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Substitution of wheat flour with watermelon peel flour in the production of baguette bread

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ABSTRACT

Today, the use of agricultural product waste to maximize the availability of nutrients is highly considered. In current research, the effect of adding watermelon peel flour at levels of 2.5, 5, 7.5, and 10 % w/w to wheat flour on the physicochemical, rheological, and sensory properties of baguette bread was investigated. The experiments included the evaluation of chemical characteristics (moisture, protein, fibre, ash content, pH, and acidity) of the flour and bread, rheological properties, physical properties, textural attributes, color indices and sensory characteristics. The results showed that moisture in watermelon peel flour was higher than in wheat flour. Fiber, protein and ash content increased with the addition of watermelon peel flour. Bread moisture increased due to the high-water absorption capacity of fibres in watermelon peel flour. Farinograph tests indicated that water absorption in the dough increased with higher levels of watermelon peel flour, while dough elasticity decreased. Bread density increased and specific volume decreased, which may be due to reduced gas retention capacity and a decrease in final volume. In terms of sensory attributes, samples (2.5%) followed by (5%) received the highest scores for taste and overall acceptability. This study showed that adding watermelon peel flour can enhance the nutritional value of bread, but attention should be paid to the decrease in bread volume and dough elasticity.

1-Introduction

In recent decades, bakery products have gained widespread popularity with the increasing demand for quick and easy foods among various social groups. These products are considered nutritionally rich and recognized as an important part of individuals' dietary composition [1]. To meet the nutritional needs of low-income groups, one effective and simple solution is the production of bread enriched with proteins, minerals, and vitamins. The global importance of cereals has led to increased attention toward the fortification of cereal-based products such as flour, bread, and biscuits [2]. Numerous studies have been conducted to substitute wheat flour with flour derived from fruit residues in bakery products. Fruit residues can be significant sources of nutrients, and to meet consumer demand for healthier products, the food industry is seeking ways to incorporate functional ingredients into its products [3]. Ahmadi Balootaki and Nasehi used dried orange pulp powder in Barbari bread dough and demonstrated that Barbari bread with 2% dried orange pulp powder had greater acceptability due to its fibre content and minimal changes compared to the control sample [4]. Feili et al. investigated high-fibre bread using jackfruit peel flour. The addition of jackfruit peel flour had a significant impact on bread volume and textural characteristics. Increasing the jackfruit flour level led to increased hardness and darkening of the bread, while its volume decreased compared to the control. Bread samples containing 5% jackfruit flour showed the highest overall acceptance scores [5]. Salinas et al. studied the effect of carob flour derived from two different parts of the seed sprout and fruit pulp on wheat dough [6]. Ashoka et al. prepared three versions of sponge cakes and fruit cakes by adding watermelon peel flour and concluded that watermelon peel flour, a by-product of watermelon, was effectively used to enhance the nutritional composition of the cakes [1]. Tuna Ağirbaş et al. examined the use of various seed flours in cake production and their effects on dough rheology. Overall results showed that the rheological characteristics of wheat flour depend on the substitution level, and cakes with improved features and high protein content can be produced [7]. Verbeke et al. studied the effects of chickpea fibre, cocoa, and apple on the dough and wheat-based bread characteristics [8]. Globally, 100 million tons of watermelon are produced annually on approximately 3 million hectares of land, making it the second most cultivated fresh fruit after bananas. In our country, watermelon is cultivated on 73,000 hectares with an estimated production of 3,096 thousand tons [9]. Watermelon provides a wide range of dietary antioxidants in addition to vitamins (A, B, C, and E), mineral salts (K, Mg, Ca, and Fe), and specific amino acids [10]. Watermelon peel constitutes nearly 40% of the total watermelon mass. It contains various compounds that make it nutritionally valuable. These include dietary fibre, water, vitamin C, citrulline, and antioxidants. The direct disposal of watermelon peel causes environmental issues; therefore, instead of treating it as agricultural waste, it is ideal to utilize its nutritional potential to produce commercially valuable products. Accurately, a 1-inch cube of watermelon peel contains 1.8 calories and provides 2% of the recommended daily intake of vitamin C and 1% of vitamin B6 [11].

The main objective of this study is to improve the textural properties and physicochemical characteristics of baguette bread using watermelon peel flour, as well as to enhance the nutritional value and dietary benefits of the final product.

