



Evaluation of the Physicochemical Characteristics and Quality Attributes of Sweet Potato Supplemented Bread

Bushra Gul^{1*}, Aliza Batool², Mumtaz Hussain¹, Muhammad Aqeel¹ and Muhammad Mueed Tanveer Malik³

¹Department of Food Safety and Quality Management, Faculty of Food Science and Nutrition, Bahauddin Zakariya University, Multan-Pakistan.

²Department of Food Science and Technology, Faculty of Food and Home Sciences, MNS University of Agriculture, Multan-Pakistan.

³Department of Food Science and Technology, Faculty of Food Science and Nutrition, Bahauddin Zakariya University, Multan-Pakistan.

Article Info

Keywords:

Bread, Sweet potato flour, Supplemented flour, Innovative food, Consumer perception

Date:

Received: 26 January 2025

Accepted: 17 April 2025

Published: 15 June 2025

Volume: 03 (01), 2025



Copyright: © 2025 by the authors. This article is distributed under the Creative Commons Attribution (CC BY) license, allowing for open access and sharing under specified terms and conditions. (<https://creativecommons.org/licenses/by/4.0/>).

Abstract

Consumer interest in health-enhancing supplemented flour-based products has increased over the past decade. Sweet potato (*Ipomoea batatas*), a high-value root crop, is a potential ingredient since it contains natural pigments, antioxidants, and disease-resistance qualities. But its limited shelf life due to moisture loss, sprouting, and rotting restricts it for direct use. Its flour conversion (SPF) prolongs its shelf life and allows its use in bakery foods. The current research examined the impact of adding various percentages of sweet potato flour (0%, 10%, 15%, and 20%) to wheat flour on the physico-chemical, proximate, mineral, and sensory characteristics of bread. Outcomes indicated extremely significant differences between treatments. Moisture content increased from $33.50 \pm 0.42\%$ (T_0) to $38.04 \pm 0.04\%$ (T_3), ash from $1.09 \pm 0.05\%$ to $2.45 \pm 0.03\%$, and crude fat from $2.51 \pm 0.02\%$ to $4.77 \pm 0.02\%$, while crude protein decreased from $12.01 \pm 0.02\%$ to $8.42 \pm 0.02\%$. Among minerals, Na rose from 415.67 ± 0.05 mg/kg (T_0) to 562.88 ± 0.03 mg/kg (T_3), Ca from 3.56 ± 0.04 mg/kg to 5.15 ± 0.02 mg/kg, and Fe from 0.38 ± 0.04 mg/kg to 0.60 ± 0.08 mg/kg, whereas K declined from 390.56 ± 0.04 mg/kg to 150.96 ± 0.03 mg/kg. Gumminess decreased from 47.32 ± 0.04 to 18.46 ± 0.03 , while chewiness increased from 9.25 ± 0.05 to 37.05 ± 0.03 with SPF addition. Sensory analysis indicated that the breads supplemented with 10–15% SPF showed best flavor, texture, and acceptability. Sweet potato flour enrichment overall greatly improved the nutritional and sensory quality of wheat bread. Replacing 10–15% SPF is advisable for making nutrient-rich, consumer-acceptable bread that helps in mitigating malnutrition and enhancing food security in Pakistan.

1. Introduction

Functional foods have become an impetus in food innovation due to the established relationship between diet and health. Maintaining a balanced diet is recognized as a key factor in mitigating the risk of non-communicable diseases, which has consequently stimulated growing consumer demand for diverse and health-oriented food

alternatives. In response to evolving consumer demand, research and development in the food industry are increasingly focused on innovating food products like bread to improve their quality, organoleptic properties, and market accessibility. Cereals are edible and belong to grass family, (Cereal crops, such as wheat, rice, and corn, belong to the grass family known as Poaceae, also called Gramineae.).

Corresponding Author: Bushra Gul Email: bushragul900@gmail.com

Cereals, including major crops, are cultivated globally. The two most important commodities in the world are rice and wheat. Cereals are an essential source of nourishment and are a staple diet in both the developed and developing cultures. They provide essential micronutrients including vitamin E, several B vitamins, magnesium, and zinc, as well as energy in the form of carbohydrates, proteins, and fiber. Consuming cereal has been associated with a lower risk of heart disease and other chronic illnesses. Cereals are further distinguished by their low cost of production, ease of storage, economical transportation, and strong resistance to drying-out deterioration (McKevith, 2004).

As a significant source of energy, bread prepared from wheat flour is an integral part of the daily diet. Although not a common dietary component in all developing countries, its use has grown significantly there. Bread made from wheat has seen a significant increase in consumption, making it a more significant source of dietary energy. Despite being high in carbs, wheat-based bread is a poor supplier of vital amino acids like lysine and threonine. In areas where it hasn't been a staple food, its use has increased significantly in recent years. Cake is created with a combination of wheat and sweet potato flours: nutritional and sensory aspects (Olatunde, 2019). Freshly Baked, Orange-Fleshed Sweet Potato Types' Potential to Help Fight Deficiency in Vitamin A (Olatunde, 2019).

Sweet potato (*Ipomoea batatas*) is a natural source for the tropics (JC Bouwkamp - 2018) is a globally significant crop, with an annual worldwide production exceeding 135 million metric tons of food. It is one of the world's highest-yielding and most important sources of palatable plant-based food. 80-85% production of sweet potato from China (FAO, 2003) followed by the 20-25% remaining Asian countries like Latin America and Africa (Wanda, 2020). There is an accelerating demand for health-promoting, value-added wheat-based food products. specialty breads, recent innovation in the bakery sector, utilize non-wheat flour to offer additional nutrients, addressing the nutritional limitations often found in conventional wheat bread (Martin, 2005).

A root crop that is successfully incorporated into human food systems is the sweet potato (*Ipomoea batatas*) (Van Hal, 2000; Walter *et al.*, 2002). In addition to preserving food security, sweet potatoes can delay the onset of several chronic illnesses. It contains vital nutrients that are necessary for human nutrition. In addition to vital vitamins and minerals, its composition includes nutritional fiber, proteins, and carbs.

To supplement the nutritional deficiencies of many staple foods which often lack sufficient vitamins (A), minerals like (iron& potassium), fiber and high-quality protein in sweet potato can be processed into a variety of products to meet human dietary needs (Wheatley and Bofu,

2000). for the food industry, the inherent properties of sweet potato starch and the cost-effectiveness of its manufacturing are significant concerns, as these factors determine its potential as a primary food additive in a wide range of products (Chen *et al.*, 2002; Chen, 2003).

Current research on sweet potato and yam primarily focuses on two critical areas: physicochemical properties and starch processing. The food industry recognizes that the physicochemical properties of the root crops, including amylose-to-amylopectin ratio, granular size, and molecular structure, particularly inorganic components, are key determinants of starch quality and its industrial applications (Chen, 2003; Katayama *et al.*, 2004).

