Egypt. J. Chem. **Vol. 68**, No. 4, pp. 257 - 269 (2025)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

The Impact of Eggplant Peel Fortification as a Potential Source of Dietary Fibers and Phytochemicals on the Rheological Properties and Quality of Pan Bread

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Abstract

Eggplant peels (EPP) are the primary byproduct of eggplant, which is mainly produced by food manufacturers and restaurants and contains substantial quantities of bioactive compounds. This study aimed to assess the impact of using EPP as a dietary supplement for wheat flour to enhance its phytochemical and dietary fiber content. The study examined the effects of fortifying EPP at four different levels (2.5%, 5%, 7.5%, and 10%) on the phenolic content, antioxidant activity, and rheological characteristics, baking quality, staling rate, texture, microstructure, and sensory qualities of the pan bread. According to the chemical profile analysis, EPP is a special source of phenolic compounds and dietary fiber. The peel of eggplant contained 48.76% total dietary fiber (11.04% soluble and 37.72% insoluble dietary fiber) compared to 2.89% total dietary fiber for wheat flour. Eleven phenolic compounds were identified in EPP. Chlorogenic acid was the abundant compound (311.77 µg/g), followed by chrysin (75.08 µg/g) and ferulic acid (29.95 µg/g). Water absorption of wheat flour (57.6%) increased gradually with increasing the EPP level to reach 64.2% for wheat flour containing 10% EPP. Specific volume of pan bread samples reduced as the concentration of EPP increased. The total color difference (ΔE) exhibited a significant increase as the level of replacement increased. The hardness of fortified bread samples increased gradually with increasing addition levels of EPP. Cohesiveness recorded the highest value in EPP 10%, whereas EPP 2.5 and 5% bread samples recorded the lowest value. In general, the addition of EPP in pan bread affected how consumers evaluated the product. However, consumers still showed acceptance towards all processed products. Microstructure results reveal that the cell structure of bread containing 2.5 and 5% EPP was similar to the control sample. During a 72-hour of room temperature storage, eggplant peels showed significant effects in delaying the staling of baked pan bread. It can be concluded that EPP could be considered a functional ingredient in the food sector and added to either functional or enriched fiber foods.

Keywords: Eggplant peel, bread, dietary fiber, phenolic compounds, rheology, microstructure, staling

1-Introduction

Nowadays, food manufacturers produce a considerable amount of by-products, which are not suitable for direct consumption. The by-products mentioned are derived from a range of sources and consist of different plant components, including stem, leaf, peel, kernel, seed, and more [1]. Production of these by-products is increasing every day and represents a growing problem. They are mostly susceptible to microbial spoilage, which limits their utilization [2]. Therefore, they are mainly removed as waste in landfill sites, leading to significant economic costs and ecological problems [3].

Eggplant (*Solanum melongena L.*) is a vegetable that is widely cultivated and known for its distinct texture, flavor, and nutritional benefits. Approximately 50 million metric tons of eggplants are cultivated on over 1,800,000 hectares of land globally, as stated by Gürbüz *et al*. [4]. Nevertheless, eggplant processing results in a significant quantity of waste, specifically the peel, which is commonly disposed of as a byproduct. Eggplant peels (EPP) and calyx, which are the major waste products of eggplant, are mostly produced by food manufacturers, restaurants, and other food processing establishments. These by-products are affordable, easily accessible, and contain significant quantities of bioactive compounds.

Eggplant peels are an excellent source of many bioactive components including dietary fibers, polyphenols, flavonoids, anthocyanins, minerals, and polysaccharides such as pectin and cellulose [5, 6]. Eggplant peels contain a high concentration of

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Receive Date: 12 July 2024, Revise Date: 16 August 2024, Accept Date: 18 August 2024
DOI: 10.21608/EJCHEM.2024.303659.9996

polyphenols, including anthocyanins and phenolic acids. These two compound families are highly prevalent in eggplant and possess remarkable antioxidant, antimicrobial, and anticancer properties [7, 8]. Therefore, many studies have reported the possibilities of utilizing extracts or powders from EPP in various industries such as food, pharmaceuticals, and cosmetics [8]

From the nutrition view, it is well stated that dietary fibers have the impact of lowering the risk of many types of diseases, such as gallstones, diabetes, obesity, hiatus hernia, appendicitis, constipation, and blood pressure [9, 10]. In addition, dietary fiber consumption is associated with weight loss and potentially enhancing immune function [11]. Furthermore, several studies have demonstrated that consuming sufficient amounts of dietary fiber is linked to a reduced likelihood of acquiring colorectal cancer, stroke, and cardiovascular disorders [12, 13]. Dietary Guidelines for Americans recommended 30.8-33.6 g and 25.2-28 g of total fiber as a daily intake for men and women, respectively based on age [14].

