

*Research Paper***Quality Assessment and Storage Stability of Snack Bars Enriched with Pomegranate Waste**Aamna Rabbani ^a, Asad Riaz^{a,b*}, Irum Aslam ^a^a Department of Food Science and Technology, School of Food and Agricultural Sciences, University of Management and Technology Lahore, Pakistan^b Department of Microbiology & Biotechnology, Atta-ur-Rahman School of Applied Biosciences, National University of Sciences and Technology, Islamabad, Pakistan***Corresponding author:** Asad Riaz (Asad.riaz@asab.nust.edu.pk)

Abstract: The present study examined the incorporation of pomegranate peel powder (PoP) into snack bars to enhance their nutritional profile and evaluate their quality attributes during storage. There were four treatment plans which are T0, T1, T2 and T3 with increasing levels of PoP. The snack bars were evaluated for proximate composition, instrumental color parameters (L^* , a^* , b^*), texture (hardness), and sensory attributes for storage period. Moisture values were seen same, only slight changes were recorded in T1 and T2. The incorporation of PoP significantly increased dietary fiber, the highest value was seen in 9% PoP, 10.10 ± 0.1 in T0 and 18.33 ± 0.49 in T3 $p < 0.05$ indicating its role as a functional ingredient. Color analysis revealed a progressive decrease in L^* values and corresponding increase in a^* and b^* values with increasing levels of pomegranate peel powder (PoP), reflecting the natural pigments of peel. The incorporation of PoP in the snack bars suggest highly significant impact ($p < 0.05$) between the different types of treatment and same for storage time over the interval of 7 days (Day 1, 7, 14, 21) which suggest that during storage hardness changes among treatments. Sensory evaluation indicated that moderate levels of PoP were acceptable, while higher incorporation reduced overall consumer preference due to darker color and firmer texture. These findings highlight the potential of PoP as a sustainable and functional ingredient in snack bar development.

Keyword: Pomegranate peel powder, snack bars, texture, sensory evaluation, antioxidants, functional foods

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1. Introduction

The generation of agro-industrial waste has become a significant challenge to the sustainability of the agricultural sector (Mukherjee, 2023). In the last decades, food demands have significantly increased due to a number of causes, including population growth and rising economic status. However, the quest to increase food production has drastically maximize the production of food waste (FW). According to recent estimate about 1.3 billion tonnes of food waste are produced annually world-wide, this amount

is expected to be double to 2.6 billion tonnes in 2025 (Omama et al., 2023). Food waste presents a severe sustainability challenge and if there is no improvement, then this amount expected to be double by 2050 (Crocker, 2025). Non-traditional plant based foods also have significant amount of nutrition and bioactive compounds (Sheikh et al., 2026) as well oat rich source have strong antioxidant activity (Akhtar et al., 2026; Manzoor et al., 2023). To overcome the significant challenge of food waste during food processing is the usage of the

waste materials of fruits for the development of food by-products is an innovative way to reduce environmental pollution. One of the United Nations, SDG (12th) supported by the Food and Agriculture Organization (FAO), aims to enhance human well-being by promoting sustainable use of food, water, and energy resources while minimizing waste throughout the production and consumption chain (Sustainable Development Goals FAO, 2023). Wild and under-utilized fruits and vegetables are significance source of essential nutrients, phytochemicals, minerals, and therapeutic potential. There are various methods to preserve foods like processing through drying (Younas et al., 2026) icecream formation (Syed et al., 2022), turns into pomace cake (Tariq et al., 2024) Jam (Nasir et al., 2024) and functional products (Zia 2025). Recent research has highlighted the health-enhancing potential of bioactive compounds present in fruits and foods-by-products including antioxidant, anticancer, antiproliferative, anti-neurodegenerative, antidiabetic, anti-inflammatory, hepatoprotective, and neuroprotective (Krajewska, 2023). Many agricultural and food processing by-products have been reported to possess antioxidant and antimicrobial properties comparable to or greater than those of the primary edible products (Younas et al., 2026; Asranudin, 2022).

Pomegranate (*Punica granatum* L.), a member of the family Punicaceae, is one of the oldest cultivated fruit species in the world. Pomegranate (*Punica granatum* L.) is native to Iran and the Himalayan region of Northern India and has been cultivated throughout the Mediterranean region since antiquity. The parts of pomegranate fruits is widely consumed fresh and is extensively processed into products such as fresh juice, jam, jelly, canned beverages, natural food colorants, and flavoring agents owing to its desirable sensory and nutritional properties (Viuda-Martos et al., 2010).

