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Effect of Kohlrabi Peel Powder as a Dietary Fibre Enrichment on Technological, Nutritional, and Sensory Properties of White Bread

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The addition of dietary fibres (DF) obtained from by-products into bread is an attractive way to enhance consumers' fibre consumption while simultaneously reducing waste from by-products. This study aimed to examine the viability of replacing kohlrabi peel powder (KPP) into white bread at levels ranging from 0% to 12%. The technological and nutritional characteristics of white breads were evaluated, and sensory analysis was conducted. The specific volume values of the samples ranged from 1.486 to 1.861 mL/g. The findings showed that the specific volume of the white bread samples decreased when KPP was used at concentrations higher than 3%. The sample coded N4 (9%) exhibited higher moisture levels in both the crumb and crust, compared to the all bread samples ($p<0.05$). The nutritional features of the bread samples varied as follows: ash content ranged from 0.573% to 0.588%, protein from 6.460% to 7.998%, fat from 3.200% to 4.200%, total DF from 0.250% to 3.214%, total carbohydrate content from 51.963% to 69.272%, and energy levels from 211.7 to 324.0 kcal. The sample coded N3 (6%) was approved by the panelists, however the other samples with a greater quantity of KBB were not favored. SEM images showed the gluten structure in the enriched bread samples coded N2, N3 and N4 were constituted by fibrous components that established a more open network. The study's results indicated that elevated amounts of KPP might enhance the DF content of white bread; however, consumers do not favor higher fibre content in the bread samples. Utilization of 6% KPP could enhance the technological, nutritional, and sensory characteristics of white bread.

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Introduction

Obesity and associated disorders, including cardiovascular diseases, diabetes, and hypertension, have been increasing in recent years in both industrialized and low to middle-income countries. If this trend continues, almost 38% of the global adult population is projected to be overweight and 20% obese by 2030 (Kelly et al., 2008). Obesity is rising due to factors such as altered dietary habits and decreased physical activity resulting from globalization. Analysis of consumed products reveals a decline in the intake of fibre, whole grains, fruits, and vegetables, contrasted by an increase in the consumption of processed carbs and saturated fats (Popkin, 2006). Individuals who consume inadequate amounts of fruits and vegetables are prone to poor intake of several micronutrients, including folic acid and vitamin C, hence elevating the chances of DNA damage, such as cancer and other degenerative disorders. Moreover, deficiencies in micronutrients not predominantly sourced from fruits and vegetables, including zinc, iron, and vitamins E, niacin, B6, and B12, also elevate the risk of DNA damage (Maietti et al., 2021).

Despite the growing interest in whole grain breads for their superior fibre content, white bread remains the most prevalent variety globally. Among this popularity, fibre concentrates or high-fibre content products, such as banana flour, can be included into bread production (Agama-Acevedo et al., 2019). The primary factor is to enhance the dietary fibre content of breads by reformulating them with fibre-rich components while little altering the sensory attributes of the finished product.

Functional foods may be produced by using the by-products from fruits and vegetables as natural raw materials that are high in antioxidants and dietary fibre. A fruit or vegetable's main components include its flesh, peels, seeds, and stems, which are high in valuable chemicals, especially dietary fibres (DF), with a balanced ratio of soluble and insoluble fibre fractions as well as its nutritional profile, colour, texture, and volume characteristics (Torbica et al., 2019). The growing interest in transforming waste into value, particularly through the production of value-added products from organic waste, has led to an increase in study within this field. There have been previous studies on the use of chestnut peels for breads (Alinovi et al., 2022; Mironeasa & Mironeasa, 2019), sausages (Choi et al., 2010), and cookies (Joo & Choi, 2012) in an effort to decrease food waste and to enhance a variety of food. Also banana peel was used in the researches with same respect (Akhter et al., 2024). This study will be the first to evaluate Kohlrabi peel powder (KPP) as a bread ingredient and will serve as a good example of utilizing DF-rich food waste in food production.