2- Materials and Methods

2-1-Materials

Setareh flour (Khusheh Fars), Glenlen S500 improver, and baker's yeast (active dry yeast produced by Razavi Yeast Company) were used. Golha brand table salt, Famila sunflower oil, and municipal water were included in the bread formulation. A dry-farmed variety of watermelon was purchased from the local market. All chemicals used in this study were of analytical grade and obtained from Merck, Germany.

2-2- Methods

2-2-1- Preparation of Watermelon Peel Flour

The fruits were washed and wiped clean with a dry cloth. The outer green peel of the watermelon was removed using a sharp knife, and the remaining peel was cut into small pieces (approximately sciced). These pieces were dried in a convection oven toaster (60-liter Karjca model K260) at 60°C for 6 hours (with both upper and lower elements on and fan enabled). The dried peel was ground using a semi-industrial peeler (Seddighi 0.5 kg peeler) and then sieved through a 60-mesh sieve to obtain a fine powder. Table 1 shows the different ratios of wheat flour and watermelon peel flour used. The watermelon peel flour was added to wheat flour in the amounts specified in Table 2 and thoroughly mixed. These proportions were based on pre-tests conducted using a farinograph.

Table 1- Different flours used in research

Sample	Wheat flour (%)	Watermelon peel flour (%)
A	100	0
B	97.5	2.5
C	95	5
D	92.5	7.5
E	90	10

2-2-2-Determination of Flour Properties

Moisture, total ash, pH, acidity, crude fibre, and protein content of the flour were measured based on AACC methods (2002) [12].

2-2-3- Bread Preparation

Dough was prepared according to AACC Method No. 10-10B. For each dough batch, 100 grams of flour were used. Based on this, 1.5% salt, 2% yeast, and 0.5% oil were added. The amount of water used is listed in Table 2. After dough preparation, rheological properties were measured, and the dough was baked in a convection oven (setting 1) at 170°C and 40% humidity for 24 minutes [12]. The baked samples were cooled, packaged, and subjected to various tests.

Table 2-Bauggete breads used in research

Sample	Wheat flour (%)	Watermelon peel flour (%)	Yeast (%)	Salt (%)	Water (%)
A	100	0	2	1.5	55
B	97.5	2.5	2	1.5	57
C	95	5	2	1.5	69

D	92.5	7.5	2	1.5	71
E	90	10	2	1.5	73

2-2-4- Dough Tests

Wet gluten content was determined using AACC (2002) methods. Farinograph analysis was carried out following the method of YanYan et al. The farinograph curve provided values for water absorption, dough development time, dough stability time, and dough softening degree [13].

2-2-5- Bread Tests

2-2-5-1-Physical Properties of Bread

Moisture, ash, fibre, and pH of bread samples were measured using the same method as for flour. Specific volume was determined by the rapeseed displacement method [14]. Bread density was assessed using AACC (2002) methods. Water activity was measured using a water activity meter (Labmaster, Novasina, Switzerland) on the day of baking and again 72 hours after baking.

2-2-5-2-Bread Color Measurement

Color of bread samples was measured using a Hunter Lab colorimeter, which reports results using the L*, a*, and b* color indices [15, 16].

2-2-5-3- Texture Profile Analysis of Bread

Texture was evaluated using an Instron texture analyser with a Kramer shear cell equipped with 5 blades, a constant applied force of 500 Newtons, 25 mm elongation range, speed of 120 mm/min, and a stop point at 12 mm. Bread sample thickness was uniformly set to approximately 5 mm. The peak force recorded on the graph was reported as the cutting force required, in Newtons [17].

2-2-5-4- Sensory Evaluation

Bread samples were evaluated using a 5-point hedonic scale. Sensory evaluation was performed by 30 trained panelists to assess quality attributes. Evaluation factors included flavor, taste, aroma, color, texture firmness/softness, chewability, stickiness, and overall acceptability [18].

2-3- Statistical Analysis

Different samples were compared using a completely randomized design and Duncan’s test at a 5% significance level. Each test was performed in triplicate. Mean values were analysed using ANOVA and SPSS software version 20.

3- Results and Discussion

3-1- Flour Composition

Table 3 presents the proximate analysis of wheat flour and mixtures containing watermelon peel flour. The reported results include moisture, ash, fibre, protein, gluten, pH, and acidity for the various flour samples.

As the proportion of watermelon peel flour in the mixture increases, moisture content consistently decreases, with a statistically significant difference observed ($p < 0.05$). This reduction is due to the lower moisture content in watermelon peel compared to wheat flour, leading to an overall decline in moisture in the mixture. In general, increasing the proportion of fruit peel powders (such as watermelon peel powder) in bread formulations tends to reduce the moisture content of the final product.