Around the world, the production of pomegranate exceeds 2 million tons per year.

In 2018, the global pomegranate market was valued at USD 8.2 billion and will reach USD 23.14 billion by the year 2026, as expected (Yin et al., 2023). Pakistan ranked 10th with a yearly yield of roughly about 57,800 tons in the production of pomegranate fruit. However, the yield is low, at approximately 3.88 tons per hectare. The waste of Pomegranate (*Punica granatum* L.) is one of the most valuable among the fruit waste. According to the Leta et al., 2023, Magangana et al, 2020 and Katharine et al., 2021, there were 3 million tonnes of production of pomegranate worldwide, out of which 1.62 million tonnes of waste was produced. Pomegranate peel, a common fruit by-product, contains a relatively high levels of total phenolics at 1.26%. It also has notable crude fat content at 12.17% and significant inorganic residues. These bioactive and nutrient components suggest potential health promoting properties. Reported benefits include protection against cardiovascular diseases, hypoglycemic, anti-inflammatory, anti-parasitic and prebiotic potential. Recent studies show that pomegranate peel is high in ellagitannins that improve meat products (Kushwaha et al., 2013). Due to its antioxidant properties, pomegranate peel extract has the potential to increase the α -tocopherol content of broilers. The inclusion of 200-300 mg/kg of PoP extract in the feed can further augment antioxidant capacity. These findings suggest its utility as a functional feed supplement to improve oxidative status in poultry (Saleh et al., 2017). The nutritional profile of biscuits was improved by the dried PoP because of the presence of polyphenols, fiber and β -carotene. As polyphenols are higher in PoP, the utilization of dried peel powder improves the surface quality, rheology and sensory properties of the biscuit (Srivastava et al., 2014). The PoP also shows great potential to enhance the antioxidant attributes and shelf life of curd (fermented milk products) (Sandhya et al., 2018). Sun dried PoP were incorporated in cookies at different concentration. PoP significantly affected nutritional profile by enhancing

cookies mineral content. It also positively impacted the physical attributes for instance thickness, spread ratio and weight (Muhammad et al., 2023). Furthermore, mango shelf life was improved after storage of 18 days at 4°C and 23°C in which an active antioxidant agent Px was used (0.2 g/mL) for the synthesis of chitosan-pullulan (50:50) complex edible coating and determines its efficacy in extending the shelf life of mango fruit (Kumar et al., 2021). The addition of PoP at varying concentration (0 to 10%) to increase the organoleptic properties and total antioxidant activity of wheat bread, which showed that 10% has highest antioxidant capability while 2.5% had good acceptance score in sensory attributes such as taste, mouthfeel, aroma, color and texture while 10% had lowest scored. The study shows that antioxidative capacity depended on PoP amount during storage (Altunkaya et al., 2013). Pomegranate peel extract had the highest antioxidant capacity on the three edible oils (soyabean oil, sunflower oil, corn oil) and showed low peroxide values when compared to synthetic antioxidant THBQ-200 and no antioxidant compound in oils. The results figured out that 200 ppm, 400 ppm and 600 ppm had good antioxidant activity and there is no need to apply synthetic antioxidant to the three edible oils. When compare to literature it could also provide thermal resistance and shelf life (El-Hadary & Taha, 2020).

Snackbars (SBs) also known as cereal bars, are widely used worldwide because they give rapid energy and are convenient. Snackbars have both commercial and nutritional value because they reduce direct hunger and affect consumer nutritional status (Canti et al., 2024). This situation demands that the amount of natural ingredients or functional food be increased daily (Manguldar et al., 2022).

Although fruit processing by-products have gained considerable attention as functional food ingredients, limited studies have comprehensively evaluated the incorporation of pomegranate peel powder into snack bars

and its impact on nutritional composition, physicochemical properties, antioxidant potential, sensory acceptability and storage stability. Most available studies have focused on bakery or meat products, while data on snack bars particularly concerning physicochemical characteristics, antioxidant potential, textural changes, and sensory acceptability over storage-remain scarce. Furthermore, the optimal incorporation level of pomegranate peel powder that balances enhanced nutritional and antioxidant benefits with consumer acceptability has not been clearly established.

