DEVELOPMENT AND CHARACTERIZATION OF BARLEY-BASED COOKIES FOR ADOLESCENT NUTRITION

Komal Azam[1], Maha Hanif[2]

1. University Institute of Food Science and Technology, The University of Lahore, Lahore, Punjab, Pakistan
2. Food and Nutritional Sciences, University of Central Punjab, Lahore, Punjab, Pakistan

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Corresponding author:
Komal Azam
Email:
komalshaheryar123@gmail.com
University Institute of Food Science and Technology, The University of Lahore, Lahore, Punjab, Pakistan

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ABSTRACT

Background: In Pakistan, many adolescents still do not get enough nutrients from their daily diet. A low-cost snack made with locally available ingredients can therefore be a useful extra food item, especially when it provides better energy and nutrient value. **Objective**: This study aimed to prepare cookies with increasing levels of barley flour replacement (0, 10, 20, 30 and 40%) and assess their proximate composition, energy value, antioxidant activity, mineral profile, FTIR characteristics, physical quality, color and sensory acceptability. **Methodology**: The study was conducted at University of Engineering and Technology (UET), Lahore, Pakistan from 2022-2024. FTIR analysis was performed at the Department of Chemistry, University of the Punjab, Lahore. Cookies were prepared by replacing wheat flour with barley flour at five levels: 0, 10, 20, 30 and 40%, and the samples were labelled as T0, T1, T2, T3 and T4. All formulations were analyzed for proximate composition, calculated energy value, physical quality, color, antioxidant activity, mineral content, FTIR bands and sensory acceptability. The data were statistically analyzed using one-way ANOVA followed by Fisher's LSD test at $p < 0.05$.

Results: Barley flour addition noticeably influenced the quality of the cookies. Moisture remained within a low range, whereas protein, fiber, ash and fat showed an overall increase with the incorporation of high barley flour. Nitrogen free extract (NFE) decreased, and the calculated energy value ranged from 451.09 to 462.88 kcal/100 g. Antioxidant values improved with the addition of barley; the highest TPC, TFC and DPPH activity were recorded in T4 treatment. Calcium and sodium were highest in T3, whereas potassium was highest in T0. Higher barley levels made the cookies darker and firmer, but all sensory scores remained above 7.0. FTIR spectra showed bands related to proteins, lipids and other fiber components.

Conclusion: Barley flour improved the nutritional and antioxidant profile of the cookies without reducing sensory scores below the acceptable range. The product may be considered as an energy-dense supplementary snack option, but shelf-life, microbiological stability and target-consumer testing are needed before any health-related claim is made.

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INTRODUCTION

Adolescence is a period of rapid physical growth, and poor dietary intake at this stage can affect body weight, stamina and daily activity. In many schools and colleges, students often depend on cheap snacks during break time. These snacks may provide calories and are low in protein, fiber and micronutrients but provide inadequate nutritional support [1,3].

In Pakistan, undernutrition among adolescents remains an important nutrition concern, particularly in families where regular intake of diverse foods is difficult. A locally prepared snack cannot replace a balanced diet, but it may work as an additional food item if its composition, safety and acceptability are properly evaluated[1].

Cookies were selected because they are easy to prepare, portable and acceptable to many age groups. However, ordinary cookies are usually prepared mainly from refined wheat flour and may contain limited dietary fiber and selected minerals. Replacing part of wheat flour with another cereal flour can improve composition, but it may also change spread, color, hardness and eating quality [4,5]. Barley flour is used for this purpose because it contains protein, minerals and fiber contents, including beta-glucan and arabinoxylan fractions. These components can contribute to the nutritional value of cereal products, but their addition in baked products must be balanced with texture and sensory quality [6,11].

This work was aimed to prepare an energy-dense cookie using ingredients that are easily available in local markets, including barley flour, wheat flour, fruits, nuts, honey, butter, milk powder and egg. Barley flour was used at graded replacement levels so that both nutritional improvement and quality changes could be detected. Since a high level of barley may affect dough handling, browning, hardness and taste, the product was evaluated for composition, antioxidant activity, minerals, FTIR-based functional groups, physical quality, color and sensory response before suggesting a suitable formulation.

MATERIALS AND METHODS

Study design

This was a laboratory-based food product study. No clinical trial, feeding intervention or health-outcome assessment was conducted. The experiment compared five cookie formulations containing different barley flour replacement levels.