Unfortunately, modern lifestyles and eating habits have contributed to the spread of obesity and chronic diseases [15]. In addition, the rapid development in cereal processing, especially wheat grains, has led to highly refined flour which satisfies the consumer demands for better sensory quality. However, these refined flours are lack several essential nutrients such as vitamins, minerals, bioactive compounds, and dietary fibers which discarded with the bran fractions as by-products [16]. Fortifying meals with fiber sources, rich in bioactive compounds, provides consumers with additional dietary options such as functional bread, cereals, cookies, and pasta [17]. Despite these nutritional benefits, incorporation of non-wheat flour into wheat flour dough system disrupts gluten network, starch-gluten matrix and alters the rheological properties of dough and, subsequently, declines bread quality [18] and tenacity, and smaller extensibility. Regarding the effect on bread properties, the fibre always decreased loaf volume from lowered gas retention, increase in crumb firmness value and gritty texture, darkening of crumb and unsuitable mouthfeel and taste [19]. The process of replacing wheat flour can be difficult and necessitates a thorough comprehension of how non-wheat flour affects the rheological qualities of dough, as well as the internal structure and staling process of bread [20].In this concern, the current study was done to assess the impact use of EPP as a dietary supplement for wheat flour to improve its phytochemical and dietary fiber content. The impact of EPP fortification at 4 levels (2.5 % 5 %, 7.5 and 10%) on the phenolic content and antioxidant activity as well as the rheological properties were investigated. Also, baking quality, staling rate, texture, microstructure, and sensory properties of the produced pan bread were evaluated.

2-MATERIAL AND METHODS

2.1. Preparation of eggplant peel flour

Eggplant peels dried at 45°C for 48 hours in an oven. The dried EPP was ground using a kitchen blender (TORNADO MX-5200) and screened through a 60-mesh sieve, then packed and stored at 4°C.

2.2. Chemical composition

The moisture, ash, crude protein, fat, crude fiber, and dietary fiber contents of EPP were determined according to AOAC [21]

2.3. Phytochemical and antioxidant activity estimation

The Folin-Ciocalteu method was used to assess the total phenolic content, and the aluminum chloride method determined the total flavonoid content as described by Yousif *et al*. [22]. Free radicals scavenging activity was measured using a stable DPPH approach [23].

2.4. Determination of phenolic profile

Samples were hydrolyzed and the phenolic compounds were extracted and determined using an Agilent Technologies 1100 series high-performance liquid chromatography according to Yaseen *et al.* [24].

2.5.Rheological properties of wheat flour and eggplant peel blends

Mixing and pasting properties of wheat flour and wheat flour fortified with EPP at the levels of 2.5, 5, 7.5 and 10% were evaluated using the Mixolab (Chopin Technologies, France) according to using the ICC method No. 173 [25]. Chopin+ protocol running parameters were as follow: mixing rate (80 rpm), dough weight (75 g), water (as required to reach a torque of 1.11 Nm) and the initial temperature (30°C). Temperature was programmed to kept at 30 °C for 8 min, increased at the rate of 4 °C/min to reach 90 °C in 15 min, held at 90 °C for 7 min, cooled at the rate of 4 °C/min to 50 °C in 10 min, and then kept at 50 °C for 5 min. Various mixing and pasting parameters like water absorption (WA), dough development time (DDT), stability, minimum consistency (C2), protein weakening (C1-C2), peak viscosity (C3), breakdown (C3-C4) and retrogradation (C5-C4) were recorded. Also, the angles of ascending and descending curves α, β and γ (Nm/min) were recorded as protein weakening rate, gelatinization rate, and cooking rate, respectively.