Fibre content increased significantly with higher levels of watermelon peel flour ($p < 0.05$). Watermelon peel is rich in fibre, and its incorporation into wheat flour enhances the fibre content of the resulting mixture. The final reduction in moisture in the flour mixture upon the addition of watermelon peel flour is attributed to the higher water absorption capacity of the fibres, the porous structure of the fibres, reduced water availability for dough development, and the physical characteristics of watermelon peel. As a result, water retention by the fibres increases, leading to a decrease in free moisture in the mixture.

Ash content showed an increase across the samples, although the difference was not statistically significant. Ash content reflects the mineral composition of the sample. As the percentage of watermelon peel increases, ash content rises due to the higher mineral and fibre content of the peel, contributing more inorganic material to the flour mixture. Fruit peels, particularly watermelon peel, are known to contain higher levels of minerals such as potassium, calcium, magnesium, phosphorus, and other trace elements. These minerals remain after combustion during ash determination and increase the overall ash content in the flour mixture. Similar findings have been reported by other researchers, indicating a rise in total ash with the addition of watermelon peel in baked products, which aligns with the current study [1, 19, 23].

Protein content increased with the rising percentage of watermelon peel flour, due to the nutritional value and protein content in the peel itself. The protein content of pure watermelon peel flour was found to be 14.23%. Watermelon peel naturally contains a certain amount of protein, which contributes to the overall increase in protein in the mixture.

Gluten is present only in wheat flour; since watermelon peel flour contains no gluten, its addition results in a reduction in overall gluten content. Therefore, gluten values were not reported for the other samples.

The pH remained relatively constant across nearly all samples, indicating the relative chemical stability of the flour mixtures containing both wheat and watermelon peel flour.

Acidity increased with the addition of watermelon peel flour. The peel contains more acidic compounds than wheat flour, leading to a higher acidity in the mixture. This may be attributed to the presence of naturally occurring organic acids in watermelon peel, such as citric acid and malic acid, as well as the interaction of fibres, phenolic compounds, and microbial fermentation processes. Watermelon peel contains high amounts of both soluble and insoluble fibres and phenolic compounds, all of which can contribute to increased acidity. Furthermore, the addition of watermelon peel flour may enhance the conditions for natural fermentation in the dough, promoting lactic acid bacteria activity and resulting in greater acid production. These findings are consistent with the study by Hou and Che Dahari on the use of watermelon peel powder in yellow noodle formulations [25].

Table 3- Approximate analysis of wheat flour and watermelon peel flours

	A	B	C	D	E

Moisture	10.1±0.2a	10.0±0.2a	9.82±0.2b	9.65±0.2c	9.6±0.1c
Fiber	0.01±0.0f	2.82±0.1e	3.36±0.1d	3.87±0.0c	4.28±0.0b
Ash	0.50±0.0b	0.66±0.0b	0.93±0.0b	1.01±0.0b	1.35±0.0b
Protein	11.27±0.0f	11.4±0.0e	12.02±0.0d	12.17±0.0c	12.43333b
Gluten	26.16±0.0	-	-	-	-
pH	5.97±0.0a	5.94±0.0a	5.96±0.0a	5.95±0.0a	5.97±0.0a
Acidity	1.26±0.0f	2.43±0.0e	2.96±0.0d	3.23±0.0c	4.6±0.0b

Different lowercase letters in each column indicate a significant difference at the level ($p<0.05$). The numbers in the table are the mean of three replicates ± standard deviation.

3-2- Farinograph Analysis

The relationship between the viscoelastic properties of dough and its strength and stability can be assessed using a farinograph. The farinograph curve is one of the key tools in evaluating flour dough characteristics, allowing the measurement of dough resistance, water absorption, development time, and stability. The results of the farinograph analysis are presented in Table 4.

S1 indicates the time required for the dough to reach full development, which is the point at which it achieves its maximum resistance to mixing. This parameter, reported in minutes, reflects the optimal dough mixing time. With the addition of 5% watermelon peel flour, the development time increased, and water absorption also rose, indicating that watermelon peel flour has a higher water absorption capacity.

S2 represents dough stability—the duration during which the dough remains at peak resistance before its quality and strength begin to decline. Dough stability during baking is related to the thermal stability of starch granules. It is likely that watermelon peel improves dough structure by enhancing interactions between hydrophilic hydrogen bonds and hydrophobic hydrophobic interactions in wheat proteins. Excessive mixing can break down gluten particles—critical for baking quality—into smaller fragments, making them behave more like free polymers in solution. During this phase, interactions may occur between compounds in the watermelon peel and gluten proteins [26].