Setting and duration

The experimental work was conducted at the laboratory facilities of University of Engineering and Technology (UET), Lahore, Pakistan, during 2022-2024. FTIR analysis was carried out at the Department of Chemistry, University of the Punjab, Lahore, Pakistan. Sensory testing was performed under controlled laboratory conditions using coded samples.

Raw materials

Barley flour, wheat flour, banana, dates, raisins, peanuts, almonds, butter, honey, sugar, milk powder, egg and baking powder were obtained from local markets. All materials were used without chemical treatment.

Sample size and Treatment plan

Five formulations were made by replacing wheat flour with barley flour at 0, 10, 20, 30 and 40% of the total cereal flour portion. The treatments were coded as T0, T1, T2, T3 and T4, respectively. Laboratory analyses were carried out in triplicate. Sensory evaluation was performed by 15 semi-trained panelists, which was considered suitable for an initial acceptability test of the developed product.

Selection criteria for sensory evaluation

Inclusion criteria were adult panelists who were willing to participate, available during the sensory session, familiar with bakery product evaluation and free from self-reported allergies to wheat, barley, egg, milk, peanuts, almonds or other cookie ingredients. Exclusion criteria included unwillingness to participate, known allergy or intolerance to any formulation ingredient, active oral or respiratory illness affecting taste or smell, and incomplete sensory scoring. Informed consent was obtained before sensory participation.

Operational Definitions

Energy-dense cookies were defined in this study as cookies providing more than 400 kcal/100 g according to the Atwater calculation. A sensory score of 6 or above on the 9-point hedonic scale was considered acceptable. Barley replacement level indicated the percentage of wheat flour replaced by barley flour in the fixed 135 g cereal flour portion.

Data collection procedure

Data were collected during formulation, baking and laboratory analysis of cookie samples. Raw materials were weighed, samples were prepared under the same conditions, and physical, proximate, antioxidant, mineral, FTIR and sensory information were recorded using coded treatments. Sensory data were collected from adult semi-trained panelists after consent.

Formulation of Cookies

For each set, total cereal flour was set aside at 135 g. Only the wheat flour and barley flour ratio was changed in T0, T1, T2, T3 and T4. Other ingredients, including banana, dates, raisins, peanuts, almonds, butter, honey, sugar, milk powder, egg and baking powder, were added in the same quantity in all treatments. This was done to compare the effect of barley flour replacement only. The complete treatment level is shown in Table 1.

Table 1. Formulation of cookies with different levels of barley flour

Ingredient (g)	T0 0% barley	T1 10% barley	T2 20% barley	T3 30% barley	T4 40% barley
Wheat flour	135.0	121.5	108.0	94.5	81.0
Barley flour	0.0	13.5	27.0	40.5	54.0
Banana	52.7	52.7	52.7	52.7	52.7
Dates	47.0	47.0	47.0	47.0	47.0
Raisins	38.0	38.0	38.0	38.0	38.0
Peanuts	20.0	20.0	20.0	20.0	20.0
Almonds	20.0	20.0	20.0	20.0	20.0
Butter	50.0	50.0	50.0	50.0	50.0
Honey	20.0	20.0	20.0	20.0	20.0

Ingredient (g)	T0 0% barley	T1 10% barley	T2 20% barley	T3 30% barley	T4 40% barley
Sugar	30.0	30.0	30.0	30.0	30.0
Milk powder	4.0	4.0	4.0	4.0	4.0
Egg	50.0	50.0	50.0	50.0	50.0
Baking powder	1.5	1.5	1.5	1.5	1.5
Total dough weight	468.2	468.2	468.2	468.2	468.2

Note: Barley replacement was considered on total cereal flour basis (wheat flour + barley flour = 135 g per batch). All other ingredients were kept constant across formulations.

Cookie Preparation

All dry ingredients were weighed and mixed in a bowl. Dates, raisins, peanuts and almonds were cleaned and cut into small pieces before mixing with the flour blend. Egg was beaten separately and mixed with mashed banana and honey. This wet mixture was then added to the dry ingredients, followed by butter, and mixed until a uniform dough was formed. The dough was separated into 50 g servings, shaped by hand, placed on a greased tray and baked at 150 °C for 15-20 min after oven preheating. The cookies were cooled at room temperature and packed in airtight packaging until analysis. The main preparation steps and final appearance are shown in Fig. 2.