2.6. Manufacturing of eggplant peels fortified pan bread samples

The straight dough method for producing pan bread was conducted according to AACC [26]. Wheat flour and wheat flour fortified with EPP at the levels of 2.5, 5, 7.5 and 10% were used for pan bread production. The components included wheat flour or wheat flour-eggplant formula (100 g), water (as reported in the Mixolab test), dry yeast (2 g), corn oil (2 g), and salt (0.5 g). The ingredients (except oil) were mixed for 4 minutes at a slow speed (30 rpm), followed by the addition of oil, and the dough was further mixed for 6 minutes at a rapid speed (60 rpm). The dough was proofed for 20 minutes at 28°C then formed and left to ferment for 60 minutes at 36°C in aluminum pans. Then pan bread samples were baked at 240°C for 20 minutes in an electric oven. The bread loaves were let to cool at room temperature**.**

2.7. Determination of baking quality of bread samples

Weight, volume, and specific volume of pan bread were measured using the rapeseed displacement method as described in the AACC [26].

2.8. Determination of color attributes of bread samples

Color parameters of bread samples [lightness (L*), redness (a*), and yellowness (b*)] were measured using the Hunter Lab method according to the CIELAB system. Each sample was measured multiple times and the average value was recorded for each color parameter. Total color difference (ΔE) was calculated for each sample using the following equation: ΔE = [(ΔL*)2 + (Δa*)2 + (Δb*)2]0.5[27].

2.9. Sensory evaluation of bread samples

Sensory evaluation of pan bread samples was done as described in Yosif *et al*. [28] using twenty panelists of the members of Food Technology Department, National Research Center. Prior to the evaluation, the bread samples were sliced into 1 cm pieces, coded with random three-digit codes, and randomly presented at the same time to the panelists, along with water to cleanse the palate between samples. The panelists were asked to evaluate the symmetry of shape (5), break & shred (10), mouth feel (10), crust color (10), crumb color (10), crumb texture (15), aroma (20), and taste (20). Overall acceptability (100) was calculated as the sum of the previous parameters for each sample.

2.10. Texture profile analysis of bread samples

Texture parameters of fresh bread samples (hardness, adhesiveness, cohesiveness, gumminess, springiness, and chewiness) were measured using a Brookfield texture analyzer (Model TA-CT3, USA). A piece of the center of each bread sample (2×2×2 cm) was double compressed using the apparatus equipped with a cylindrical probe TA-AACC36 (36 mm diameter) and a 10000 g load cell according to the standard method 74-09 AACC [26].

2.11. Staling properties of pan bread samples

The freshness of pan bread samples was tested at room temperature during the storage period (0, 24, and 72 days) using the alkaline water retention capacity (AWRC) method according to Yamazaki [29], as modified and described by Licciardello *et al.* [30]. Staling of bread samples was calculated according to the following equation:

$$\textbf{Staling rate (\%)} = [(AWRCot-AWRCnt)/ AWRCot] \times 100.$$

Where: AWRCot = AWRC at zero time, and AWRCnt = AWRC at a specific period.

2.12. Microstructure

Pan bread samples were cut into cubes (0.5×0.5 cm), and the microstructure of low-moisture bread samples was examined by sputtering them with a thin layer of gold. The microstructure of the sample was scanned with a Scanning Electron Microscopy (SEM) (QUANTA FEG250).

2.13. Statistical analysis

The experiment was done using a completely randomized design (CRD) with three replications. The experimental data were analyzed using one-way ANOVA and Duncan multiple comparisons at $P \leq 0.05$. The analysis was performed using SPSS 15.0 for the Windows Software Package [31].

3. Results and discussion

3.1. Chemical profiles and antioxidant activity of wheat flour and eggplant peels

The results of the proximate analysis of wheat flour and EPP are shown in Table (1). The obtained data showed that EPP is composed of 11.73% moisture, 11.54% protein, 1.05% fat, 8.07% ash, and 12.00% crude fiber. These results are consistent with the findings of the earlier study performed [32, 33, 34]. Compared to wheat flour, EPP showed comparable protein and fat content, while it had very high ash and crude fiber contents. The peel of eggplant contained 48.76% total dietary fiber (11.04% soluble and 37.72% insoluble dietary fiber) compared to 2.89% total dietary fiber for wheat flour. Our finding was higher than those reported [34, 35] which recorded 43.31 and 39.19% total dietary fibers, respectively. Also, data in Table (1) show that the phenolic content of EPP was 307.14 mg GAE/100g, the flavonoid content was 69.84 mg CE/100g and the antioxidant activity was 253.73 mg TE/100g. Our findings agree with those demonstrated by Kadivec et al. [36]; however, higher total phenolic (900 mg/100g) and flavonoid (660 mg/100g) values were reported by Helmja *et al.* [37]