Kohlrabi (*Brassica oleracea* var. gongylodes) is a bulbous, onion-like vegetable that is part of the Cruciferae (*Brassicaceae*) family. It grows in temperate nations and certain subtropical areas. Türkiye ranks as one of the significant cabbage-producing nations globally, with an output of roughly 500,000 tons. Vegetable species like cauliflower, Brussels sprouts, broccoli, green cabbage, and red cabbage, which are part of the *Brassicaceae* family, are extensively cultivated in our country. Kohlrabi, a member of the same family, is a cool-weather vegetable characterized by a fleshy, turnip-like stem that develops above the ground through nutrient storage (Yildirim et al., 2017). Kohlrabi is strongly advised for dietary inclusion due to its nutritional advantages and low caloric content (Marcinkowska et al., 2021). It is an abundant source of vitamin C, vitamin B6, fibre, and potassium (K) (Golob et al., 2020). Kohlrabi possesses anti-inflammatory, antibacterial, and antioxidant properties. Oxidative stress is diminished, cancer is inhibited, asthma, cancer, and Alzheimer's disease are prevented, Type II diabetes is managed, and cardiovascular health is enhanced (Marcinkowska et al., 2021).

Kohlrabi peel is less frequently used in research, while having equally amazing qualities as the flesh. A study that looked at kohlrabi peel found that it had higher levels of organic acid, vitamin C, minerals, essential amino acids, and total amino acids. It was also an excellent source of free sugar and unsaturated fatty acids (Seon-Suk Cha et al., 2013). The primary and secondary metabolites, comprising organic acids, amino acids, sugars, and an amine from Kohlrabi peel, were examined in a separate study (Park et al., 2017). They stated that kohlrabi peel is a valuable source of primary metabolites, which impart significant nutritional characteristics, and secondary metabolites, which are utilized as medicinal agents for human health (excluding anthocyanins).

Dietary fibre (DF) constitutes the indigestible component of fruits, vegetables, and grains. Fibre facilitates the softening of feces, hence avoiding constipation. DF is known to diminish the digestion rate of starchy foods owing to its significant water absorption capacity and enhanced food viscosity, leading to a reduced blood sugar response post-ingestion (Angioloni & Collar, 2011). Bread and bakery products are the primary sources of DF in overall food intake. High-fibre bread constitutes a cereal-based diet and is more effective than a low-carbohydrate diabetic diet in managing maturity-onset diabetes (Babiker, 2013). The incorporation of DF in bread production is attributable to their technological attributes. The water retention capacity of DFs, which inhibits bread staling and prolongs product shelf life, might be used as an example (Kurek, 2015). Furthermore, the incorporation of fibre enhances and modifies the textural and sensory attributes, as well as the shelf life of food products, owing to its gelling capabilities, fat mimicry, and texturizing and thickening effects (Sabanis et al., 2009). Numerous studies have demonstrated the possible enhancement of wheat-based cereal products through the incorporation of dietary fibre (Gómez et al., 2003; Rios et al., 2020; Rosell et al., 2006; Sabanis et al., 2009). Research on the conversion of food processing by-products into various valued goods, owing to their vital nutritional components such as fibre, vitamins, and minerals, is on the rise (Babiker, 2013). The choice of DFs in bread production is crucial. Meticulous selection of dietary fibres (DF) possessing suitable physicochemical characteristics that avert irreversible degradation of the protein matrix is essential for producing doughs with optimal workability, resulting in sensory-acceptable breads (Angioloni & Collar, 2011).

The purposes of this study were i) to develop a novel, healthy, and desirable bread recipe that is enriched with KPP in various amounts, and ii) to provide a practical example for assessing peel powder, which is a waste or by-product.

Materials and Methods

Material

The kohlrabi used in the study was purchased from a greengrocer in Sivas, Türkiye. The other ingredients of the breads given in Table 1 were obtained from local markets.

Manufacture of Kohlrabi Peel Powder

Kohlrabi was manually peeled, cleaned of any wounds and damaged regions on the skin, and dehydrated in an oven at 55°C until it had attained a moisture content of 7%. The peels were pulverized into flour by a food processor and utilized in bread manufacturing after being filtered through a 150 µm sieve.