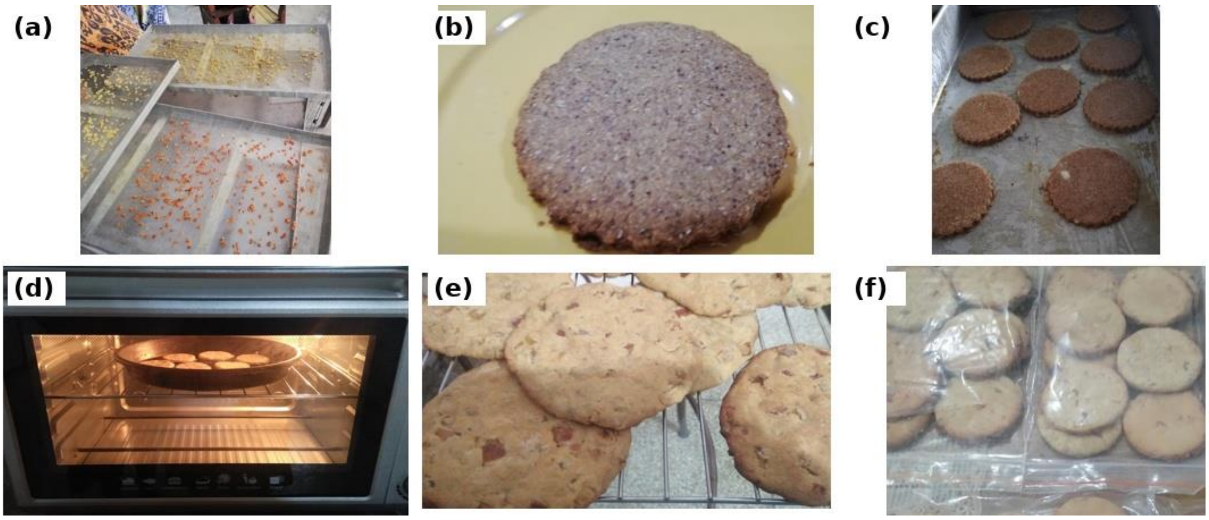

Fig. 1. Original photographs showing preparation and final appearance of barley-based cookies: (a) size reduction of ingredients, (b) shaped cookie dough, (c) placement of cookies on greased baking tray, (d) baking, (e) cooling at room temperature and (f) packaging of cookies.

Proximate composition and energy value

Moisture, ash, crude fat, crude protein and crude fiber were determined using standard AOAC procedures [12]. Moisture was determined by hot-air oven drying, ash by muffle furnace incineration, fat by Soxhlet extraction, protein by Kjeldahl method and crude fiber by acid-alkali digestion. Nitrogen-free extract was calculated by difference. Energy value was estimated using Atwater factors: 4 kcal/g for protein, 9 kcal/g for fat and 4 kcal/g for nitrogen-free extract.

Physical and instrumental color assessment

After cooling, the diameter and thickness of cookies were measured with a digital vernier caliper. Spread ratio was calculated by dividing diameter by thickness and then multiplying by 10. Baking loss was calculated from the difference between dough weight before baking and cookie weight after baking. Cookie surface color was measured at room temperature using a color grader (Satake, NCGA, Japan) under a D65 light source. Three readings were taken for each treatment and recorded as L* for lightness, a* for redness and b* for yellowness. Total color difference (ΔE) was calculated against T0 by using the CIELAB color difference equation [13].

Total color difference was calculated as:

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2}$$

Antioxidant properties

Antioxidant properties of cookie samples were evaluated using standard colorimetric assays. Total phenolic content was determined using the Folin-Ciocalteu method and expressed as mg gallic acid equivalent per g sample (mg GAE/g) [14,15]. Total flavonoid content was determined using the aluminium chloride colorimetric method and expressed as mg quercetin equivalent per g sample (mg QE/g) [16,17]. DPPH radical scavenging activity was determined using the free-radical method described by Brand-Williams et al.[18] and expressed as percentage inhibition.

Mineral composition

Mineral composition was determined after sample digestion. Laboratory-reported instrumental values were expressed as mg/kg and converted to mg/100 g by dividing by 10. Calcium, sodium, magnesium and potassium were quantified to assess the contribution of barley flour and other ingredients to the mineral profile of the developed cookies.