Consumer-acceptable bread can be formulated by substituting wheat flour at percentage of 10% and 15% (Greene and Howell-Benjamin (2004). This finding is earlier research by Coursey *et al.* (1979), who reported that a 20% substitution resulted in unacceptable bread due to deficiencies in texture, flavor, and loaf volume. While a lack of research exists regarding the acceptability of breads with higher levels of yam flour blends with whole wheat flour, bread containing 10% yam flour, generally acceptable in the same study by Greene and Howell-Benjamin (2004).

A panel of tasters did not perceive a considerable difference in the sensory attributes (appearance, aroma, taste, and texture) of the breads, (Yusupova *et al.*, 2010). Findings from Yusupova *et al.* (2018) demonstrated that replacing wheat flour with yam and tiger nut flour reduced protein content while increasing fiber content. The levels of fat and ash, however, were not significantly altered. Furthermore, the study showed that the water retention capacity of the bread increased as the substitution level of yam and tiger nut flour. A negative correlation was examined between the substitution level and bread volume, with a 20% replacement leading to a clear reduction in specific and loaf volume. While the control bread (100% wheat) scored highest in all physical properties, a sensory evaluation found no significant difference in acceptability between the control and breads with a 5% substitution of sweet potato and tiger nut flour.

After the current investigation we planned to assess the sensory and consumer acceptance of composite bread formulations, wheat bread incorporating different percentages of sweet potato flour. to determine consumer preferences and acceptability for the different bread formulations. To evaluate physicochemical and rheological properties of the enriched bread and examine its effect. To analyze the functional properties and nutritional composition of the sweet potato flour-supplemented bread.

2. Materials and Methods

2.1. Preparation for Sweet potato flour

Fresh sweet potato tubers were procured from a local market Multan, Punjab. Fresh sweet potato tubers were thoroughly

washed to remove surface soil. The tubers were then air-dried for several hours before peeling and shredded to reduce particle size, and facilitate dehydration. The shredded sweet potatoes were subsequently spread onto steel trays and dried in a deck oven at 101 °C for 1–3 hours. The dehydrated sweet potatoes were ground into a fine powder using an electric grinder (MJ-M176P, Panasonic, Malaysia). To prepare uniform particle size, the powder was sieved using a 0.35 mm mesh. The obtained sweet potato flour (SPF) was preserved in zip-bags made of polyethylene and stored in an air-tight environment at room temperature for further use in experiments (Oluwalana *et al.*, 2012). To compare the effect of sweet potato flour (SPF) on the characteristics of bread, it was utilized as a replacement for wheat flour (WF) at different ratios 90 or 85%. Experimental formulas were made by substituting WF with SPF at levels of substitution of 10% and 15% respectively. A control sample was produced using 100% WF and no SPF.

2.2. Supplemented flour analysis:

2.2.1. Farinograph

To assess mixing characteristics (development time, stability, and water absorption). A sample of 50 g flour was mixed with distilled water until the dough consistency levelled off at a value of 500 Brabender Units (BU). A 15 min mixing curve measured the dough rheological characteristics. (Trejo-González *et al.*, 2014).

2.2.2. Mixograph

To find out the mixing behavior of the dough, especially gluten development. A 35 g sample of flour was kneaded in a mixer having vertical pins that move around three fixed arms. The mixer measured the kneading force, which is higher when the gluten network is developing (Xin, 2015).

2.2.3. Proximate Composition

The proximate composition moisture, carbohydrate, crude protein, crude fat, crude ash, and crude fiber of both samples composite flour and bread were determined by using the methods recommended by AOAC (2005).

2.3. Preparation of Sweet Potato Flour Supplemented bread

Bread was produced via the straight dough method. 4 blends of sweet potato flour (SPF) and wheat flour (WF) were prepared at ratios of 0:100, 10:90, 15:85, and 20:80 (SPF:WF). The 0:100 blend served as the control. All dry ingredients were first combined, followed by the addition of wet ingredients. The mixture was blended for 10–12 minutes using an electric mixer. The final dough temperature reached 30 °C. After an initial 15-minute rest, the dough was kneaded and placed in a proofer for 15 minutes. Portions were then weighed to 500 g, rounded, and then proofing at 30°C 75 min & relative humidity 80%. Baking

was performed in an infrared electric oven at 230 °C until the surface was golden-brown.

2.4. Analysis of supplemented bread

2.4.1. Texture

Bread texture properties were determined using Texture analyzer (TA-XT plus, Stable Micro Systems) based on the technique outlined by (Angioloni *et al.*, 2011). Hardness and gumminess were measured to determine the textural attributes of bread.

2.4.2. Color

Bread crumb color analysis was determined using Minolta handheld chroma meter (CR-310 -) following the procedure of (Greene and Bovell-Benjamin, 2004). The color values were approximated as L* (dark = 0, white = 100), a* (greenness redness), and b* (blueness & yellow)

2.4.3. Minerals

The mineral composition (Na, K, Ca, Mg, Fe, Cu, Zn, Mn, Se) was quantitated after the ashing method outlined by AOAC (2003). The concentrations of the minerals were measured with the aid of a Perkin-Elmer Model 403 Atomic Absorption Spectrometer (AAS). Flame atomization was performed with an air-acetylene flame and single-element hollow cathode lamps, using the standard operating procedures outlined by AOAC (2003).

2.4.4. pH

The pH of bread crumb was determined following AOAC (2000) procedures. Sample was prepared a paste by dilution of 10 g of bread crumb in 20 mL of distilled water. A combined glass-calomel electrode of a pH meter (Model Lino-Lab 720) was directly placed into the paste to read the pH.

2.4.5. Sensory evaluation

Ten members of a trained sensory panel evaluated the prepared bread's sensory qualities using a nine-point hedonic scale to gauge customer approval. According to Onabanjo *et al.* (2014), the scale went from 1 (strongly disliked) to 9 (strongly loved).

2.5. Statistical analysis

Statistics 8.1's "Two Factor Factorial under Completely Randomized Design" tool was used to statistically analyze the data gathered for this investigation. ANOVA was used to determine the level of significance ($P=0.05$), as assessed by Svec and Hruskova (2010).

3. Results and Discussion

3.1. Farinograph testing

With a farinograph, the rheological behavior of the flour supplemented with varying levels of sweet potato flour (SPF) was analyzed to ascertain its dough mixing and handling properties. Among the farinograph properties measured were dough weakening (UF), water absorption (%), dough stability (min), and dough development time (min) as shown in Fig 1.