Table (1): Chemical composition and antioxidant activity of wheat flour and eggplant peel flour

Parameter	Wheat flour	Eggplant peel flour
Moisture (%)	13.56±0.21	11.73±0.06
Protein (%)	12.35±0.53	11.54±0.62
Fat (%)	1.92±0.17	1.05 ±0.05
Ash (%)	0.93±0.09	8.07 ±0.30
Crude fiber (%)	1.06±0.12	12.00±0.99
Soluble dietary fiber (%)	1.16±0.26	11.04±1.06
Insoluble dietary fiber (%)	1.73±0.31	37.7±1.56
Total dietary fiber (%)	2.89±0.24	48.76±2.15
Total phenolic (mg GAE/100g)	4.04±0.12	307.14 ± 1.33
Total flavonoids (mg CE/100g)	ND	69.84 ± 0.48
DPPH (mg TE/100g)	18.06±0.28	253.73 ± 0.85

ND = not detected

The phenolic profile of wheat flour and EPP are presented in Table (2). Ferulic and sinapic acids dominated the phenolic profile of wheat flour. P-hydroxybenzoic and syringic acids recorded lower concentrations (4.11 and 1.55 µg/g, respectively). While trace amounts of protocatechuic and cinnamic acids were detected. On the other hand, eleven phenolic compounds were identified in EPP. Chlorogenic acid was the abundant compound (311.77 µg/g), followed by chrysin (75.08 µg/g) and ferulic acid (29.95 µg/g). Among the identified compounds, p-hydroxybenzoic and protocatechuic, gallic acids, and rutin represented 9.61, 8.90, 5.13, and 5.16µg/g, respectively. Syringic, vanillic p-coumaric, and sinapic acids represented lower concentrations (1.13-3.46 µg/g).

Several studies investigated the phenolic compounds of eggplant cultivars in different locations all over the world. Up today, these reports demonstrated that chlorogenic and delphinidin are abundant phenolics in eggplant and a significant portion of these compounds are concentrated in the peels [3,6,8]. Furthermore, the therapeutic potential of eggplant phenolic compounds, especially those linked to the peels, against diabetes complications, dyslipidemia, and atherogenic cardiovascular diseases has been verified [35, 38].

Table (2): Phenolic compounds of wheat flour and eggplant peels flour

Compound	Wheat flour	Eggplant peels flour
Gallic acid	0.47	5.13
Protocatechuic acid	1.55	8.90
p-hydroxybenzoic acid	4.11	9.61
Chlorogenic acid	ND	311.77
Syringic acid	2.47	3.46
Vanillic acid	ND	3.29
Ferulic acid	65.81	29.95
Sinapic acid	20.02	1.13
Rutin	ND	5.16
p-coumaric acid	ND	2.76
Cinnamic acid	0.21	ND
Chrysin	ND	75.08

ND = not detected

Although dietary fibers and antioxidants are separately discussed as different groups in the nutritional studies, however significant proportions of these antioxidants are linked to dietary fibers. Moreover, some of the stated advantages of consuming fiber could be related to these associated compounds [39]. Thus, it could be concluded that EPP may be utilized as a functional component in the food industry and incorporated into either functional or enriched fiber foods.

3.2. Rheological properties of wheat flour as affected by eggplant peel flour addition

Mixing parameters (WA, stability, DDT, C2, protein weakening, and α), which describe protein behavior is shown in Table (3). When the amount of EPP increased, wheat flour's water absorption (57.6%) progressively increased to reach 64.2% for wheat flour containing 10% EPP. This result could be due to the high water-holding capacity of pectin substances in EPP [40]. The presence of hydroxyl groups in fibers makes them polar and liable for water binding [41]

The value of DDT represents the time required to reach a consistency of 1.1 Nm, after the hydration of flour ingredients. The incorporation of EPP increased DDT up to 1.68 min, compared to wheat flour (1.28 min). During the mixing process (repeated extension and compression of dough), covalent and non-covalent bonds occur between the protein chains resulting in the formation of a gluten network [42]. The presence of fibers and phenolic compounds may disturb the formation of gluten via several complexations with wheat proteins [43]. The stability values of wheat flour dough incorporated with EPP decreased as the addition level increased. The stability of the control dough (9.60 min) decreased to 5.21 min for wheat flour incorporated with 10% EPP.