FTIR-based structural analysis

Fourier transform infrared spectroscopy was used to identify major functional groups in the cookie matrix. Spectra were interpreted in the 4000-500 cm-1 range. Absorption regions associated with O-H, C-H, C=O, amide and C-O-C/C-O vibrations were used to compare structural features of cookies prepared with different barley flour levels using standard interpretation approaches for food carbohydrates, proteins and polysaccharide-rich matrices [19,20,21].

Sensory evaluation

Sensory evaluation was conducted using a 9-point hedonic scale [22]. Fifteen semi-trained panelists assessed color, appearance, texture, taste and overall acceptability. Scores ranged from 1 (dislike extremely) to 9 (like extremely). Samples were presented under controlled conditions, and water was provided between samples to minimize carry-over effects. Informed consent was obtained from all panelists before sensory evaluation. Ethical approval for sensory evaluation was obtained from the relevant institutional ethics committee before data collection.

Data analysis plan

Data were entered and checked in Microsoft Excel and analyzed using IBM SPSS Statistics software. Analytical determinations were performed in triplicate unless otherwise stated, and results were expressed as mean ± standard deviation. Sensory results were based on 15 panelists. One-way analysis of variance (ANOVA) was used to determine significant differences among treatments, followed by Fisher least significant difference (LSD) test at $p < 0.05$. Different superscript letters within the same column indicate statistically significant differences.

RESULTS

Proximate composition

Table 2 presents the proximate composition of cookies prepared with different barley flour levels. Moisture ranged from 4.00 to 4.73%, with no significant difference among treatments. The low moisture level is suitable for cookies because it helps maintain crispness and may limit microbial spoilage during storage [4,23] Fat content differed significantly and was highest in T4. Protein increased at the higher replacement levels, and T3 and T4 formed the higher statistical group. Fiber and ash showed an increasing numerical trend, although the differences were not statistically separated. NFE decreased from T0 to T4 as the contribution of protein, fat, fiber and ash increased. These results show that barley flour changed the nutritional balance of the cookies, as also reported for cereal- and fiber-containing biscuit or cookie products [11,24.]

Table 2. Proximate composition of cookies prepared with different barley flour levels

Treatment	Moisture (%)	Fat (%)	Protein (%)	Fiber (%)	Ash (%)	NFE (%)
T0	4.00 ± 0.22^a	16.51 ± 0.02^d	7.79 ± 0.61^b	0.87 ± 0.71^a	0.71 ± 0.61^a	70.12 ± 1.14^a
T1	4.25 ± 0.36^a	15.33 ± 0.06^e	8.32 ± 0.44^b	1.24 ± 0.82^a	0.90 ± 0.74^a	69.96 ± 1.24^a
T2	4.53 ± 0.50^a	17.41 ± 0.08^c	8.11 ± 0.31^b	1.41 ± 0.66^a	1.21 ± 0.62^a	67.33 ± 1.08^b
T3	4.61 ± 0.62^a	18.51 ± 0.07^b	11.42 ± 0.53^a	1.91 ± 0.90^a	1.50 ± 0.78^a	62.05 ± 1.45^c
T4	4.73 ± 0.74^a	19.20 ± 0.20^a	12.00 ± 0.15^a	1.97 ± 0.97^a	1.58 ± 0.57^a	60.52 ± 1.39^c

Values are expressed as mean ± SD (n = 3). Different superscript letters within the same column indicate significant differences according to LSD test at p < 0.05.

Estimated energy value

The calculated energy values are given in Table 3. Values ranged from 451.09 to 462.88 kcal/100 g, so all formulations met the energy-dense criterion used in this study. A 50 g cookie provided about 225.55-231.44 kcal. Because these values were calculated from mean proximate results, statistical grouping was not applied.

Table 3. Estimated energy value of cookies based on proximate composition

Treatment	Energy (kcal/100 g)	Energy per 50 g cookie (kcal)
T0	460.23	230.12
T1	451.09	225.55
T2	458.45	229.23

Treatment	Energy (kcal/100 g)	Energy per 50 g cookie (kcal)
T3	460.47	230.24
T4	462.88	231.44

Energy was calculated using Atwater factors: protein × 4 kcal/g, fat × 9 kcal/g and NFE × 4 kcal/g.

Physical attributes

The physical quality results of cookies are given in Table 4. Barley flour changed the diameter, thickness and spread ratio of the cookies. T1 showed the highest diameter, whereas T2 and T3 had smaller diameter values. Thickness was highest in T0 and decreased up to T4. This shows that the dough did not behave the same at all barley levels during baking.