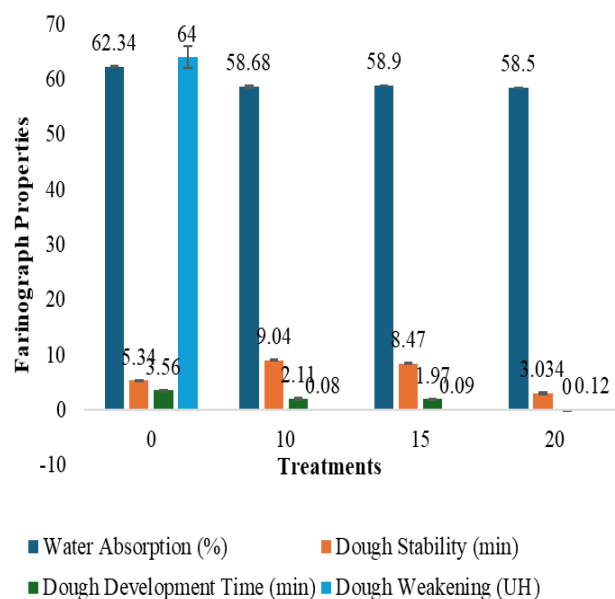


Figure 1. Effect of sweet potato flour supplementation

3.1.1. Dough development time

The findings showed that the addition of sweet potato flour (SPF) had a significant influence on the dough development time at all levels of treatment. Table 1 presents the average comparison of the treatments, which shows that the dough development time varied from 1.96 to 3.55 minutes. An interesting observation was that, at the 15% level of substitution of SPF, the dough development time was higher than with respect to the overall declining trend for higher levels of SPF addition. Specifically, development times for 0%, 10%, 15%, and 20% levels of SPF substitution were 3.55, 2.10, 1.97, and 2.43 minutes, respectively. Nevertheless, it was concluded that the rise at the 15% and 20% levels of SPF was not statistically significant. These findings agree with Trejo-González *et al.* (2014), whose results also showed similar effects of composite sweet potato flour on bread and dough quality. Decrease in wheat gluten content, which changes the viscoelastic characteristics of the dough and consequently its development behavior, can be the cause of the observed decrease in dough development time for increasing SPF substitution.

3.1.2. Dough Stability

The dough stability time of the flour was dramatically impacted by supplementation with varying percentages of sweet potato flour (SPF). Based on the data, the dough stability time varied significantly between the treatments (Table 1). All preparations had stability times between 3.03 and 9.03 minutes. As the ratio of SPF substitution in wheat flour increased, a declining trend in dough stability time was

noted. Nevertheless, compared with 100% wheat flour, the stability times of the dough containing 10% and 15% SPF were longer, which means that a certain content of SPF can strengthen the stability of dough. Specifically, the stability times of the dough with 0%, 10%, 15%, and 20% replacement of SPF were 5.33, 9.03, 8.47, and 3.03 minutes, respectively. The results indicated a significant increase in stability in the range of 10% to 15% SPF levels, followed by a sudden fall at 20%. These findings are consistent with those consistent with those Oluwalana, Malomo, and Wang, (2016), who studied sweet potato-fortified composite flours' dough behavior and optimization of the dough stability for wheat-tuber breads. Greater replacement levels result in lower stability of dough since they contain less wheat gluten and more tuber starch, which disrupts the formation of the gluten network and weakens the dough's structure.

3.1.3. Water absorption (%)

The results showed that adding sweet potato flour (SPF) had a significant effect on the water absorption percentage in composite flour. Table 1 compares the means of the various treatments and shows that the water absorption levels ranged from 58.4% to 62.3%. As wheat flour was sequentially replaced by SPF, there was a common trend towards decreased water absorption. Specifically, water absorption values for 0%, 10%, 15%, and 20% SPF substitutes were 62.34%, 58.67%, 58.80%, and 58.40%, respectively. The general trend was a reduction in water absorption capacity with an increase in the percentage of SPF despite a minor, non-significant increase at 10% and 15% SPF levels. 100% wheat flour possesses the maximum water absorption rating (62.34%). These findings agree with those of Oluwalana *et al.* (2012) and Hathorn *et al.* (2008), who reported similar effects of sweet potato flour supplementation on bread and dough characteristics. However, the results contradict those of Trejo-González *et al.* (2014), who found that water absorption rose in proportion to SPF substitution levels. According to their research, the increase was caused by the tuber starches' greater tendency to expand and hold water. However, the reduced gluten concentration and distinct water-binding behavior of sweet potato starch in comparison to wheat gluten may account for the decrease in water absorption in the current study. This impacts the flour's capacity to hold onto water while mixing.

3.1.4. Dough weakening

The findings showed that the addition of sweet potato flour (SPF) had a highly substantial impact on the dough weakening (UH) values. The mean comparison of several treatments is shown in Table 1 which reveals that the dough weakening values varied from 0.084 UF to 64.000 UF. There was a general downward trend in dough weakening as the amount of SPF substitution in wheat flour increased. The 15% substitution rate was the exception, however, as

Table 1. Effect of sweet potato flour supplementation on wheat flour mixograph characteristics

Treatments	Water absorption (%)	Dough stability (min)	Dough development time (min)	C ₁	C ₂	C ₃	C ₄	C ₅	C _s	α (Nm/min)	β (Nm/min)	gamma (Nm/min)
T ₀	61.4±0.25 ^a	9.7±0.01 ^a	1.5±0.02 ^a	1.1±1.01 ^a	0.5±0.0 ^a	2.0±1.63 ^a	2.0±0.0 ^a	3.4±0.0 ^a	1.1±1.03 ^a	-0.09±0.0 ^a	0.5±0.35 ^a	8.00E-03±0.01 ^a
T ₁	58.6±0.02 ^b	9.7±0.02 ^b	1.4±0.02 ^b	1.0±0.01 ^b	0.5±0.0 ^b	1.9±1.97 ^a	1.9±0.01 ^b	3.3±0.0 ^b	1.06±1.10 ^b	-0.10±0.01 ^b	0.4±0.49 ^b	-0.02±0.0 ^b
T ₂	58.3±0.02 ^c	9.5±0.02 ^c	1.4±0.03 ^b	1.9±0.01 ^c	0.5±0.0 ^b	1.9±1.96 ^a	1.5±0.0 ^c	3.12±0.0 ^c	1.03±1.06 ^c	-0.1±0.0 ^c	0.6±0.40 ^c	-0.02±0.0 ^b
T ₃	57.4±0.15 ^d	9.4±0.01 ^d	1.2±0.02 ^c	1.6±1.0 ^c	0.5±0.0 ^c	1.6±2.0 ^b	1.4±0.0 ^d	2.3±0.0 ^d	1.02±1.02 ^c	-0.3±0.0 ^c	0.2±0.21 ^d	-0.10±0.0 ^c

T₀= 100% Wheat flour
T₁= 10% Sweet potato flour + 90% Wheat flour
T₂= 15% Sweet potato flour + 85% Wheat flour
T₃= 20% Sweet potato flour + 80% Wheat flour

significant compared to the 10% treatment. Specifically, at 0%, 10%, 15%, and 20% SPF substitutions, the values of dough weakening were 64.001 UF, 0.085 UF, 0.089 UF, and 0.113 UF, respectively. Generally, at 10%, 15%, and 20% substitution rates, the incorporation of SPF resulted in a reduction in dough weakening that was non-significant.