Therefore, the objective of this study was to investigate the effect of incorporating different concentrations of pomegranate peel powder (0%, 3%, 6%, and 9%) on the quality characteristics of snack bars during 21 days of storage. The findings of this research are expected to contribute to the valorization of pomegranate peel as a sustainable functional ingredient and provide practical insights for the development of nutritionally enhanced snack bar products with acceptable quality attributes.

2. Materials and Methods

2.1 Collection of samples

Pomegranate (*Desi Anar*) was bought from the local market of Lahore, Pakistan.

2.2. Pomegranate peel powder preparation

Fresh pomegranate fruits were thoroughly washed with clean water to remove surface contaminants, including dirt, dust and residues of agrochemicals such as pesticides, fungicides, herbicides, etc. The peels were separated from the seeds and cut into small pieces. Then, peels were dried at room temperature 25-40°C. Then the dried peels having moisture level of less than 10%, were finely ground using a grinder. The obtained peel powder was subsequently stored in airtight polyethylene zip bags to prevent moisture absorption and maintain its quality (Ranjha et al., 2020).

2.3. Treatment Plan

Snack bars were supplemented with pomegranate peel powder at 3%, 6% and 9% followed as treatment T1, T2 and T3 respectively.

2.4. Snack Bar preparation

The snack bars were made by adding pomegranate peel powder at different concentration (0%, 3%, 6%, 9%). Each ingredient was precisely measured. The preparation began by roasting all the ingredients in the pan and add oil. Following with the making of jaggery paste by heating jaggery with some drops of water, heat on low flame until a thread like structure form. When jaggery paste is formed, then add all the ingredients and mixed them. Make the shape of the bars or put them in an oil greased container. The snack bars were cooled at room temperature for two hours and being kept in airtight box at ambient temperature.

2.5. Proximate analysis

Proximate evaluation of pomegranate peel powder and snack bars were performed followed by the Association of Official Analytical Chemist AOAC, (2019) to find out moisture, crude protein, ash, crude fat and carbohydrates by difference method outlined by Gerzhova et al., (2016). However, crude fiber followed AOAC (2019) and AACC 32-10.01. All procedures were conducted in triplicate to ensure precision and reliability of the results.

2.6. Texture analysis

Evaluation of the snack bars' texture has been performed using the Imada Texture Analyzer, a sphere probe of 20 diameter moved at a constant rate of compression 2 mm/sec, displacement 5 mm touching the surface of the snack bars and measured the parameters like hardness and springiness. Several experiments were done on each test to minimize data errors (Urgancı & Isık, 2021).

2.7. Color parameters of snack bars

The chromaticity of the snack bars was determined with the help of a colorimeter

since this is significant in determining the visual value of the product. The sample, when mixed in the jaggery paste was allowed to cool to room temperature and analysis was done on a plain white surface to avoid differences in lighting during the reading. Before taking measurements of the sample, the colorimeter was calibrated using a plain white reference plate and then three measurements of each sample were taken to check the surface variations. These included L^* (lightness), a^* (the ratio of red to green), and b^* (the ratio of yellow to blue), all of which define how color is represented on the snack bars. ΔE shows the total difference in color (Urgancı & Isık, 2021).

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

Whereas, $\Delta L = L_{\text{sample}} - L_{\text{control}}$,
 $\Delta a = a_{\text{sample}} - a_{\text{control}}$, $\Delta b = b_{\text{sample}} - b_{\text{control}}$.

2.8. Antioxidant activity assay

The dried and grounded peels were used for the extraction of pomegranate peel extract with 70% ethanol (w/v). 1 g peel powder with 100 mL 70% ethanol was taken to make the dilutions. The sample was placed in ultrasonic homogenizer bath for 30 minutes, after following with the rotatory evaporator at 30°C temperature until sample is done. All tests are performed at room temperature (Khan, 2017) (Yasoubi et al., 2007)

2.9. Total phenolic content (TPC)

The total phenolic content (TPC) was quantified based on the Folin-Ciocalteu reagent. Briefly, 1 mL of the sample extract was mixed with 4 mL distilled water, followed by the addition of 1 mL of 10% (v/v) Folin-Ciocalteu reagent. The mixture was allowed to stand for 5 minutes, after which 5 mL of 7.5% (w/v) of sodium carbonate (Na_2CO_3) solution was added. The reaction mixture was thoroughly mixed and incubate at room temperature for 90 minutes. The absorbance was read at 765 nm using a UV-visible spectrophotometer. Total phenolic content was calculated from a gallic acid standard calibration curve and

expressed as milligrams of gallic acid equivalents per 100 g of dry weight (mg GAE/100 g of DW) (Younas et al., 2024; Mashkor, 2014).