Preparation of Bread Dough

The components and their respective ratios to be incorporated into the bread dough are presented in Table 1. The dough was produced following the method outlined by (Angioloni & Collar, 2011). All ingredients, except for oil, were added to the dough mixer (KitchenAid, USA) and mixed for 15 min. Thereafter, oil was added to the mixture and blended for an additional 5 min.

Table 1. Formulations of breads

Sample	KP (%)	Formulation (g)						
		Flour	Yeast	Sugar	Salt	Water	Sunflower oil	Total
N-1	0	120	1.25	5	1.25	86	1.25	215
N-2	3	117	1.25	5	1.25	86	1.25	215
N-3	6	114	1.25	5	1.25	86	1.25	215
N-4	9	111	1.25	5	1.25	86	1.25	215
N-5	12	108	1.25	5	1.25	86	1.25	215

The container was sealed with stretch film, and the dough underwent fermentation for 2 hours in an incubator (Membert, Germany) at 28°C. At the end of the period, the dough (500 g) was transferred to a rectangle loaf pan and permitted to ferment under the same incubation conditions for 30 min. Upon completion of the allotted time, the dough was baked at 190°C for 30 min.

Evaluation Technological Properties of Breads

The weight (g) of the breads was measured, and subsequently their volume (ml) was estimated using rapeseed displacement recommended by AACC method 10-05.01 (2000). The specific volume (ml/g) was determined by dividing the volume by the weight.

The moisture content of crumb and crust was measured by using an infrared moisture analyser (Shimadzu, MOC63U).

The crust colour of baked samples were measured using the Chroma Meter CR-400 (Konica Minolta Co., Ltd., Osaka, Japan) in the CIE $L*a*b*$ colour space. L^* indicates whiteness (value 100) or blackness (value 0), *a* indicates redness (positive value) or greenness (negative value), and b* indicates yellowness (positive value) or blueness (negative value).* Colour was assessed at five spots on the bread crust after 2 h after baking.

Evaluation of the Nutritional Composition of Breads

The procedures established by the Association Official of Analytical Chemists (AOAC, 2000) for moisture (925.09), ash content (923.03), total lipid content (922.06), and protein content (920.87) were employed to ascertain the chemical composition of breads. The total carbohydrates (TC) were determined by the difference, as per the subsequent equation:

$$TC = [100 - (moisture + ash + protein + fat)] \quad (1)$$

with data reported as g/100 g in wet weight.

The energy levels (kcal) were calculated by multiplying the amount of macronutrients by their corresponding conversion factors (4 kcal/g for protein, 9 kcal/g for fat, and 4 kcal/g for total carbohydrates) (Krupa-Kozak et al., 2021).

The total DF level of the samples was quantified using an enzymatic-gravimetric analysis with a commercial assay kit (K-TDFR-200A, Megazyme International Ireland Limited, Bray, Ireland). The procedure was executed following the AOAC (2000) Method 985.29 enzymatic-gravimetric method as outlined in the kit instructions. This method entails the hydrolysis of 1 g of dried, crushed, and sieved bread sample (0.5 mm mesh) using α-amylase, protease, and amyloglucosidase, succeeded by ethanol precipitation to get a residue for protein and ash analysis. The comprehensive DF calculations for the samples were performed with MegaCalc™ Excel®, which can be downloaded from the Megazyme website (www.megazyme.com) where the product is featured.

All nutritional analysis were conducted in duplicate.

Sensory Analysis

A total of forty panellists, consisting of both males and females aged between 25 and 55, were selected to evaluate the sensory characteristics of the bread samples. Following a concise briefing, participants became knowledgeable about the breads they had evaluated. The participants were instructed to assess each bread based on its colour, apperance, flavor, aroma, taste, and overall acceptability using a five-point hedonic scale. This scale, ranges from 1 (indicating extreme dislike) to 5 (indicating extreme liking) for each sensory characteristic. Breads were deemed satisfactory if their average ratings for general acceptance exceeded 3 (indicating a neutral opinion).

SEM Analysis

The pore structure of the bread samples was assessed using scanning electron microscopy (SEM) (TESCAN MIRA3 XMU, Brno – Czech Republic). The samples were attached to circular aluminum studs using double-sided sticky carbon tape and subsequently gold-plated for 100 seconds. The examination was conducted at room temperature using SEM mode at 10 kV voltage. The magnification ratio for the bread samples was set at x1000. These specific micrographs were selected because to their superior clarity and sharpness.