These results are in line with those of Oluwalana *et al.* (2012) and Trejo-González *et al.* (2014), who found that fortifying sweet potato flour had comparable impacts on the quality of composite flour and dough behaviour. The strength and stability of the gluten network, which gives wheat-based dough its elasticity and structure, are closely correlated with the dough's weakening value. The gluten matrix was weakened in this study by the partial substitution of SPF for wheat flour, which added another source of starch devoid of proteins that make gluten. As SPF levels rose, the flour's ability to produce cohesive and elastic gluten strands decreased, which resulted in a notable decrease in dough weakening values.

3.2. Rheological Properties of SPF Supplemented Flour

Mixolab was used to measure the rheological characteristics of wheat flour substituted with different proportions of sweet potato flour (SPF), with a maximum sample weight of 35 g of flour per analysis as shown in table 1.

3.2.1. Water Absorption

Appreciable variation in water absorption percentage among treatments existed. Table 1 indicates comparison of mean values of water absorption, which ranged from 57.41% to 61.43%. From the findings, water absorption decreased with increased wheat mixes' level of SPF. The water absorption percentage of 0%, 10%, 15%, and 20% levels of SPF replacement were 61.437%, 58.633%, 58.317%, and 57.413%, respectively.

Interestingly, the maximum water absorption (61.437%) was recorded in the control sample (0% SPF). The results disagree with those of Schopf and Scherf (2021), whose research based on establishing the optimum dough consistency potato flour to be added on wheat flour mixtures required greater water absorption. The potato starch hydroxyl groups that improve water interaction by virtue of hydrogen bonding because of starch gelatinisation are accountable for the difference.

3.2.2. Dough Development Time

The replacement of the SPF had a significant impact on dough development time. The values declined as the SPF value rose, from 1.22 to 1.51 minutes. The 0%, 10%, 15%, and 20% SPF registered development times of 1.5133, 1.4633, 1.4467, and 1.2267 minutes, respectively. There was a drastic decline at the 20% level of replacement, despite the non-significant increase at the 10% and 15% levels. These findings concur with Cappelli *et al.* (2020), which also reported that dough development time decreased

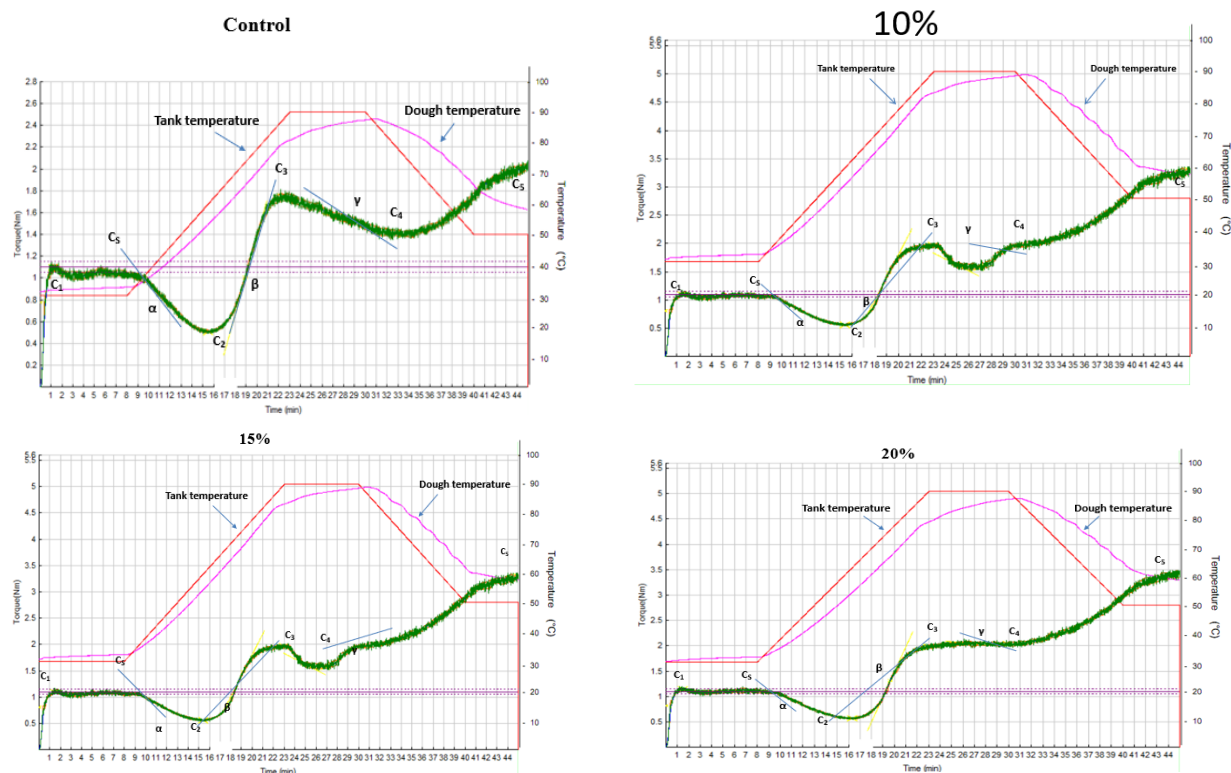


Figure 2. Effect of sweet potato flour supplementation @ 0%(T₀), 10% (T₁), 15%(T₂) and 20 (T₃) with wheat flour on mixograph analysis

as the level of potato flour substitution increased. This decrease is because gluten-forming proteins are diluted, which reduces the network strength of the gluten and accelerates the development of dough.

3.2.3. Dough Stability Time

In addition, the incorporation of SPF significantly influenced the dough stability time. When the percentage level of replacement of SPF was raised, stability gradually decreased from 9.41 to 9.75 minutes. The average values of 9.7500, 9.7167, 9.5200, and 9.4100 minutes were reported after the application of 0%, 10%, 15%, and 20% SPF, respectively. These results are in line with rheological properties of composite flour containing potato flour reported by Cappelli *et al.* (2020). As the primary ingredient responsible for dough elasticity and power is gluten, therefore the reduction in gluten strength can be justified through the reduction in the stability of the dough (Dowell *et al.*, 2008). If wheat flour is replaced with sweet potato flour, the gluten content reduces, breaking down the dough structure and reducing its stability time.

3.3. Mixolab Parameter

The results indicated that the addition of sweet potato flour at various substitution levels significantly affected

parameters C₁, C₂, C₃, C₄, and C₅. The comparison of treatment means for these attributes is presented in Table 1. The values measured for C₁ were 1.144 (Nm), 1.097 (Nm), 1.082 (Nm), and 1.050 (Nm) for 0%, 10%, 15%, and 20% sweet potato flour substitutions, respectively. For the same substitution degrees, the values of C₂ were 0.572 (Nm), 0.572 (Nm), 0.558 (Nm), and 0.506 (Nm), whereas for C₃, they were 2.018 (Nm), 1.975 (Nm), 1.965 (Nm), and 1.629 (Nm) shown in Fig 2, 3, 4 and 5.