Baking loss was also reduced with barley flour replacement. It decreased from 15.00% in T0 to 12.01% in T4. This may be because barley flour contains fiber, which can hold moisture during baking. Hardness increased from 7.61 N in T0 to 14.51 N in T4, so the cookies became harder as barley level increased. The same trend was also noticed in sensory results, where texture scores were lower at higher barley levels. Similar changes have been reported in fiber-added bakery products [5,24].

Table 4. Physical attributes of cookies prepared with different barley flour levels

Treatment	Diameter (mm)	Thickness (mm)	Spread ratio (D/T × 10)	Baking loss (%)	Hardness/breaking force (N)
T0	67.43 ± 0.71^{b}	19.20 ± 0.11^{a}	35.12 ± 0.42^{c}	15.00 ± 0.01^{a}	7.61 ± 0.04^{e}
T1	76.92 ± 1.13^{a}	18.77 ± 0.14^{a}	40.98 ± 0.68^{b}	14.77 ± 0.04^{b}	9.22 ± 0.07^{d}
T2	55.95 ± 0.83^{d}	16.31 ± 0.54^{b}	34.30 ± 1.24^{c}	13.65 ± 0.10^{c}	12.31 ± 0.03^{c}
T3	57.00 ± 0.07^{d}	14.55 ± 0.61^{c}	39.18 ± 1.64^{b}	12.44 ± 0.03^{d}	12.70 ± 0.11^{b}
T4	60.63 ± 0.41^{c}	12.71 ± <0.01^{d}	47.70 ± 0.32^{a}	12.01 ± 0.04^{e}	14.51 ± 0.01^{a}

Values are expressed as mean ± SD (n = 3). Different superscript letters within the same column specify significant differences among treatments according to Fisher LSD test at $p < 0.05$.

Color characteristics in cookies

The color results are given in Table 5. The L* value decreased from 61.05 in T0 to 50.11 in T4. This shows that cookies became darker when the barley flour level was increased. This dark color can be due to barley flour, dates, raisins and browning during baking. The a* value was highest in T3, while the b* value was highest in T1 and lowest in T2. The ΔE value was higher in all barley-added cookies than the control. The highest ΔE was found in T4, which means that 40% barley flour made the most visible color difference compared with T0. These instrumental results are consistent with the sensory color and appearance trend [13,27].

Table 5. Color values of cookies prepared with different barley flour levels

Treatment	L*	a*	b*	Delta E vs T0
T0	61.05 ± 0.42^{a}	6.21 ± 0.91^{c}	33.31 ± 0.27^{b}	0.00 ± 0.00^{e}
T1	59.67 ± 0.17^{b}	7.76 ± 0.15^{b}	36.51 ± 0.14^{a}	3.81 ± 0.48^{d}
T2	54.31 ± 0.44^{c}	7.15 ± 0.39^{b}	25.51 ± 0.16^{e}	10.35 ± 0.47^{b}
T3	53.00 ± 0.27^{d}	9.16 ± 0.09^{a}	30.37 ± 0.08^{c}	9.06 ± 0.54^{c}
T4	50.11 ± 1.10^{e}	6.13 ± 0.04^{c}	26.41 ± 0.15^{d}	12.93 ± 1.01^{a}

Values are expressed as mean ± SD (n = 3). Delta E was calculated relative to T0 using the CIELAB color difference equation. Different superscript letters within the same column indicate significant differences according to LSD test at $p < 0.05$.

Antioxidant properties

Antioxidant results are presented in Table 6. TPC increased from 1.99 mg GAE/g in T0 to 5.32 mg GAE/g in T4, while TFC increased from 0.22 to 1.71 mg QE/g. The increase is likely linked with barley flour and the phenolic contribution of dates, raisins and nuts used in the formulation.

DPPH inhibition increased from 22.11% in T0 to 57.61% in T4. T3 and T4 showed the higher statistical group for DPPH activity. The rise in DPPH activity followed the increase in TPC and TFC, indicating that phenolic and flavonoid compounds contributed to the antioxidant potential of the cookies. Similar trends have been reported in bakery products enriched with cereal or plant ingredients [11,24].