Statistical Analysis

The research investigated the impact of different levels of KPP as a fibre addition on the technological and nutritional properties of bread. The reported results are the mean of two replicates. The data were analysed using the analysis of variance technique (ANOVA), and the difference between the samples was assessed by the Fisher LSD method. Statistical significance was assessed at a *p*-value of less than 0.05. The statistical analyses were conducted using the MiniTab (20th Edition) software (MiniTab, State College, Pennsylvania, USA).

Results and Discussions

Technological Properties of Breads

Specific volume is a critical technological attribute since it affects both the appearance and sensory acceptance of bread. Table 2 indicates that the specific volume values of the white bread samples varied from 1.2488 to 1.861 mL/g. ANOVA test findings showed that the sample coded N1 (control) exhibited the maximum specific volume, also no statistically significant difference observed with the sample coded N2 (p <0.05). The results indicated that the usage of KPP at concentrations over 3% resulted in a decrease in the quality of the white bread samples. Including fibre and fibre-rich sources into gluten-free dough and bread enhances the fluidity of liquid batter. Consequently, it enhances the gas retention ability during proofing and baking, thereby increasing the specific volume of the bread. Nonetheless, enhancing the consistency of a more rigid dough inhibits its rise and diminishes loaf volume (Begum et al., 2020). It has been established that the incorporation of higher level of fibre decreases the volume of bread due to the dilution of gluten in the flour mixtures (Koletta et al., 2014).

Moisture levels quantifies the freshness of bread. The enriched bread samples' crumb moisture level varied from 33.61% to 41.50%, and the control sample was 37.06%. The crust moisture level of the enhanced bread varied from 19.83% to 26.58%, whereas the control samples measured 23.40%. The highest crumb and crust moisture levels detected in the sample coded N4 among the bread samples

(p <0.05). Eshak (2016) obtained identical results in enriched wheat bread utilizing banana powder, and they reported that the incorporation of banana fibre into bread enhances its water absorption, as it is recognized as effective water binders, resulting in elevated moisture content in the bread. Nonetheless, the KPP levels both below and above 9% resulted in a reduction of moisture levels in the crumb and crust. A similar trend was noted by Begum et al. (2020), indicating that the incorporation of a DF source leads to an increase in moisture content up to a certain percentage of DF consumption; beyond this point, moisture content begins to decline. This attribute arises from gluten production and may lead to a fragile protein network in the dough. As indicated in a study, the incorporation of 4 g per 100 g of DF influences gluten production and may lead to a compromised protein network in the dough (Rosell et al., 2001).

Colour is an essential characteristic of bakery products, as it, together with texture and flavor, influences consumer acceptance. The colour is dependent on the properties of the dough and the baking conditions. The findings from the investigation of crust colour are displayed in Table 2. The L*, a*, and b* values of white breads samples, the values ranged from 46.700 to 68.160, 10.00 to 17.117, and 28.373 to 35.400, respectively. For the L*, the sample coded N1 (control) had the lowest value, in contrast N5 (12%) had the highest value (p <0.05). The L* values, which denote lightness, rise with increased KPP concentration, leading to lighter crumbs. On the other hand, a* and b* values of bread crumbs were changed depend on the concentration of KPP used in the breads. The a* values of the samples increased until a concentration of 6%, after which they declined with increasing concentrations. On the other hand, the greatest b* value was recorded in the sample designated N2 (3% KPP). Same trend was observed by Sławińska et al. (2022) in the wheat bread samples supplemented with freeze-dried white and brown button mushrooms (2.5% and 5%). Djordjević et al. (2019) reported that the crust colouration is primarily due to Maillard and caramelization reactions occurring at elevated temperatures, likely caused by an increased concentration of soluble sugars and free amino acids in the enriched breads, which influences the L* and a* values of the breads.