Dough stability increased in the sample containing 0.5% watermelon peel flour. Increasing the watermelon peel flour content to 7.5% resulted in even greater water absorption and a longer dough development time. In sample E, which contains the highest level of watermelon peel flour (10%), dough development time was the longest, and water absorption reached its maximum. However, dough stability significantly decreased, possibly indicating a weakening of the gluten network due to the excessive addition of watermelon peel flour. The 100% wheat flour sample had appropriate dough development time and stability.

DDT (Dough Development Time) refers to the time required to form optimally developed dough—essentially the point when the farinograph curve peaks and indicates the most efficient mixing time. With the addition of 2.5% watermelon peel flour, DDT increased, along with a slight increase in water absorption. This suggests that watermelon peel enhances the dough's water retention capacity. Development time continued to increase as watermelon peel flour content rose. The 10% watermelon peel sample had the longest development time, while the 100% wheat flour sample had the shortest.

DS, or Dough Stability, reflects the decline in dough resistance over time after reaching peak strength. It indicates the weakening of the gluten structure over time. In the samples containing watermelon peel flour, dough stability decreased.

FQN (Farinograph Quality Number), a general indicator of flour quality for bread-making, gradually increased with higher watermelon peel flour percentages. This increase may be due to the fibre content and other compounds in watermelon peel flour that improve certain physical properties of the dough, although this does not necessarily indicate better gluten quality or dough strength.

Water absorption reflects the percentage of water the flour can absorb to form a dough with standard consistency. This is typically reported as a percentage and is one of the most important parameters in determining flour quality, as it affects the bread's volume and texture. Water absorption steadily increased with higher watermelon peel flour content, owing to the peel's high capacity to absorb and retain water.

The addition of watermelon peel flour to wheat flour causes significant changes in the dough's rheological properties. Higher levels of peel flour lead to increased water absorption and longer dough development time, but reduced dough stability. Although watermelon peel enhances water retention, excessive addition can weaken the gluten network and reduce final dough quality. Therefore, optimal use of watermelon peel flour is essential to maintain desirable rheological properties in the dough.

Table 4- Farinograph characteristics of baguette bread samples

	A	B	C	D	E
S_1 (min)	1.40^{c}	1.53^{b}	2.11^{a}	1.43^{c}	1.15^{d}
S_2 (min)	7.12^{d}	7.42^{c}	7.39^{c}	8.20^{b}	8.43^{a}
DDT(min)	4.42^{e}	5.14^{d}	5.23^{c}	5.52^{b}	6.22^{a}
DS (min)	64.0^{bc}	59.0^{d}	66.0^{a}	63.0^{c}	49.0^{e}
Water absorption (%)	56.0^{e}	57.5^{d}	59.3^{c}	60.7^{b}	62.5^{a}
DS(ICC)	111^{b}	115^{a}	116^{a}	109^{c}	101^{d}
FQN	61^{d}	70^{c}	71^{b}	80^{a}	80^{a}

Different lowercase letters in each column indicate a significant difference at the level ($p<0.05$). The numbers in the table are the mean of three replicates ± standard deviation.

3-3-Bread Tests

Table 5 presents the proximate analysis results of breads prepared using wheat flour and watermelon peel flour. This table reports changes in moisture, ash content, pH, water activity on days 1 and 3, density, specific volume, and fibre content in breads containing varying percentages of watermelon peel flour. With increasing amounts of watermelon peel flour, the moisture content of the breads significantly increased. This can be attributed to the higher water absorption capacity of the fibres present in the watermelon peel. The elevated moisture may result in a softer bread texture. A significant increase in fibre content in breads with watermelon peel flour is expected, as the peel naturally contains substantial amounts of fibre. This increase in fibre can improve the nutritional properties of bread and makes it suitable for consumers seeking high-fibre products. Fruit peel powders are rich in both soluble and insoluble fibres, which have high water-holding capacities and absorb more water during dough formation. In other words, the water in the bread dough, instead of remaining in the free phase, is absorbed by the fibres in the fruit peel powder. As a result, during and after baking, the final product retains more moisture [27].

The synergistic effect of fibre on gluten proteins may also influence the moisture content of bread. Adding fruit peel powders and their associated fibres directly affects the structure of gluten proteins. As fibre content increases, water absorption between the fibres and gluten proteins rises. Consequently, fibres absorb more water and a stronger gluten network form, which can effectively retain moisture [28, 29]. Thermal effects and reduced moisture loss during baking also impact the final moisture level of bread. Dietary fibres retain water throughout the baking process, resulting in higher post-baking moisture content. This is because the structural degradation of fibres at high temperatures is limited, resulting in less water being released as vapor and thereby increasing the final moisture in the bread [30]. These findings align with those reported by Verbeke et al., Pereira et al., and Plustea et al. [8, 31, 32].