Table 6. Antioxidant properties of cookies prepared with different barley flour levels

Treatment	TPC (mg GAE/g)	TFC (mg QE/g)	DPPH (%)
T0	1.99 ± 0.51^{d}	0.22 ± 0.03^{e}	22.11 ± 3.20^{c}
T1	3.31 ± 0.26^{c}	0.51 ± 0.01^{d}	27.00 ± 4.99^{bc}
T2	3.99 ± 0.08^{b}	0.99 ± 0.12^{c}	31.25 ± 2.11^{b}
T3	4.17 ± 0.18^{b}	1.24 ± 0.06^{b}	52.89 ± 5.99^{a}
T4	5.32 ± 0.14^{a}	1.71 ± 0.16^{a}	57.61 ± 0.28^{a}

Values are expressed as mean ± SD (n = 3). TPC = total phenolic content; TFC = total flavonoid content; DPPH = radical scavenging activity. Different superscript letters within the same column indicate significant differences according to LSD test at $p < 0.05$.

Mineral composition

Table 7 shows the mineral composition of cookies prepared with different barley flour levels. Calcium varied significantly among treatments and was highest in T3 (166.16 mg/100 g), followed by T4 (103.70 mg/100 g). Sodium values were maximum in T3 (9.38 mg/100 g), whereas the lowest sodium value was recorded in T1 (4.90 mg/100 g). Magnesium reached its maximum value in T2 (182.29 mg/100 g) and then declined in the higher replacement treatments. Potassium, after conversion from instrumental concentration to mg/100 g, was highest in T0 (154.20 mg/100 g), followed by T2 (134.10 mg/100 g) and T3 (116.50 mg/100 g), while the lowest value was observed in T4 (78.90 mg/100 g). The mineral pattern was not strictly linear, which may be due to the combined contribution and distribution of cereals, fruits, nuts, egg and milk powder in the baked cookie matrix.

Table 7. Mineral composition of cookies prepared with different barley flour levels

Treatment	Calcium (mg/100 g)	Sodium (mg/100 g)	Magnesium (mg/100 g)	Potassium (mg/100 g)
T0	65.32 ± 0.07^{e}	6.13 ± 0.02^{c}	131.20 ± 0.07^{d}	154.20 ± 0.30^{a}
T1	79.53 ± 0.01^{d}	4.90 ± 0.01^{e}	156.62 ± 0.05^{b}	113.70 ± 0.50^{d}
T2	98.12 ± 0.02^{c}	8.51 ± 0.02^{b}	182.29 ± 0.02^{a}	134.10 ± 0.10^{b}
T3	166.16 ± 0.01^{a}	9.38 ± 0.05^{a}	144.61 ± 0.03^{c}	116.50 ± 0.20^{c}
T4	103.70 ± 0.04^{b}	5.11 ± 0.01^{d}	105.41 ± 0.01^{e}	78.90 ± 0.10^{e}

Values are expressed as mean ± SD (n = 3). Different superscript letters within the same column indicate significant differences according to LSD test at p < 0.05.

FTIR-based structural characteristics

The FTIR spectra of the cookies are shown in Fig. 2. A broad band in the 3200-3500 cm^-1 region was assigned to O-H stretching of starch, moisture and fiber-associated hydroxyl groups. Bands around 2920-2850 cm^-1 were related to C-H stretching of lipid and carbohydrate components. The 1740-1650 cm^-1 region represented carbonyl and amide-related vibrations from fat and protein fractions 19.

The fingerprint region between 1150 and 850 cm^-1 showed C-O-C and C-O stretching associated with starch, glycosidic linkages and cereal polysaccharides. Differences in peak intensity among treatments may reflect the increasing barley flour level and the changing proportion of fiber, starch and protein in the cookie matrix. Similar absorption regions have been reported for polysaccharide-rich and plant-based food matrices 20,21.