2.10. Radical scavenging activity (DPPH)

For the preparation of 0.1mM DPPH solution in 70% ethanol, dissolved 1.9 mg DPPH in 70% ethanol and make the volume up to 100 mL. For the DPPH assay, 1 mL of each sample extract prepared at the desired concentration was transferred into a falcon tube, followed by the addition of 3 mL of freshly prepared DPPH solution. The reaction mixture was thoroughly mixed, and the absorbance was measured at 517 nm using a UV-visible spectrophotometer immediately after mixing (0 minute) and again after 30 minutes of incubation at room temperature. Readings were taken in triplicate to avoid any error.

The formula for calculating DPPH radical scavenging activity (%) is as follows:

$$\text{RSA} \% = \frac{\text{blank absorbance} - \text{sample absorbance}}{\text{blank absorbance}} \times 100$$

Where, absorbance of the control at time 0 minutes, and the absorbance of the sample after 30 minutes (Allai et al., 2022)

2.11. Sensory evaluation of snack bars

Sensory evaluation of the snack bars was performed by trained panelists under blind conditions. Each sample was given a random alphabetical code to ensure impartial assessment. Water was provided as a palate cleanser between samples to ensure consistency. The sensory quality of the snack bars were evaluated based on appearance, texture, aroma, flavor, taste, and overall acceptability using a 9-point hedonic scale. The scale ranged from 1 (Dislike extremely) to 9 (Like extremely), with intermediate ratings of 2 = Dislike very much, 3 = Dislike moderately, 4 = Dislike slightly, 5 = Neither like nor dislike, 6 = Like slightly, 7 = Like moderately, 8 = Like very much. Upon completion of the sensory evaluation forms, scores for each attribute

were averaged and tabulated to analyze the sensory profile of the snack bars comprehensively. This method ensured thorough assessment of sensory attributes essential for understanding consumer preferences and product quality (Abraha et al., 2018).

Table 1. Mean and standard deviation (STD) for proximate analysis of pomegranate peel powder

Proximate composition	Pomegranate peel powder content
Moisture Content	7.66 ± 0.61
Ash Content	4.05 ± 0.35
Crude Fat Content	0.78 ± 0.24
Crude Protein Content	9.04 ± 0.25
Crude Fiber Content	22.2 ± 0.21
Carbohydrates (by Diff)	56.33 ± 1.13

3. Results and Discussion

3.1. Proximate analysis of powder

Proximate parameters such as moisture content, crude ash content, crude fiber, crude protein and crude fat have shown substantial effect on PoP. It has moisture content 7.6%, crude ash content 4.05%, crude fat content 0.78%, crude protein content 9.04% and crude fiber content 22.2%. Mean values and standard deviation for proximate composition analysis of pomegranate peel powder is presented in Table 1. The findings are in agreement by previous research results by Muhammad et al. (2023) stated that PoP contains moisture content 7.78%, ash 4.6%, fat 0.64%, crude fiber 14.82%, and crude protein 2.96%. These outcomes are consistent with the Kaur et al. (2023) that peel powder has the moisture 8.43%, protein 3.24%, fat 0.55%, crude fiber 35.19%. The findings of carbohydrates in the pomegranate peel powder are 56.33% based on using the difference method that has significant effect

on PoP and this result is supported by study Kaur et al. (2023) that described carbohydrates in pomegranate peel powder are 59.52%.

3.2. Antioxidant activity of pomegranate peel powder

3.2.1. TPC and DPPH

The mean total phenolic content (TPC) and DPPH radical scavenging activity of the pomegranate peel powder were 478.27 mg GAE/100 g and 30.23% respectively. The phytochemical composition of peel powder is presented in Table 2. The obtained TPC values are elevated than that reported by Muhammad et al. (2023), who observed a TPC of 350 mg GAE/100 g, whereas their reported DPPH radical scavenging activity (42%) was higher than that observed in the present study. Similarly, Sweidan et al. (2023) reported a TPC of 297.70 mg GAE/100 g, whereas the present study yielded a substantial upward trend. The variations in TPC and antioxidant activity among studies may be attributed to differences in pomegranate cultivator, geographical origin, maturity stage, extraction method, solvent type and analytical conditions.

