drying techniques. Results revealed that incorporation of PSP significantly enhances the proximate composition, such as protein, fat, fiber, and ash contents, while decreasing its nitrogen-free extract. Mineral analysis showed that the addition of PSP (35%) significantly increased the iron, potassium, magnesium, and phosphorus contents in fortified almond milk powder. Moreover, the supplementation of PSP in almond milk powder enhanced the biofunctional and physicochemical properties. Organoleptic properties results confirmed that 35% PSP containing almond milk treatment is best. In conclusion, pumpkin seed powder is a promising natural fortifier for creating functional, iron-rich almond milk powder with good sensory acceptance. This plant-based approach can help treat iron deficiency anemia and satisfy the increasing demand for wholesome dairy substitutes.

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