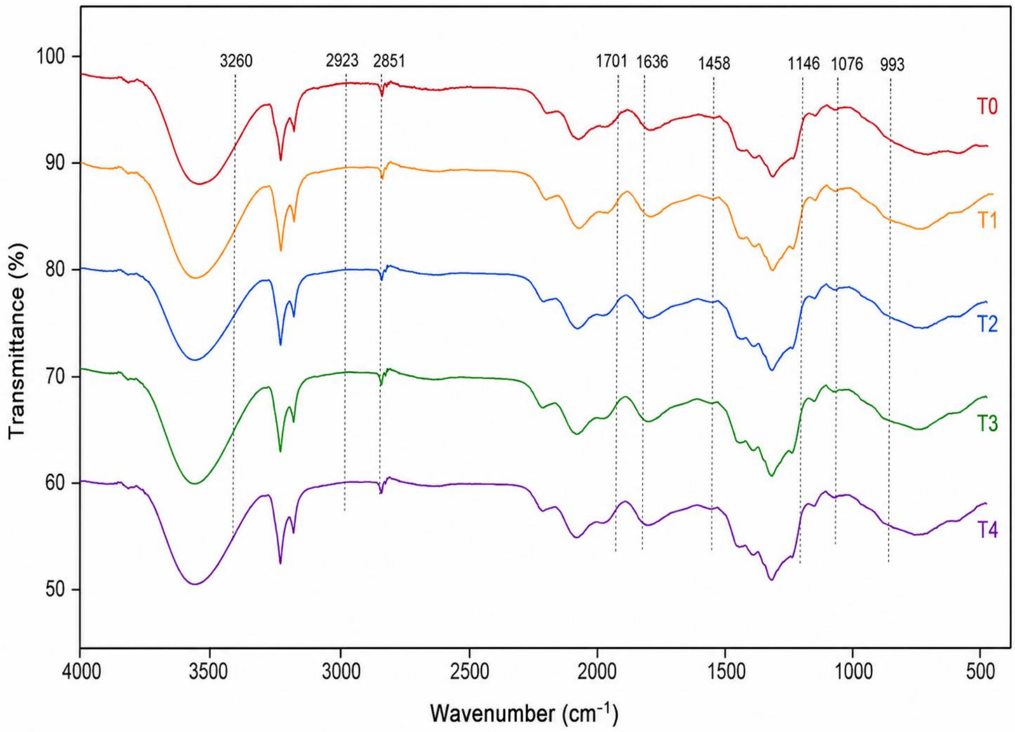

Fig. 2. FTIR spectra of cookies prepared with different barley flour levels (T0-T4), showing major absorption regions associated with O-H, C-H, carbonyl/amide and carbohydrate-related vibrations.

Sensory acceptability

The sensory profile is shown in Fig. 3. All treatments received mean scores above 7.0 for color, appearance, texture, taste and overall acceptability. This indicates that the products remained acceptable on the 9-point hedonic scale. T0 and T1 showed the wider sensory profiles, while T2 also maintained good scores for appearance, texture and taste.

Scores declined gradually at higher barley levels, mainly from T2 to T4. The decrease may be due to darker color, firmer texture and stronger cereal flavor. However, T4 still remained in the acceptable range, suggesting that barley flour can be used up to 40% in this formulation, although lower levels such as T1 and T2 gave a better sensory balance 11,25,26.