When 0%, 10%, 15%, and 20% sweet potato flour were incorporated, the C₄ values were 2.03 (Nm), 1.97 (Nm), 1.57 (Nm), and 1.41 (Nm), respectively, while the C₅ values were 3.42 (Nm), 3.282 (Nm), 3.13 (Nm), and 2.3 (Nm), respectively. The C₁–C₅ values had a clear declining trend as the proportion of the wheat flour mix with sweet potato flour increased (using 100% wheat flour as the control). These findings agree with Codină (2019), who investigated the impact of varying potato-to-wheat ratios on dough's properties. In mixograph evaluation, the readings C₁–C₅ represent essential pasting attributes that express the quality and behavior of wheat starch under heat treatment directly Codină (2019). Proteins, besides starch, play a role in controlling the pasting qualities of dough as previously

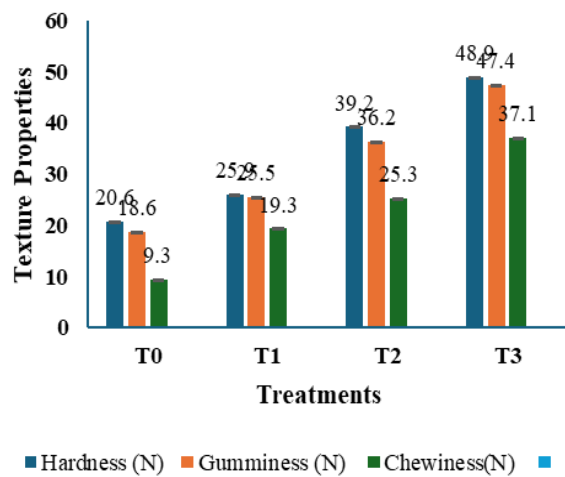


Figure 3. Effect of sweet potato flour supplementation on the textural properties of bread prepared from supplemented flour

reported by the inhibitory effect of proteins on starch viscosity may be the cause of the observed decrease in these metrics with increased substitution of sweet potato flour. Furthermore, a decrease in the overall protein level results from partially substituting sweet potato flour for wheat flour, which accounts for the dough's diminished ability to gelatinize starch. This phenomenon can be further explained by the increased proportion of gelatinized starch from sweet potato, as also noted by Kim *et al.* (2023). The values of α (alpha), β (beta), and γ (gamma) with different amounts of sweet potato flour substitution also showed a highly significant difference. The mean comparison for these parameters is shown in Table 1. The α values were -0.093 (Nm/min), -0.157 (Nm/min), -0.113 (Nm/min), and -0.113 (Nm/min) for 0%, 10%, 15%, and 20% substitution, respectively. For the same substitute levels, the γ values were 8.00×10^{-3} (Nm/min), -0.021 (Nm/min), -0.091 (Nm/min), and -0.104 (Nm/min), whereas the β values were 0.493 (Nm/min), 0.395 (Nm/min), 0.356 (Nm/min), and 0.214 (Nm/min).

Table 2. Effect of sweet potato flour supplementation on the proximate composition of bread prepared from supplemented flour

Parameters %	T ₀	T ₁	T ₂	T ₃
Moisture	33.6± 0.41 ^d	35.5±0.41 ^c	36.5±0.03 ^b	38.1± 0.03 ^a
Ash	1.1±0.04 ^c	2.7±0.03 ^a	2.6±0.02 ^b	2.5±0.02 ^b
Crude protein	12.1±0.03 ^a	11.3±0.01 ^b	9.4±0.01 ^c	8.5±0.03 ^d
Crude Fat	2.6±0.03 ^c	4.7±0.04 ^b	4.8±0.02 ^a	4.8±0.01 ^a
Crude fiber	2.9± 0.01 ^a	2.1±0.02 ^b	2.9± 0.01 ^c	2.9±0.01 ^d

3.4. Texture properties of Sweet Potato Flour Supplemented Bread

Sweet potato flour had a very noticeable impact on the chewiness, gumminess, and hardness of the bread. Figure 3 displays the average bread textural parameter values for different SPF concentrations. T₀, T₁, T₂, and T₃ had respective mean hardness values of 20.16 ± 0.06, 26.18 ± 0.03, 38.20 ± 0.07, and 49.18 ± 0.03 N. Similarly, at T₀, T₁, T₂, and T₃, the average gumminess was 18.46 ± 0.03, 24.50 ± 0.03, 35.16 ± 0.02, and 47.32 ± 0.04 N, respectively. At T₀, T₁, T₂, and T₃, the average chewiness was 9.25 ± 0.05, 19.25 ± 0.04, 25.52 ± 0.02, and 37.05 ± 0.03 N, in that order as shown in figure 3.

Since texture has a direct impact on mouthfeel and consumer impression, it is an essential bread quality feature. The results of the study indicated there were great differences between the treatments in the three texture properties: chewiness, gumminess, and hardness. While SPF replaced wheat flour gradually, an increasing trend in chewiness, gumminess, and hardness was observed. The main cause of such differences in texture is the thinning of gluten due to the introduction of SPF, which lowers the retention of gas in dough and increases hardness and affects gumminess and chewiness. The higher the SPF level in the bread, the higher the value of hardness, reflecting that mastication becomes more energetically costly. Depending on customer preferences, this feature may be advantageous because different textures satisfy a range of market expectations. The current study's results are in line with those of Peressini *et al.* (2009) and Iglesias-Puig and Haros (2013), who investigated the physicochemical and sensory characteristics of bread that had been fortified with chia and SPF, respectively. Higher doses of supplementation were found to increase bread's hardness and chewiness in both tests.

3.5. Proximate Analysis

The results of the proximate analysis showed that the bread samples made with varying amounts of sweet potato flour (SPF) replacement were very different from one another. Among the metrics measured were moisture content, ash content, crude fat content, crude fiber content,

Table 3. Effect of sweet potato flour supplementation on the mineral profile(mg/100g) of bread prepared from supplemented flour

Treatment	Na	Ca	K	Zn	Fe	Cu	P
T ₀	41.7±0.04 ^d	3.5±0.05 ^d	39.5±0.02 ^a	0.3±0.03 ^c	0.38±0.03 ^b	0.11±0.03 ^b	13.2±2.03 ^d
T ₁	55.7±0.02 ^b	5.4±0.02 ^a	16.5±0.03 ^b	1.2±0.03 ^a	0.62±0.05 ^a	0.10±0.04 ^c	14.2±0.04 ^c
T ₂	55.2±0.02 ^b	5.2±0.03 ^b	16.2±0.02 ^b	1.2±0.04 ^a	0.55±0.06 ^a	0.12±0.05 ^a	14.1±0.06 ^b
T ₃	56.8±0.04 ^a	5.1±0.03 ^c	15.9±0.01 ^c	1.7±0.03 ^b	0.60±0.07 ^a	0.08±0.06 ^d	16.3±0.07 ^a