The increase in ash content in the breads indicates a higher mineral content. Due to its naturally higher mineral concentration compared to wheat flour, watermelon peel flour contributes to elevated ash levels in breads containing higher percentages of it.

Changes in pH across the samples were not significant, showing no meaningful differences between formulations.

The increase in water activity in samples containing watermelon peel flour compared to those without it suggests that the peel flour enhances water retention, which could improve the bread's shelf life.

As the percentage of watermelon peel flour increased, bread density also increased. This indicates that breads with peel flour are heavier and more compact, as the fibre content in the peel tends to reduce bread volume while increasing weight. The decrease in specific volume suggests that breads with higher levels of watermelon peel flour are less aerated and have reduced overall volume. This is likely due to a diminished ability of the dough to retain gases, leading to smaller loaf sizes.

Feili et al. also reported that fibres negatively impact gluten network formation and reduce bread volume. Their study showed that increasing jackfruit flour in bread formulation led to higher density and lower specific volume—results that align with the current study [5]. Other studies have also pointed to the effect of plant fibres on water absorption and the reduction in bread's specific volume [33]. These findings suggest that incorporating watermelon peel flour into bread formulations can enhance its nutritional properties—particularly in terms of fibre and minerals—yet may also result in reduced volume and increased bread density.

Table 5- Approximate analysis of baguette bread samples

	A	B	C	D	E
Moisture	29.66±0.3	31.70±0.0^{a}	32.09±0.1^{b}	33.0±0.2^{c}	34.86±0.1^{c}
Fiber	0.01±0.0^{f}	0.70±0.0^{e}	1.33±0.0^{d}	2.06±0.0^{c}	2.78±0.0^{b}
Ash	1.62±0.0^{f}	1.64±0.0^{e}	2.09±0.0^{d}	2.18±0.0^{b}	2.51±0.2^{a}

pH	5.41±0.0[a]	5.44±0.0[a]	5.36±0.0[a]	5.30±0.0[a]	5.26±0.0[a]
aw (1st day)	0.90±0.0[f]	0.90±0.1[e]	0.90±0.1[d]	0.90±0.0[c]	0.91±0.0[b]
aw (Third day)	0.88 ±0.0[f]	0.88±0.0[e]	0.88±0.0[d]	0.89±0.0[c]	0.89±0.0[b]
Density	0.20±0.0[f]	0.21±0.0[e]	0.24±0.0[d]	0.26±0.0[c]	0.29±0.0[b]
Specific volume(cm³/g)	123.9±0.5[f]	111.5±1.4[e]	96.6±1.5[d]	73.33±2.7[c]	63.46±3.3[b]

Different lowercase letters in each column indicate a significant difference at the level ($p<0.05$). The numbers in the table are the mean of three replicates ± standard deviation.

3-4- Bread Texture

Table 6 presents the texture data of the bread samples on the first and third days. Hardness represents the resistance of bread dough to applied force. A harder bread requires more force to be compressed. It is observed that the hardness of the breads increases over time, indicating that they become firmer as time passes.

Adhesiveness reflects the internal cohesion of the dough. Bread with higher adhesiveness is more difficult to pull apart. It is observed that adhesiveness decreases on the third day, suggesting that the breads become drier and less cohesive over time.

Elasticity indicates the bread's ability to return to its original shape after being compressed. As seen in the data, elasticity generally increases on the third day, which may suggest better preservation of bread structure over time.

Gumminess represents the amount of force needed to chew a piece of bread until it is ready to be swallowed and is indirectly influenced by the dough's adhesiveness and hardness. This parameter is a combination of hardness and adhesiveness. As observed, gumminess increases over time, especially with the increasing percentage of watermelon peel flour, indicating that the breads become stickier and harder with time.

Chewiness refers to the amount of force and time required to chew the bread until it is ready to be swallowed. As shown, chewiness increases over time.

Surface adhesion indicates the extent to which the surface of the bread dough adheres to measuring instruments. It is observed that surface adhesion is very low and approaches zero.

Firmness indicates the bread's resistance to deformation. Greater firmness indicates a stiffer and less flexible bread. It is observed that firmness significantly increases on the third day, indicating that the breads become firmer over time.