Nutritional Properties of Breads

The ash levels in the white bread samples ranged from 0.573% to 0.588% (Table 3). The incorporation of KPP into the white bread dough led to an important increase in ash content, seen in samples N2 and N3 (p<0.05). The same results was observed in the study (Akhter et al., 2024) who searched enrichment of wheat bread with banana peel powder. The increase in ash level indicates the presence of minerals supplied by KPP in the enriched breads.

The protein levels ranged from 6.460% to 7.998%, whereas the fat content varied from 3.20% to 4.2% in the bread samples. No statistically significant difference was seen between the control and enriched bread samples for both contents (p>0.05). TC content of the samples varied from 51.963% to 69.272%. The addition of KPP to the samples resulted in significantly higher total carbohydrate levels, with the highest total carbohydrate value recorded in sample N3 (6% KPP) (p<0.05). The energy level of the samples was detected between 211.7 kcal and 324.0 kcal. The sample coded N5 has the lowest energy value between the samples (p<0.05), there was no significantly importance difference between control and enriched breads (p>0.05). This was due to the sample coded N5 has the lowest flour content. The elevated carbohydrate content enhances the baked qualities, including texture and structure, which are desirable in bakery products (Ezeocha et al., 2022).

The level of DF in enriched bread samples were measured between 0.347% and 3.214% (Table 3), whereas the control sample had only 0.25% DF content. Also it was detected that the DF content of enriched bread samples exhibited a statistically significant increase with greater KPP addition. The coded sample N5 had the highest KPP at 12%, resulting in an almost 12-fold increase in the DF of the white bread sample. Numerous studies on bread enrichment yielded findings consistent with our research. Gadallah (2017) manufactured wheat flour with pomegranate peel powder at varying ratios of 5%, 10%, 15%, and 20%, and detected a maximum increase of 6.2-fold in the samples. Omran et al. (2020) manufactured wheat flour with yellow onion peel powder (OPP) at concentrations of 1, 2, 3, 4, and 5%, and observed a maximum 3.2-fold increase, García et al. (2023) used 10% pomegranate peel powder, resulting in an approximate 3.9-fold increase, Akhter et al. (2024) incorporated 10% banana peel powder into wheat bread, resulting in an approximate 11.28-fold increase, in total DF levels. A product may be included as a “source of fibre” if it contains at least 3 g of fibre per 100 g or at least 1.5 g of fibre per 100 kcal, according to the declaration of Reg. (EC) No. 1924 (2006), which allows us to declare enriched breads coded N4 and N5 as sources of fibre.

Sensory analysis is an important criterion for assessing quality in the development of new products and for meeting consumer requirements (Chisa & Jonah, 2023). The sensory properties of the bread samples are shown in Figure 1.

Table 2 Technological properties of bread samples

Sample code	Spesific Volume (mL/g)	Crumb moisture (%)	Crust Moisture (%)	L*	a*	b*
N1	1.8610±0.06 a	37.060±0.71 b	23.400±0.71 b	46.700±0,678 d	11.577±0,499 c	28.373±0.755 c
N2	1.7318±0.04 ab	36.162±0.00 b	22.230±0.71 bc	57,697±1,057 c	16,533±0,127 a	35.40±2.19 a
N3	1.6738±0.04 b	33.610±0.71 c	19.830±0.71 c	64.990±01.356b	17,117±0,842 a	31.613±0.402 b
N4	1.4863±0.01 c	41.510±0.71 a	26.575±0.73 a	65.793±1.542 b	12,970±0,576 b	30.897±0.440 b
N5	1.2488±0.04 d	37.920±0.71 b	24.370±0.71 ab	68,160±1.163 a	10,00±0,530 d	30.393±1.442 bc

Values are expressed as mean ± standard deviation from five replicates for L*, a*, b* measurements, and from two replicates for specific volume and moisture analysis. N1: Control, white bread with no addition; N2: White bread with 3% Kohlrabi peel powder addition, N3: White bread with 6% Kohlrabi peel powder addition, N4: White bread with 9% Kohlrabi peel powder addition, N5: White bread with 12% Kohlrabi peel powder addition