Table 1. Antioxidant activity of pomegranate peel powder

Antioxidant Activity	Pomegranate peel powder
DPPH	30.23 ± 0.5 %
TPC	478.27 ± 0.58 mg GAE/100 g

3.3. Proximate content of pomegranate peel enriched snackbars

The proximate analysis of the pomegranate peel powder enriched bars are presented in Table 3. Moisture content is a significant factor that influence physical characteristics and shelf life of food and also quality

attributes such as freshness (Pinela & Ferreira, 2017). The Statistical analysis showed that $p > 0.05$, there is a statistically non-significant difference among the group although the result confirms a slight difference between the treatments. The moisture content from T0 to T2 increases and T3 shows a drop which means increasing the amount of pomegranate decreases moisture content. It is because pomegranate peel powder has higher water binding capacity. The findings are aligned with the study by Gadallah Shabib & El-Hazmi, (2022) that the moisture content of fiber-enriched cupcakes was affected by the inclusion of pomegranate peel powder, the decreased from 13.25% to 11.25% was recorded and influence moisture retention within the product matrix.

The protein content of the snack bar samples compared with the control, the fortified treatments exhibited statistically significant difference ($p < 0.05$). The highest protein content was observed in T3 (11.13), while the control sample T0 exhibited the least protein content (8.5). Protein content of different treatments is T0, T1, T2 and T3 has 8.5%, 9.7%, 10.4% and 11.13% respectively.

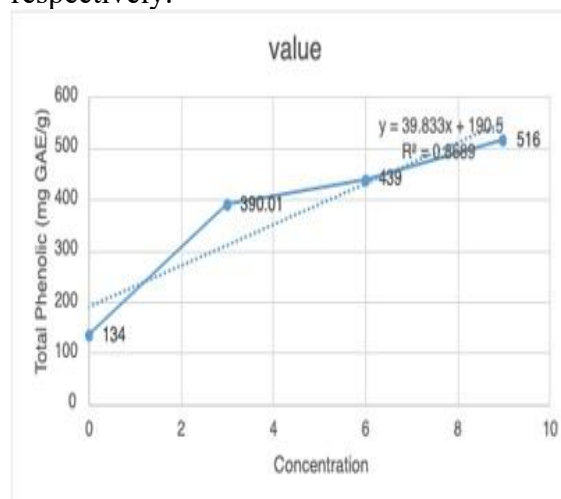


Figure 1. Total phenolic content (TPC) of pomegranate peel powder (PoP) supplemented bars expressed as mg GAE/g.

The increase in protein of the bars attributed to the incorporation of pomegranate peel powder (PoP), which contributes additional nutrients and bioactive components to the

product matrix. Similarly, Pamisetty et al., 2020 observed same trend of increase protein in bread by the addition of pomegranate seed powder.

Crude Fat is an important source of energy as it contributes in many functions in the human body. The crude fat content of pomegranate peel powder-based bars exhibited a significant variation ($p < 0.05$) among the treatment groups with varying levels of pomegranate peel powder incorporation. The maximum crude fat content was recorded in T3 (16.69%), whereas the least value was noted in T0 (9.56%). The following values are 9.56%, 12.81%, 15.02%, and 16.69% of T0, T1, T2 and T3 respectively. The result demonstrates that crude fat content increases with the increase of PoP. The increase of fat content also seen by Singh et al., 2022 findings that fat is increased in the cookies enriched with banana peel compare to control group.

The crude fiber content across different treatments shows a significant result ($p < 0.05$) by PoP-treated snack bars. The fiber content of T0, T1, T2 and T3 are 10.1%, 11.65%, 14.43% and 18.33% respectively. The highest amount is observed in T3 which has 9% of PoP. The outcomes of this observation are comparable by earlier research, which reported similar observations by the Jumaa Jandal & Naji, 2021 that reported upward trend in fiber as the fortification of powder increases T1, T2 and T3 having 0.85%, 0.95% and 1.18% respectively.