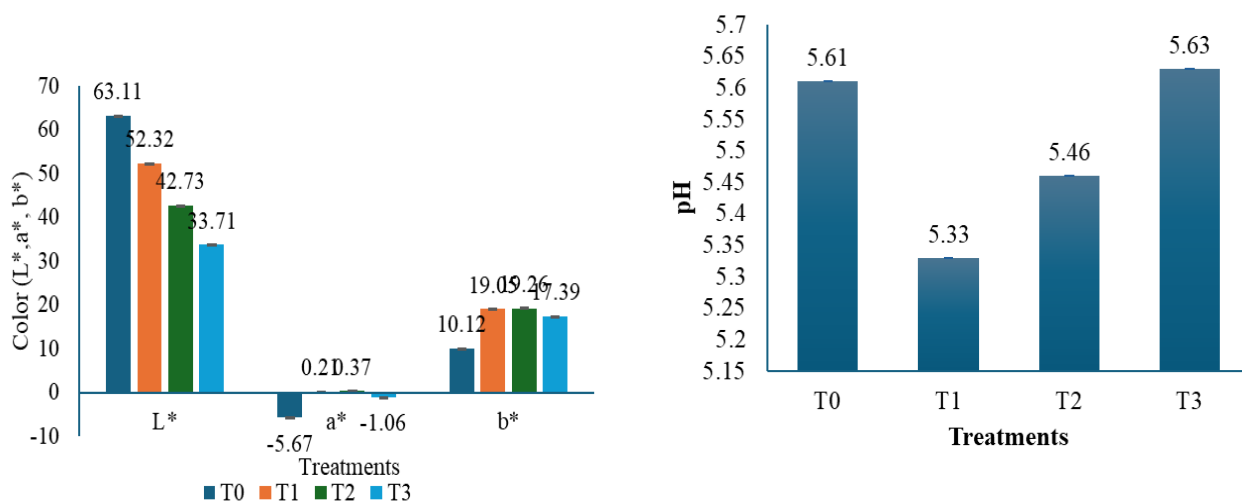
and crude protein content as demonstrated in table 2.

Table 4 shows that T₀, T₁, T₂, and T₃ had average moisture contents of 33.50 ± 0.42%, 35.41 ± 0.42%, 36.04 ± 0.02%, and 38.04 ± 0.04%, respectively. 1.09 ± 0.05%, 2.63 ± 0.04%, 2.51 ± 0.01%, and 2.45 ± 0.03% were the average ash contents, in that order. Similarly, for T₀, T₁, T₂, and T₃, the crude fiber contents were 2.83 ± 0.02%, 2.91 ± 0.01%, 2.93 ± 0.02%, and 2.89 ± 0.02%, respectively, while the crude fat contents were 2.51 ± 0.02%, 4.64 ± 0.03%, 4.74 ± 0.03%, and 4.77 ± 0.02%. The corresponding treatments had crude protein concentrations of 12.01 ± 0.02%, 11.21 ± 0.02%, 9.32 ± 0.02%, and 8.42 ± 0.02%.

The findings show that there is a considerable difference in the treatments' moisture contents. The enhanced water-binding capacity of sweet potato flour may be the reason for the steady rise in moisture content that was seen as SPF substitution levels in wheat flour increased. The level of crude fiber was also on the increase in a similar pattern across treatments. The incremental replacement of SPF with wheat flour reduced crude protein content significantly. This loss of crude protein might have been

because sweet potatoes naturally have a low protein content; they are rich in carbohydrates but poor in protein. The crude fat and ash content, in return, showed a rising trend; nonetheless, the increase in the level of ash was not statistically significant at 15% and 20% SPF replacement levels.

The current study's results are in line, who looked at the proximate, sensory, and physicochemical properties of bread enhanced with SPF. Dhingra and Jood (2004) found an increase in ash content and noted the similar impact of flour enrichment on bread's nutritional and functional qualities. As the formulation has the optimal amount of SPF, the higher moisture content with increased SPF replacement also indicates better production potential. The reduction in protein content as observed agrees with the observations of Tiimub (2013), where such trends were exhibited by bread made using cassava, soybean, and sweet potato flour blends. Nonetheless, the results for crude fat content in this research differ from those of Bibiana *et al.* (2014), who had decreasing contents of fat and acceptability at higher levels of substitution with sweet potato flour. They

**Figure 4.** Effect of Sweet Potato Flour on the color (L*, a*, b*) and pH of bread

explained that this was due to the dilution effect of non-fat solids and the high blending ratio of SPF in composite flour.

3.6. Minerals Contents

Mineral composition analysis indicated highly significant variability among the bread samples made with different amounts of sweet potato flour (SPF) replacement. The analyzed minerals were sodium (Na), calcium (Ca), potassium (K), iron (Fe), zinc (Zn), copper (Cu), and phosphorus (P) (mg/kg) as shown in table 3.

For T₀, T₁, T₂, and T₃, the mean Na values were 415.67 ± 0.05, 555.74 ± 0.03, 558.23 ± 0.03, and 562.88 ± 0.03 mg/kg, respectively, as shown in Table 5. The mean Ca contents were 3.56 ± 0.04, 5.43 ± 0.01, 5.27 ± 0.02, and 5.15 ± 0.02 mg/kg, while the mean K values were 390.56 ± 0.04, 168.54 ± 0.02, 165.22 ± 0.03, and 150.96 ± 0.03 mg/kg for T₀–T₃, respectively. Similarly, the Fe contents were 0.38 ± 0.04, 0.62 ± 0.01, 0.55 ± 0.02, and 0.60 ± 0.08 mg/kg, and the Zn contents were 0.23 ± 0.02, 1.25 ± 0.02, 1.25 ± 0.02, and 1.16 ± 0.02 mg/kg for T₀–T₃, respectively. The mean Cu contents were 0.11 ± 0.02, 0.10 ± 0.02, 0.12 ± 0.02, and 0.08 ± 0.01 mg/kg, while the mean P contents were 124.24 ± 2.02, 142.12 ± 0.03, 148.19 ± 0.01, and 152.21 ± 0.02 mg/kg for T₀–T₃, respectively. The results showed a very large difference in calcium concentration among treatments with a decreasing tendency with increasing levels of SPF substitution. Although the contrast between the 10% and the 15% levels was not significant, the salt composition had an upward trend as SPF concentration increased. Increased levels of SPF substitution led to a consistent reduction in potassium concentration, indicating that SPF diluted potassium-enriched wheat flour. In contrast, phosphorus levels increased as SPF supplement doses increased. In the case of zinc, no visible rise in the concentration of zinc was seen in 10% and 15% SPF replaced breads. Negative correlation between Zn concentration and SPF substitution level is suggested by the overall trend for lower Zn content at higher SPF substitution levels. Micronutrients and minerals play a significant role in maintaining healthy physiological processes and body growth. The current study's results concur with those of Oluwalana *et al.* (2012), who investigated how SPF supplementation affected the quality of bread and flour. The observed increases in the amounts of Ca, Na, and P may be due to higher natural concentrations of these minerals in sweet potato flour; this trend has also been found in previous studies trend (Simonne *et al.*, 2014). On the other hand, there may not have been any appreciable increase in the quantities of Cu, Zn, and Fe in the fortified bread because of their comparatively low concentrations in SPF.