Table 3 Nutritional properties of bread samples

Sample code	Ash (%)	Protein (%)	Lipid (%)	Dietary Fibre (%)	Carbonhydrate (%)	Energy (kcal)
N1	0.585±0.01 b	7.998±1.25 a	3.800±0.85 a	0.250±0.006 c	51.963±0.80 c	274.04±9.41 ab
N2	0.647±0.02 a	7.337±0.08 a	3.400±0.57 a	0.347±0.074 c	52.455±0.66 c	248.8±32.5 ab
N3	0.643±0.01 a	6.555±0.25 a	4.200±0.28 a	1.395±0.020 b	69.272±0.52 a	324.0±25.6 a
N4	0.573±0.01 b	6.946±0.17 a	3.700±0.42 a	2.509±0.618 a	61.690±0.60 b	292.5±23.7 ab
N5	0.588±0.01 b	6.460±0.02 a	3.200±0.28 a	3.214±0.152 a	42.641±0.30 d	211.7±20.5 b

All values are mean ± standard deviation of two replicates. a-d Means within a column with different letters are significantly different ($p<0.05$). N1: Control, white bread with no addition; N2: White bread with 3% Kohlrabi peel powder addition, N3: White bread with 6% Kohlrabi peel powder addition, N4: White bread with 9% Kohlrabi peel powder addition, N5: White bread with 12% Kohlrabi peel powder addition.