In the present study, a significant variation ($p < 0.05$) in crude ash content among the PoP-fortified formulation of snack bars was observed. The crude ash content ranged from 3.20% to 3.92%. The data demonstrated an increasing trend in ash content with the increasing incorporation level of fortifying ingredient. Progressive rise in ash content was recorded in T4 (3.92%). The ash content for T0, T1, T2 and T3 are 3.2%, 3.39%, 3.63% and 3.92% respectively. The progressive rise in ash content with elevated levels of fruit by-

product incorporation may be due to the inherent mineral composition of peel powder. In other findings reported by Malekpour & Ansari, 2020 that the ash content increases in cupcakes when prepared with pomegranate peel powder (PoP).

Carbohydrates are calculated by the difference method mention by Gerzhova et al., (2016). Results revealed a significant difference $p < 0.05$ ($p = 0.000$, $F = 51.223$) between the treatments of snack bars containing different concentration of PoP. T0 has the highest value 56.88 while lowest value is recorded in T3 38.92. The mean values of carbohydrates. The study also correlated by Sangathi & Soni, 2024, the buckwheat incorporation in cereal bar reported 63.83% carbohydrates. Ranjha et al., 2020 also reported 62.05 carbohydrates in functional date bars added PoP 3%.

3.4. Antioxidant analysis

The phenolic compounds prevent oxidative damage by suppressing the oxidative species reaction and support defense mechanism and it is called oxidation reduction property. TPC of snack bars developed with pomegranate peel powder show significant increase. Pomegranate peel rich in polyphenols and due to this property, it act as antifungal, antibacterial, antiviral, anti-inflammatory and cardio-protective activities (Wronka et al., 2022; Rani et al., 2025). The result of TPC in this study ranges between 134-516 mg GAE/ 100 g by the inclusion of pomegranate peel powder. The value of TPC for T0, T1, T2 and T3 are 134, 390.01, 439, and 516 mg GAE/100 g respectively. Figure 1 illustrates the total phenolic content (TPC) of the snack bars. It is evident from the data that higher the ratio of pomegranate peel powder resulted in progressive increase in total phenolic content (TPC). The highest TPC value was observed in T4 (9% of pomegranate peel powder) with a value of 516 mg GAE/100 g which may contributed to the high concentration of phenolic compounds naturally present in pomegranate peel

powder. Similar findings were reported by Salem, 2020 who reported

Table 2. Proximate results of pomegranate peel enriched bars

Treatments	Moisture	Protein	Fat	Fiber	Ash	Carbohydrates (by Difference method)
T0	11.72±1.6	8.51±0.2	9.56±0.2	10.1±0.1	3.2±0.1	56.88± 1.6
T1	12.41±0.2	9.72±0.1	12.81±0.3	11.65±0.05	3.39±0.2	50.11± 0.4
T2	13.22±2.7	10.41±0.05	15.02±0.3	14.43±0.4	3.63±0.03	43.23± 3.1
T3	11.01±0.8	11.13±0.1	16.69±0.2	18.33±0.4	3.92±0.04	38.92± 1.2

Table 4. Antioxidant activity of pomegranate peel enriched snackbars

Treatments	DPPH %	TPC (mg GAE/100 g)
T0	21.8 ± 0.2	134 ± 0.3
T1	32.50 ± 0.3	390 ± 0.3
T2	44 ± 0.1	439 ± 0.2
T3	63.75 ± 0.2	516 ± 0.1

Table 3. Texture analysis of pomegranate peel enriched bars

Texture Hardness (N/m ²)				
Treatments	Storage Duration (Days)			
	Day 1	Day 7	Day 14	Day 21
T0	2.22× 10 ³ ± 0.2	2.55 × 10 ³ ± 0.1	1.52 × 10 ³ ± 0.35	1.38 × 10 ³ ± 0.16
T1	2.05× 10 ³ ± 0.5	3.20 × 10 ³ ± 0.02	3.27 × 10 ³ ± 0.09	1.53 × 10 ³ ± 0.37
T2	3.14× 10 ³ ± 0.6	1.20 × 10 ³ ± 0.06	3.33 × 10 ³ ± 0.16	2.95 × 10 ³ ± 0.07
T3	3.18× 10 ³ ± 0.11	2.27 × 10 ³ ± 0.07	1.79 × 10 ³ ± 0.28	1.2710 ³ ± 0.1

higher TPC of biscuits enriched with pomegranate peel powder from 36.52 mg GAE/100g in the control sample to 71.78 mg GAE/100g in biscuits containing 10% pomegranate peel powder.