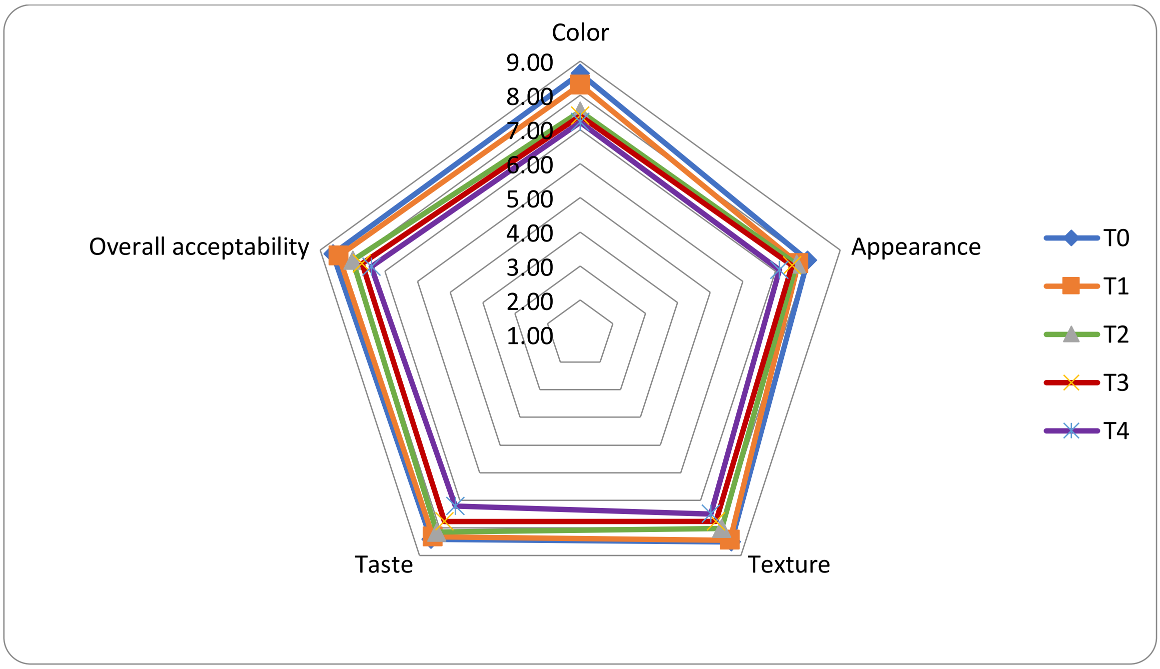

Fig. 3. Radar plot showing the sensory profile of cookies prepared with different barley flour levels (T0-T4) based on mean hedonic scores.

DISCUSSION

The study showed that barley flour changed both the composition and quality of the cookies. At higher replacement levels, protein, fat, fiber, ash, TPC, TFC and DPPH values increased. This improvement is expected because barley flour contributes cereal fiber and bioactive compounds, while fruits and nuts in the formulation also add phenolic compounds and minerals [11,24]. Physical results showed a clear effect on spread, baking loss and hardness. The decrease in baking loss may be linked with water binding by barley fiber. At the same time, the increase in hardness shows that the cookie structure became firmer as the barley level increased. This type of change can happen when fiber is added to bakery products. The fiber present in barley may limit dough flow during baking, so the cookies become more dense and harder [5,24]. Color results also changed with the incorporation of barley flour. As the L^* value decreased, the cookies became darker. The higher ΔE value showed that this difference was clearly visible when barley cookies were compared with T0. This color change may come from barley flour, fruit ingredients and browning reactions during baking. The instrumental color values therefore support the sensory observation that color and appearance scores decreased at higher barley levels [13,27]. FTIR analysis identified the expected functional groups of a cereal, fruit and nut-based cookie matrix. The O-H, C-H, carbonyl/amide and carbohydrate-related regions were consistent with starch, lipids, proteins and polysaccharide components. The spectra did not indicate formation of a new compound; rather, they supported the compositional differences produced by increasing barley flour [19-21]. Sensory results are important because nutritional improvement alone is not enough for a snack product. All formulations remained acceptable, but the decline in scores at higher barley levels suggests that texture, color and flavor should be considered during formulation. Similar reductions in liking at higher flour substitution levels have been reported in other cereal- and plant-enriched cookies [11,25,26].

On the basis of the present results, T3 and T4 gave stronger nutritional and antioxidant improvement, while T1 and T2 gave better sensory response. The final choice of formulation therefore depends on the intended priority: maximum enrichment or better consumer liking. Since no feeding trial, shelf-life study or adolescent consumer testing was performed, the cookies should be described only as a supplementary snack option and not as a therapeutic product for malnourishment.

CONCLUSION

This study concludes that barley-based energy-dense cookies can be prepared from locally available ingredients with acceptable nutritional, physical and sensory quality. The replacement of wheat flour with barley flour improved the protein, fat, fiber, ash and antioxidant contents of the cookies, while the energy value remained above 451 kcal/100 g in all treatments. Barley flour also changed the physical and color properties, including diameter, thickness, spread ratio, baking loss, hardness and L*, a*, b* values. FTIR results showed the main functional groups related to starch, proteins, lipids and cereal fiber. Among the treatments, T4 gave the maximum antioxidant response, while T1 and T2 showed better sensory acceptability. Overall, the developed cookies may be used as an energy-dense supplementary snack option for adolescents. However, before making any health-related claim, shelf-life, microbial safety and acceptability among adolescent consumers should be tested further.

STATEMENTS AND DECLARATIONS

Ethical statement: The study was a laboratory-based food product development study and did not involve clinical intervention, patient recruitment or vulnerable human subjects. Sensory evaluation was non-invasive and involved adult semi-trained panelists only. Informed consent was obtained before participation, and no personal identifying information was collected. Ethical approval for sensory evaluation was obtained from the relevant institutional ethics committee before data collection.

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Author contributions: Komal Azam contributed to conceptualization, formulation development, data compilation, analysis and manuscript drafting. Maha Hanif contributed to formulation support, data organization and manuscript review. Both authors reviewed and approved the final version for submission.

Data availability: Data used in this manuscript are available from the corresponding author upon reasonable request.

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