Based on the results, breads containing watermelon peel flour exhibit higher firmness and chewiness compared to the control bread, which may not be ideal for baguettes. However, breads containing lower percentages of watermelon peel flour (such as the 2.5% sample), which show lower hardness, adhesiveness, and chewiness compared to those with higher percentages, are more suitable for baguette preparation. The 2.5% sample, due to its lower hardness and higher elasticity, could be a better choice for baguettes, as it produces a softer and lighter bread, which are desirable characteristics in baguettes. The increase or decrease in various texture parameters over time results from physicochemical changes within the bread structure. These changes occur due to processes such as starch retrogradation and alterations in the gluten network. Over time, the starch that was gelatinized during baking gradually returns to its original crystalline form (starch retrogradation). This process increases the density of the starch network and leads to moisture loss in the bread, resulting in increased hardness [34–36].

Table 6-Textural attributes of baguette bread samples at 1st and third day

Textural attributes- 1st day	A	B	C	D	E
Bread height (20 mm)	20.00^{Aa}	20.00^{Aa}	20.00^{Aa}	20.00^{Aa}	20.00^{Aa}
Hardness (N)	3.50^{Bc}	2.57^{Be}	6.04^{Ba}	3.29^{Bd}	3.92^{Bb}
Adhesiveness	0.48^{Aa}	0.47^{Ab}	0.42^{Ac}	0.47^{Ab}	0.47^{Ab}
Springiness (mm)	7.37^{Bc}	8.08^{Ba}	7.19^{Be}	7.28^{Bd}	7.75^{Bb}
Chewability (N)	1.69^{Ac}	1.20^{Be}	2.56^{Ba}	1.54^{Bd}	1.83^{Bb}
Gumminess (N.m^2)	12.33^{Bb}	9.64^{Be}	18.34^{Ba}	11.17^{Bd}	14.24^{Bc}
Surface adhesion (N)	0.02^{Ab}	0.01^{Ac}	0.03^{Aa}	0.03^{Aa}	0.03^{Aa}
Stiffness (N/m^2)	1672.1^{Bc}	1344.9^{Be}	3650.5^{Ba}	1862.3^{Bb}	1380.7^{Bd}
Textural attributes-Third day	**A**	**B**	**C**	**D**	**E**
Bread height (20 mm)	20.00^{Aa}	20.00^{Aa}	20.00^{Aa}	20.00^{Aa}	20.00^{Aa}
Hardness (N)	3.78^{A}	5.55^{Ac}	8.16^{Ab}	4.73^{Ad}	8.78^{Aa}
Adhesiveness	0.45^{Ba}	0.42^{Bb}	0.36^{Bd}	0.39^{Bc}	0.37^{Bd}
Springiness (mm)	9.57^{Ab}	9.73^{Aa}	8.72Ac	8.01^{Ad}	7.85^{Ae}
Chewability (N)	1.68^{Ae}	2.34^{Ac}	2.91^{Ab}	1.86^{Ad}	3.17^{Aa}
Gumminess (N.m^2)	16.17^{Ad}	22.85^{Ac}	25.42^{Aa}	14.82^{Ae}	24.63^{Ab}
Surface adhesion (N)	0.00^{Bb}	0.00^{Bb}	0.01^{Ba}	0.01^{Ba}	0.00^{Bb}
Stiffness (N/m^2)	1102.2^{Ae}	1777.2^{Ad}	3760.2^{Ab}	2242.0^{Ac}	5470.2^{Aa}

Different lowercase letters indicate a significant difference between bread samples and uppercase letters between 1st and third days at the level ($p<0.05$). The numbers in the table are the mean of three replicates ± standard deviation.

Watermelon peel contains high amounts of fibre. Due to their strong water-absorbing capacity, fibres reduce the amount of moisture available to soften the dough, which in turn leads to the stiffening of the gluten network and a reduction in the bread’s flexibility. Additionally, the inclusion of fibre creates a denser network within the dough structure, resulting in increased bread hardness. The rise in bread chewiness is also attributed to the higher fibre content and the denser structure formed. Dietary fibres, such as watermelon peel powder, impart a firm and inflexible texture to the dough, requiring more effort to chew. Changes in bread adhesiveness are also due to the effect of the fibres in watermelon peel on the dough's surface [37–40]. Similar findings have been reported by other researchers studying the effects of high-fibre ingredients such as citrus peels [41], psyllium [40], chestnut flour [42], and faba bean hulls [43] on bread texture, all of which align with the present study's results.