3.7. Color (L*, a*, b*)

Analysis of variance of color characteristics indicated strongly significant variation among the samples of bread formulated from different percentages of sweet potato flour

(SPF) replacement. The color parameters that were measured were lightness (L*), redness/greenness (a*), and yellowness/blueness (b*) as shown in figure 4.

As shown in Table 5, the mean L* values for T₀, T₁, T₂, and T₃ were 63.11 ± 0.01, 52.32 ± 0.02, 42.73 ± 0.02, and 33.71 ± 0.02, respectively. The corresponding mean a* values were −5.67 ± 0.01, 0.21 ± 0.02, 0.37 ± 0.02, and −1.06 ± 0.02, while the mean b* values were 10.12 ± 0.02, 19.05 ± 0.03, 19.26 ± 0.02, and 17.39 ± 0.02, respectively.

One of the most significant sensory attributes influencing consumer acceptability is color because it is the initial visual indication of product quality. The result of the present study reflected a noteworthy decrease in L* (brightness) values with increasing levels of SPF substitution, implying darker crust and crumb color for breads with higher levels of SPF. Similarly, significant differences were observed in b* (yellowness) values between treatments, which rose at 10% and 15% replacement levels (T₁ and T₂) but fell slightly to 20% replacement (T₃). The a* (red color) values showed an increase from negative to positive with the inclusion of SPF up to 15% because of the existing natural pigments in sweet potato flour. There was a slight decline in a* at 20% substitution that might be due to pigment breakdown or Maillard browning upon baking. The results of this research are in close conformity with (Greene and Bovell-Benjamin, 2004), who also documented comparable alterations in the color attributes of bread enriched with purple sweet potato flour. The enhanced color intensity and yellowness of the SPF-added bread are contributory to the natural carotenoids and anthocyanins found in sweet potato, as well as the increased Millard reactions due to baking at higher levels of substitution.

3.8. pH

pH is the definition of a measure of hydrogen ion concentration in a compound or solution, its alkalinity or acidity. Figure 4 shows comparing the pH of bread made with different levels of supplementation of sweet potato flour (SPF) and it is highly significant among the treatments. The average pH values for treatments T₀, T₁, T₂, and T₃ were 5.62 ± 0.02, 5.34 ± 0.03, 5.56 ± 0.03, and 5.66 ± 0.03, respectively table 5. The tendency was that the higher the ratio of SPF in wheat flour, the more the pH of bread increased gradually. The highest pH was in the sample with 20% SPF supplementation.

3.9. Sensory Properties

The sensory attributes of bread enhanced with different amounts of sweet potato flour (SPF), such as crust color, texture, crumb color, aroma, flavor, and overall acceptability, showed very significant change between treatments. The mean values of the sensory attributes of bread prepared with varying amounts of SPF supplementation are displayed in Table 4. For treatments T₀,

Table 4: Effect of sweet potato supplemented bread on sensory properties of bread

Treatment	Crust Color	Texture	Crumb Color	Aroma	Taste	Overall acceptability
T ₀	8.073±0.205 ^a	7.4500±0.120 ^a	7.180±0.369 ^a	7.657±0.411 ^a	8.547±0.483 ^a	7.693±0.450 ^a
T ₁	7.127±0.370 ^b	6.737±0.563 ^a	6.980±0.221 ^a	5.500±0.348 ^b	7.260±0.374 ^b	7.630±0.564 ^a
T ₂	6.483±0.242 ^b	6.416±0.130 ^a	6.440±0.461 ^a	5.443±0.330 ^b	7.210±0.208 ^b	6.153±0.272 ^b
T ₃	5.413±0.398 ^c	4.587±0.544 ^b	4.697±0.402 ^b	4.293±0.309 ^c	5.140±0.486 ^c	4.2000±0.113 ^c

T₁, T₂, and T₃, the average crust color values (Table 4) were 8.073 ± 0.205, 7.127 ± 0.370, 6.483 ± 0.242, and 5.413 ± 0.398, respectively. The mean texture scores (Table 4.49) were 7.450 ± 0.120, 6.737 ± 0.563, 6.416 ± 0.130, and 4.587 ± 0.544, respectively. Similarly, the mean crumb color values (Table 4) were 7.180 ± 0.369, 6.980 ± 0.221, 6.440 ± 0.461, and 4.697 ± 0.402, respectively. The mean aroma scores (Table 4) were 7.657 ± 0.411, 5.500 ± 0.348, 5.443 ± 0.330, and 4.293 ± 0.309, respectively. The mean taste scores (Table 4) were 8.547 ± 0.483, 7.260 ± 0.374, 7.210 ± 0.208, and 5.140 ± 0.486, while the mean overall acceptability scores (Table 4) were 7.693 ± 0.450, 7.630 ± 0.564, 6.153 ± 0.272, and 4.200 ± 0.113, respectively.

The findings show that bread made from 100% wheat flour (T₀) had the best sensory scores for most of the characteristics. Bread with added 5% SPF (T₁) had scores not significantly different from T₀, which implies very little negative impact on sensory quality at this substitution rate. Substitution at higher levels (10% and 15%) led to a consistent decrease in sensory scores. Texture also showed a similar pattern to crust color, with the worst scores for the 15% SPF substitution (T₃). Crumb color and flavor also exhibited a declining trend with rising SPF concentration, though aroma values for 5% and 10% SPF breads were considerably different from 100% wheat flour bread. Total acceptability, the most important indicator of consumer preference, did not differ significantly between bread made of 100% wheat flour and 5% SPF-containing bread, and hence, low levels of substitution can be easily accepted by consumers.

The results in this research are different from those presented by Kamal, Islam, and Aziz (2013), who recorded the greatest sensory values at 15% SPF replacement. Nonetheless, the current findings align with those of Oluwalana *et al.* (2012). Differences in evaluation procedures, ambient factors, and panelists' sensory training and experience may all contribute to variations in the results of sensory evaluations between research.

Conclusion

The addition of sweet potato flour (SPF) to wheat flour profoundly improved the nutritional, mineral, and sensory characteristics of bread. The research showed that partial replacement of wheat flour with SPF improved moisture, ash, fat, and mineral content (Na, Ca, Fe), whereas protein and potassium contents were reduced. Textural properties were also enhanced with gumminess and chewiness values at optimum at moderate substitution levels. Sensory analysis identified breads supplemented with 10–15% SPF as most acceptable based on flavor, texture, and overall acceptability. These findings indicate that sweet potato flour is a promising ingredient for the formulation of nutritionally enhanced and consumer-acceptable bread. Its incorporation not only enhances the value of locally produced sweet potatoes but also contributes to efforts for enhancing public nutrition and ensuring food security in Pakistan.

Funding

No funding was received for this study.