DPPH is the process of finding the antioxidant activity, that protects the human body against harmful free radical elements (chain reaction). Pomegranate peel have naturally antioxidant activity, one of the most prominent natural antioxidants in the

pomegranate peel present abundantly is ellagic acid (Yang et al., 2023). The observation of this study outlined with the Essa & Mohamed, 2018 who reported addition of PoP 3%, 5% and 7% in spaghetti increases DPPH 48.83%, 61.98% and 81.62% respectively. Table 4 presents the antioxidant activity of snack bars formulated with different levels of pomegranate peel powder (PoP).

3.5. Storage Study

3.5.1. Texture analysis

The textural characteristics of snack bars plays a crucial role in determination consumer acceptability. The bars were analyzed to determine whether compression induced any structural changes. The maximum compression force recorded during the test was considered an indicator of its hardness of the snack bars. The incorporation of pomegranate peel in the snack bars suggest highly significant impact $p < 0.05$ among the different types of treatment and same for storage time over the interval of 7 days (Day 1, 7, 14, 21) which suggest that during storage hardness changes among treatments. The rise in hardness is likely is due to the increased level of pomegranate peel powder and its high fiber content. The findings are consistent with Singh et al., 2022 that addition of banana peel increase the hardness of the snack bar. the control sample has 7.45 mean compression which increases to 7.71 mean. The result of the present study are in agreement with Abd El Moneem et al., 2021, who reported a statistically significant increase ($p < 0.05$) in the fiber content of snacks with increasing supplementation levels of pomegranate peel powder. The control sampled showed lowest fiber content, while the incorporation of higher levels of peel powder resulted in enhanced fiber content due to the naturally high dietary fiber composition of pomegranate peel. The maximum fiber was studied in T5. Ayoubi et al., 2022 reported that increase in hardness of cupcake texture as pomegranate peel powder increases. The texture

(hardness) values of the snack bars under different treatments and storage periods are presented in Table 5.

3.5.2. Color analysis through E-value

The E-value (ΔE) indicates that total color difference, was significantly affected by treatment $p < 0.05$ same as for storage duration $p < 0.05$. The difference between day 1 color as standard and other days at 7-day interval shows progressive visual difference. These differences are also influenced by the different concentration of PoP. The outcome of these findings are inline with the study of Essa & Mohamed, (2018) which stated that use of pomegranate peel powder in the spaghetti has more intense color. The study by Urgancı & Isık, 2021 also observed that ΔE of biscuits increases with fortification with pomegranate peel powder (PoP). Table 6 between different treatments and storage days 1-21.

3.6. Sensory Evaluation

Sensory evaluation of the snack bars had 6 parameters taste, texture, appearance, aroma, mouthfeel and overacceptibility (OA). The statistical result of taste, texture, appearance, aroma and OA shows the non-significant result $p > 0.05$ which means there is no change in the parameters among treatments during the storage period. While the statistical difference of mouthfeel is above the threshold level $p = 0.06$, it may suggest that the different concentration of pomegranate peel may affect mouth feel, though his result is not statistically significant. Table 7(a), 7(b), 7(c) and 7(d) presented the sensory evaluation results obtained on Days 1, 7, 14 and 21 respectively. The study by Giri et al., 2024 also observe lowest score with the 8% PoP in the muffin. The taste of the muffin with 8 % PoP was bitter as compared to the other treatments. In another, findings by Zubair et al., 2024 the results obtained T2 (10% PoP) has highest overall acceptability than T3 (15 % PoP). Malekpour & Ansari, 2020 observed that among the treatment 1.5 % PoP cake has highest score while 7.5% PoP

scores the lowest. Similar trends were observed in carrot pomace (Tariq et al., 2024). The study suggested by Essa &

Mohamed, 2018 that appearance is accepted with the value

Table 4. E-value (color difference between day 1 and 7, 14 and 21)

Treatments	E-value			
	Days			
	Day 1	Day 7	Day 14	Day 21
T0	67.44 ± 1.94	2.78 ± 1.72	2.12 ± 1.81	17.26 ± 1.50
T1	68.87 ± 2.1	6.73 ± 4.53	3.56 ± 2.32	5.22 ± 0.5
T2	67.58 ± 1.6	3.87 ± 1.8	3.29 ± 1.79	5.74 ± 2.73
T3	74.45 ± 0.83	4.08 ± 0.70	9.15 ± 1.39	7.52 ± 2.38