3-5- Color Changes

Significant changes are observed in the color indices of the flours (Table 7), which can be attributed to the addition of watermelon peel flour to wheat flour. Each color index reflects specific characteristics related to the color of the flour and the final product.

The L* value represents brightness; higher L* values indicate a lighter color. As the proportion of watermelon peel flour increases, the L* value decreases, with the 10% watermelon peel flour sample showing the darkest color. This indicates that adding watermelon peel flour reduces brightness and darkens the flour.

Maillard reactions during baking further darken the bread, resulting from chemical changes in carbohydrates and proteins.

The a* value represents the red-green spectrum: positive a* values indicate a red hue, while negative values indicate a greenish hue. In all samples, the a* value is negative, suggesting a greenish tint in the flour. However, the variations are minimal, indicating that the addition of watermelon peel flour has a negligible effect on increasing the green hue.

The b* value indicates the yellow-blue spectrum: positive values show a tendency toward yellow, and negative values toward blue. As the percentage of watermelon peel flour increases, the b* value increases significantly, indicating more yellowish coloration in the flour. This may be due to the natural color of watermelon peel, which gives the final flour a more yellow hue.

The presence of polyphenols and phenolic compounds may also contribute to the increased yellowness of the bread. Additionally, the carbohydrates in the white part of the peel may undergo caramelization reactions, further increasing the b* value.

As the proportion of watermelon peel flour increases in the blend, the flour becomes darker (lower L*) and more yellow (higher b*), while changes in the a* value (greenness) remain minor. These results are consistent with the findings reported by Feili et al. on jackfruit flour-containing breads [5], as well as a study by Celik and Isik on muffins made with watermelon peel flour, which showed similar trends [44], in line with the current research.

Table 7- Color indices of baguette bread samples

Color indices	A	B	C	D	E
L*	75.37±1.1^{a}	73.22±0.2^{b}	71.50±0.0^{c}	67.69±0.0^{d}	63.75±0.2^{e}
a*	-1.44±0.0^{a}	-1.97±0.0^{c}	-2.12±0.0^{d}	-1.96±0.0^{c}	-1.66±0.0^{b}
b*	16.39±0.0^{e}	19.64±0.0^{d}	23.83±0.0^{c}	27.20±0.0^{b}	28.85±0.0^{a}

Different lowercase letters in each column indicate a significant difference at the level ($p<0.05$). The numbers in the table are the mean of three replicates ± standard deviation.

3-6-Sensory Properties

The spider chart in Figure 1 illustrates the sensory scores of five different bread samples evaluated based on various criteria such as taste, aroma, color, texture, chewiness, stickiness, and overall acceptability. An improvement in taste was observed as the percentage of watermelon peel in the formulation decreased. Although adding watermelon peel to the flour introduces bioactive compounds like antioxidants and flavonoids, it does not align well with consumer preferences. Research shows that polyphenols and dietary fibres found in fruit peels can enhance the flavor of baked products when used in small amounts. However, at higher concentrations, these compounds impart bitter and astringent flavors to the bread, which likely accounts for the lower taste scores in the samples containing watermelon peel. These findings are consistent with the results of Badr [18].

A negative effect of watermelon peel was also observed in the aroma improvement. Fruit peels contain plant-based and raw compounds, and the presence of these in watermelon peel may have contributed to the lower aroma scores in the samples containing it. Watermelon peel likely helps retain more moisture in the bread, which may promote Maillard reactions and browning, potentially enhancing the bread's appearance and increasing the color scores in samples with watermelon peel. Shivapour et al., in their study on the effects of watermelon peel flour, reported that this flour did not have a significant impact on the color of toast bread [45].

Watermelon peel also appears to negatively affect the texture. In a study by Naknaen et al., cookies containing 10% watermelon peel powder were found to be similar to the control samples in terms of color, appearance, texture, taste, and overall acceptability. However, these parameters decreased with an increased proportion of watermelon peel [46].

An improvement in chewiness was observed with the increase in watermelon peel content. Research indicates that adding fiber to baked products can enhance their chewiness and elasticity, which was evident in the increased chewiness scores of the watermelon peel-containing samples. The addition of watermelon peel powder, due to its high fiber content, can also reduce dough stickiness. This is particularly noticeable in fiber-rich breads. Once again, the 100% wheat flour sample received the highest overall acceptability score by a significant margin compared to other samples, highlighting the negative impact of watermelon peel on the final acceptance of the bread.