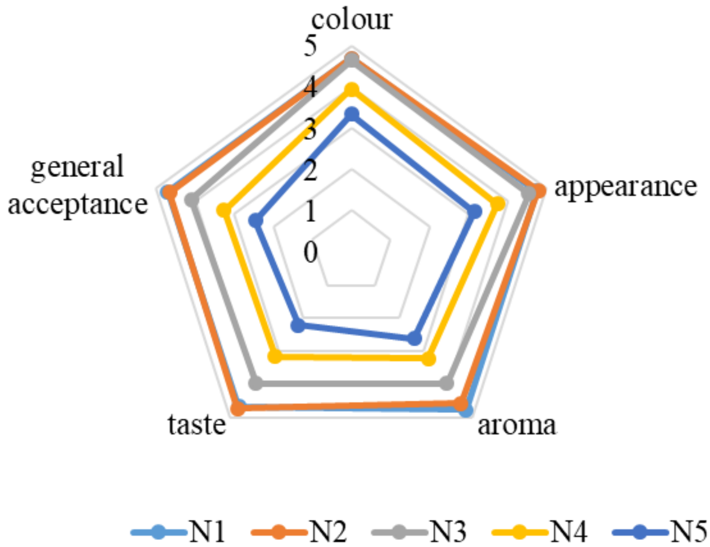

Figure 1 Sensory analysis results of bread samples

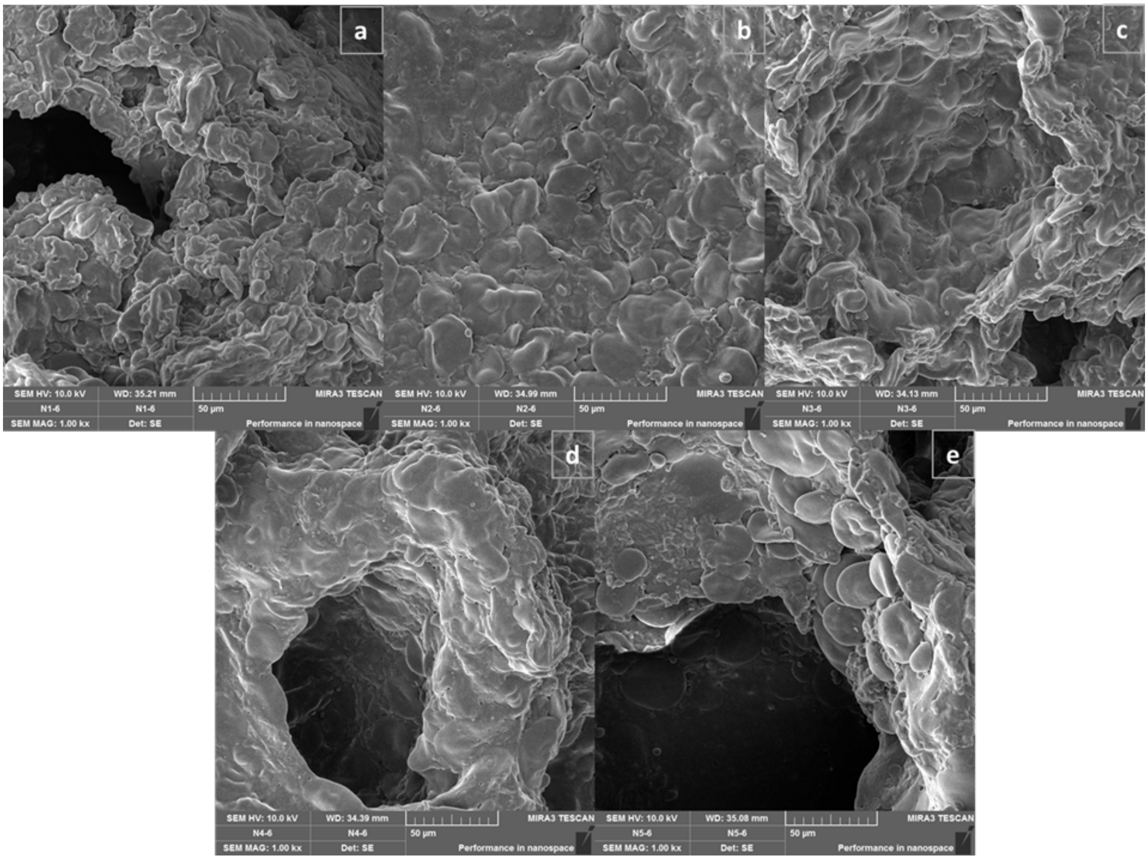

Figure 2. Scanning electron microscope images of bread samples. (a) control sample (b) sample coded N2 (c) sample coded N3 (d) sample coded N4 (e) sample coded N5

A radar map was created to visually represent the sensory profiles and variations among the samples for simple identification based on the results. Crust colour of the samples ranged from 3.35-4.7, aroma score of the samples ranged from 2.6-4.75, taste score of the samples ranged from 2.2-4.7, apperance score of the samples ranged fro 3.15-4.8, while the overall acceptability score of the samples ranged from 2.45-4.7. N1 (control) and N2 (3%) were the most favored bread samples. N3 (6%) was approved by the panelist, however the other samples with a greater quantity of KBB were not favored. The elevated fibre content in these samples disturbed the panelists.

The structure of the bread coded N1 (control) consisted of flattened and folded starch granules densely integrated inside a gluten matrix (Fig. 2a). The gluten structure in the enriched bread samples coded N2, N3 and N4 were constituted by fibrous components that established a more open network (Fig 2b,c,d). It was clearly seen that starch granules partially gelatinized in the enriched bread samples coded N2, N3, and N4. The microstructure of enrichment bread coded N5 exhibited a uniform distribution of big granules inside the gluten matrix. Significant structural alterations, manifested as voids, fissures, and fragmentation of starch granules, are evident in the microstructure of bread supplemented with KPP (Fig. 2e).

Conclusion

The application of 6% KPP may improve the technological, nutritional, and sensory attributes of white bread. Based on these results, it can be inferred that the application of KPP may be viable for producing a fibre-enriched product that contributes to the advancement of more sustainable and efficient plant-based consumption. To conclude the assessment of this ingredient, additional research must be conducted to evaluate its impact on doughs with various dietary fibre sources, sensory acceptance, and potential variations in shelf life compared to standard and enriched breads.

Declarations

Ethical Approval Certificate

Before conducting sensory analysis, a decision was made by the ethics committee of the Sivas Cumhuriyet University Social Sciences Institute Scientific Research Proposal Ethics Evaluation Board (decision No. 2023/15 dated 25.12.2023).

Author Contribution Statement

Please indicate how each author contributed to this work and at what stage. For example:

İrem Bilge TEK, and Suna Dilara AKTAS: Project administration, data collection, investigation, and formal analysis.

Hatice Aybuke KARAOGLAN: Supervision, conceptualization, methodology, writing, review and editing.

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Conflict of Interest

The authors declare no conflict of interest.

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