Acknowledgment

The authors are grateful to The University of Agriculture Faisalabad, Pakistan for lab facilities.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Contribution

Bushra Gul, Aliza Batool, Ahmad Raza, Mumtaz Hussain, Muhammad Aqeel, and Muhammad Mueed Tanveer Malik collectively contributed to the conception, design, and execution of this study. All authors participated in data collection, analysis, and interpretation of results. They were equally involved in drafting, reviewing, and refining the manuscript to ensure accuracy and clarity.

References

- Angioloni, A., & Collar, C. (2011). Physicochemical and nutritional properties of reduced-caloric density high-fibre breads. *LWT-Food Science and Technology*, 44(3), 747-758.
- Bibiana, I., Grace, N., & Julius, A. (2014). Quality evaluation of composite bread produced from wheat, maize and orange fleshed sweet potato

- flours. *American journal of Food science and Technology*, 2(4), 109-115.
- Bouwkamp, J. C. (2018). *Sweet potato products: a natural resource for the tropics*. CRC Press.
- Cappelli, A., Bettaccini, L., & Cini, E. (2020). The kneading process: A systematic review of the effects on dough rheology and resulting bread characteristics, including improvement strategies. *Trends in Food Science & Technology*, 104, 91-101.
- Codină, G. G., Dabija, A., & Oroian, M. (2019). Prediction of pasting properties of dough from mixolab measurements using artificial neuronal networks. *Foods*, 8(10), 447.
- Dhingra, S., & Jood, S. (2004). Effect of flour blending on functional, baking and organoleptic characteristics of bread. *International Journal of Food Science and Technology*, 39(2), 213-222.
- Dowell, F. E., Maghirang, E. B., Pierce, R. O., Lookhart, G. L., Bean, S. R., Xie, F., . & Chung, O. K. (2008). Relationship of bread quality to kernel, flour, and dough properties. *Cereal Chemistry*, 85(1), 82-91.
- Greene, J. L., & Bovell-Benjamin, A. C. (2004). Macroscopic and sensory evaluation of bread supplemented with sweet-potato flour. *Journal of food science*, 69(4), SNQ167-SNQ173.
- Hathorn, C. S., Biswas, M. A., Gichuhi, P. N., & Bovell-Benjamin, A. C. (2008). Comparison of chemical, physical, micro-structural, and microbial properties of breads supplemented with sweetpotato flour and high-gluten dough enhancers. *LWT-Food Science and Technology*, 41(5), 803-815.
- Iglesias-Puig, E., & Haros, M. (2013). Evaluation of performance of dough and bread incorporating chia (*Salvia hispanica* L.). *European Food Research and Technology*, 237(6), 865-874.
- Ji-chun, T. I. A. N., Rui-Bo, H. U., Zhi-ying, D. E. N. G., & Yan-Xun, W. (2007). The variation and stability analysis of wheat dough stability time. *Agricultural Sciences in China*, 6(2), 143-149.
- Kamal, M. S., Islam, M. N., & Aziz, M. G. (2013). Effect of sweet potato flour of two local varieties on quality of breads. *Journal of the Bangladesh Agricultural University*, 11(2), 301-306.
- Katayama, K., Tamiya, S., & Ishiguro, K. (2004). Starch properties of new sweet potato lines having low pasting temperature. *Starch-Stärke*, 56(12), 563-569.
- Kim, H. R., Kim, M. R., Ryu, A. R., Bae, J. E., Choi, Y. S., Lee, G. B., . & Hong, J. S. (2023). Comparison of rheological properties between Mixolab-driven dough and bread-making dough under various salt levels. *Food Science and Biotechnology*, 32(2), 193-202.
- Martin, C. A. (2005). From high maintenance to high productivity: What managers need to know about Generation Y. *Industrial and commercial training*, 37(1), 39-44.
- McKevith, B. (2004). Nutritional aspects of cereals. *Nutrition Bulletin*, 29(2), 111-142.
- Olatunde, S. J., Ajayi, O. M., Ogunlakin, G. O., & Ajala, A. S. (2019). Nutritional and sensory properties of cake made from blends of pigeon pea, sweet potato and wheat flours. *Food Research*, 3(5), 456-462.
- Oluwalana, I. B., Malomo, S. A., & Ogbodogbo, E. O. (2012). Quality assessment of flour and bread from sweet potato wheat composite flour blends. *International Journal of Biological and Chemical Sciences*, 6(1), 65-76.
- Onabanjo, O. O., & Ighere, D. A. (2014). Nutritional, functional and sensory properties of biscuit produced from wheat-sweet potato composite. *Journal of Food Technology Research*, 1(2), 111-121.
- Peressini, D., & Sensidoni, A. (2009). Effect of soluble dietary fibre addition on rheological and breadmaking properties of wheat doughs. *Journal of cereal Science*, 49(2), 190-201.
- Schopf, M., & Scherf, K. A. (2021). Water absorption capacity determines the functionality of vital gluten related to specific bread volume. *Foods*, 10(2), 228.
- Sroan, B. S., & Kaur, A. (2004). Effect of antioxidants on farinograph and amylograph characteristics of wheat flour. *International Journal of Food Properties*, 7(3), 379-391.
- Švec, I., & Hrušková, M. (2010). Evaluation of wheat bread features. *Journal of Food Engineering*, 99(4), 505-510.
- Thiex, N. (2009). Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles. *Journal of AOAC international*, 92(1), 61-73.
- Tiimub, B. M. (2013). Proximate analyses of three brands of bread under different storage conditions available on the Ghanaian market. *Food Science and Quality Management*, 12, 23-30.
- Trejo-González, A. S., Loyo-González, A. G., & Munguía-Mazariegos, M. R. (2014). Evaluation of bread made from composite wheat-sweet potato flours. *International Food Research Journal*, 21(4), 1683.

- Van Hal, M. (2000). Quality of sweetpotato flour during processing and storage. *Food Reviews International*, 16(1), 1-37.
- Wang, S., Nie, S., & Zhu, F. (2016). Chemical constituents and health effects of sweet potato. *Food Research International*, 89, 90-116.
- Wheatley, C. C., & Bofu, S. (2000). Sweetpotato starch in China: current status and future prospects. *Cassava, Starch and Starch Derivatives*, 201-205.
- Xin, L. I., & ZHANG, A. M. (2015). Improvement on Mixograph test through water addition and parameter conversions. *Journal of Integrative Agriculture*, 14(9), 1715-1722.
- Yusupova, G. G., & Yusupov, R. K. (2020). The effect of sweet potato powder on the physical, chemical and organoleptic indicators of bread quality. In *E3S Web of Conferences* (Vol. 161, p. 01054). EDP Sciences.

Disclaimer/Publisher's Note: The views, opinions, and data presented in all publications are exclusively those of the respective author(s) and contributor(s) and do not reflect the stance of Pagepal or its editorial team. Pagepal and the editor(s) disclaim any responsibility for harm to individuals or damage to property resulting from the use of any ideas, techniques, instructions, or products mentioned in the content.