Table 5(a). Sensory evaluation at Day 1

Treatments	Taste	Aroma	Texture	Appearance	Mouthfeel	OA
T0	7.25 ± 0.70	6.81 ± 1.1	7.31 ± 0.45	7.06 ± 0.7	7.37 ± 0.7	7.38 ± 0.74
T1	6.44 ± 0.72	7.06 ± 1.08	6.31 ± 1.4	6.63 ± 1.1	6.56 ± 1.23	6.56 ± 1.29
T2	7 ± 0.9	7 ± 0.53	6.75 ± 0.88	6.69 ± 0.59	6.63 ± 1.3	7 ± 0.92
T3	6.62 ± 1.9	7.25 ± 1.1	6.62 ± 1.3	6.88 ± 1.3	6.31 ± 1.9	6.5 ± 1.69

Table 7(b). Sensory evaluation at Day 7

Treatments	Taste	Aroma	Texture	Appearance	Mouthfeel	OA
T0	7.23 ± 0.8	6.96 ± 1.10	6.71 ± 1.1	6.81 ± 0.91	7.04 ± 1.2	7.29 ± 0.98
T1	6.58 ± 1.5	6.71 ± 1.05	7.0 ± 1.06	6.92 ± 1.01	6.58 ± 1.7	6.79 ± 1.5
T2	7 ± 1.0	6.73 ± 1.07	6.92 ± 1.02	6.78 ± 1.16	6.62 ± 1.2	6.88 ± 1.1
T3	6.4 ± 1.4	6.42 ± 1.01	6.42 ± 1.23	6.19 ± 1.24	6.40 ± 1.51	6.4 ± 1.6

Table 7(c). Sensory evaluation at Day 14

Treatments	Taste	Aroma	Texture	Appearance	Mouthfeel	OA
T0	6.8 ± 1.4	6.75 ± 1.5	6.55 ± 2.2	6.05 ± 2.1	6.88 ± 1.5	6.62 ± 1.07
T1	6.9 ± 0.78	7.10 ± 1.3	7.05 ± 1.4	6.68 ± 1.5	6.50 ± 1.7	7.25 ± 0.73
T2	6.3 ± 2.04	6.38 ± 1.4	6.35 ± 1.6	6.48 ± 1.1	6.12 ± 1.5	6.75 ± 1.2
T3	5.5 ± 1.7	6.45 ± 1.5	6.27 ± 1.5	6.55 ± 1.2	6.05 ± 1.7	6.55 ± 1.1

Table 7(d). Sensory evaluation at Day 21

Treatments	Taste	Aroma	Texture	Apperaence	Mouthfeel	OA
T0	6.61 ± 1.2	6.73 ± 1.03	6.57 ± 1.07	6.50 ± 1.2	6.50 ± 1.3	6.88 ± 1.3
T1	7.14 ± 0.87	6.89 ± 0.97	7.18 ± 0.9	7.32 ± 0.85	7.16 ± 0.74	6.95 ± 1.2
T2	6.23 ± 1.2	6.66 ± 1.01	6.84 ± 1.3	6.93 ± 1.05	6.75 ± 1.1	6.71 ± 1.26
T3	6.23 ± 1.3	6.39 ± 1.09	6.68 ± 1.05	6.66 ± 1.08	6.32 ± 1.32	6.42 ± 1.4

addition of powder. The results by Ranjha et al., 2020 are aligned with the study where highest score was by 2 % PoP date bars are accepted in texture

4. Conclusion

The addition of pomegranate peel powder to snack bars has a major impact on their nutritional value and texture. Notable improvements in protein, ash and fiber content became apparent as the proportion of peel powder increased. Higher pomegranate peel powder concentrations, however, also influence sensory qualities including flavor and texture, which must be carefully considered to ensure customer acceptance. The results indicate that pomegranate peel powder (PoP) levels between the range of 3-6% provide a good balance between nutritional value and sensory appeal, which makes them a good option for creating snack bars with added nutrition.

Conflict of interest

The authors confirm that they have no conflict of interest that could have influenced the work presented in this study.

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Data availability

The data supporting the findings of this study are summarized in the tables and figures included in the manuscript. Additional data and supporting information are available from the corresponding author upon reasonable request

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