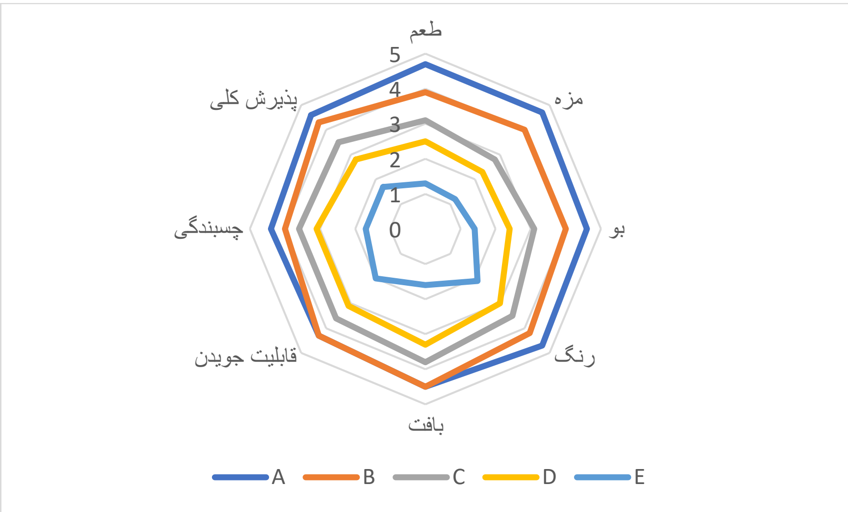

Fig 1. Sensory evaluation of baguette bread samples

4- Final Conclusion

The various effects of adding watermelon peel flour to the baguette bread formulation on the physicochemical and sensory properties of the bread, as well as dough characteristics, were examined. The results showed that increasing the amount of watermelon peel flour led to a rise in protein content of the flour blend and the final bread, due to the proteins present in the watermelon peel. A decrease in pH and an increase in the acidity of the bread were observed, indicating the presence of acidic compounds in the watermelon peel. While it was initially expected that the addition of watermelon peel flour would reduce the bread's moisture content, this study revealed that the moisture level actually increased, owing to the water-retention properties of the fibres in the peel. In sensory evaluations, various parameters such as taste, aroma, color, stickiness, chewability, texture, and overall acceptance were assessed. The results indicated that the addition of watermelon peel had a positive effect on several of these attributes, particularly in terms of taste, aroma, color, and chewability. In conclusion, incorporating watermelon peel flour into baguette bread formulation can have a positive impact on certain rheological properties of the dough, as well as on the physicochemical and sensory qualities of the bread.

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جایگزینی آرد گندم با آرد پوست هندوانه در تولید نان باگت

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چکیده

امروزه استفاده از ضایعات محصولات کشاورزی جهت به حداکثر رساندن دستیابی به مواد مغذی بسیار مورد توجه قرار گرفته است. در این پژوهش، اثر افزودن آرد پوست هندوانه در مقادیر ۲/۵، ۵، ۷/۵ و ۱۰ درصد به آرد گندم بر خواص فیزیکوشیمیایی، رئولوژیکی و حسی نان باگت مورد بررسی قرار گرفت. ویژگی‌های شیمیایی (رطوبت، پروتئین، خاکستر، pH و اسیدیته) آرد و نان مورد ارزیابی قرار گرفت. آزمون‌های رئولوژیکی ، خصوصیات فیزیکی، بافتی، شاخص های رنگی و ویژگی‌های حسی محصول نهایی اندازه گیری شد. نتایج نشان داد رطوبت در آرد پوست هندوانه بیشتر از آرد گندم است. میزان فیبر، خاکستر و پروتئین با افزایش میزان آرد پوست هندوانه افزایش یافت. رطوبت نان به دلیل ظرفیت بالای جذب آب فیبرهای موجود در آرد پوست هندوانه افزایش پیدا کرد. در آزمون‌های فارینوگراف مشخص شد که جذب آب خمیر با افزایش میزان آرد پوست هندوانه افزایش یافته و الاستیسیته خمیر کاهش یافت. دانسیته نان با افزایش پودر پوست هندوانه افزایش و حجم مخصوص نان کاهش یافت، که ممکن است به دلیل کاهش توانایی گازدهی خمیر و کاهش حجم نهایی باشد. از نظر ویژگی‌های حسی، نمونه‌های (۲/۵ ٪) و (۵٪) بالاترین امتیازها را در طعم و پذیرش کلی دریافت کردند. این پژوهش نشان داد که افزودن آرد پوست هندوانه می‌تواند به بهبود ارزش تغذیه‌ای نان کمک کند، اما باید به کاهش حجم نان و الاستیسیته خمیر توجه داشت.