Similar results were reported by Zhang and Moore [44] for bread dough systems incorporated with wheat bran fibers. They attributed this decrement to the disruption of gluten networks.

During the over-mixing stage, dough systems incorporated with EPP at 7.5 and 10% showed lower minimum consistency (C2) values (0.45 and 0.38 Nm, respectively) compared to 0.49 Nm for the control sample. Consequently, the protein weakening values (C1-C2) of these samples were higher than the control. Also, these samples showed a faster protein breakdown rate (α) compared to wheat flour dough because of exposure to the dual mechanical shear and temperature constraint. While addition of EPP at 2.5 and 5% increased C2 values to 53 Nm, indicating that these dough systems were more tolerant to mixing process. The negative effects of EPP could be due to the higher phenolic content which complicates with protein network and eliminates formation of disulphide bonds.

Also, data in Table (3) show the pasting behavior parameters of the tested samples including peak viscosity (C3), gelatinization rate (β), breakdown torque (C3-C4), cooking rate (γ), and retrogradation (C5-C4). As heating proceeded, starch granules played the predominant role in dough systems rather than protein changes. The increase in viscosity is the result of the swelling of starch granules that occurs due to the uptake of water and the leaching of amylose chains into the aqueous intergranular phase [45].

The addition of EPP at all levels to wheat flour increased C3 values. The maximum increase was recorded to EPP at the level of 7.5% (2.25 Nm) compared to 1.67 Nm for the control sample. However, wheat flour samples incorporated with EPP at 2.5 and 5% showed a lower gelatinization rate compared to the control sample. Samples incorporated with EPP at 7.5 and 10% showed higher β values. Concerning the stability of hot gel (breakdown torque and γ values), both values increased as the addition level of EPP increased up to 7.5%, then decreased for the sample containing 10% EPP. The consistency of starch increases (C5 value) as it retrogrades during cooling (C5 value). Based on the obtained results, EPP addition increased the retrogradation value up to 7.5% and then decreased again.

Table (3): Rheological properties of wheat flour dough as affected by eggplant peels addition

Parameter	Control	Eggplant fortified dough			
		EPP 2.5%	**EPP 5%**	**EPP 7.5%**	**EPP 10%**
Mixing properties					
Water absorption (%)	57.6	59.8	61.12	62.8	64.2
DDT (min)	1.28	1.53	1.53	1.63	1.68
Stability (min)	9.60	8.88	7.11	5.67	5.21
Minimum consistency (Nm)	0.49	0.53	0.53	0.45	0.38
Protein weakening (Nm)	0.57	0.57	0.57	0.65	0.74
α (Nm/min)	-0.062	-0.060	-0.060	-0.065	-0.078
Pasting behaviour					
Peak viscosity (Nm)	1.67	1.86	1.86	2.25	2.12
Gelatinization rate (β) (Nm/min)	0.406	0.364	0.364	0.588	0.423
Breakdown torque (Nm)	0.07	0.08	0.08	0.08	0.01
Cooking rate (γ) (Nm/min)	-0.026	-0.042	-0.042	-0.078	-0.017
Retrogradation (Nm)	1.01	1.34	1.34	1.48	1.04

Similar results were reported by Wang et al. [46] for wheat starch mixed with insoluble dietary fiber of Kiwifruit. Also, Zhu et al. [45] studied the effect of 25 phenolic compounds on the pasting properties of wheat starch. They found that most of the tested phenolic compounds significantly affected the functional properties of wheat starch. Regarding the identified phenolic compounds in EPP (Table 2), except coumarin, all phenolic compounds increased the peak viscosity and breakdown viscosity. Chlorogenic acid, which represents about 68.3% of phenolic compounds in EPP, recorded the greatest effect. In general, they attributed these effects to pH differences and the functional groups that could interact with amylose and amylopectin through hydrogen bonding and van de Waals forces. Additionally, the competition of dietary fiber and phenolic compounds with starch in binding water molecules could be another worthwhile factor [48].

3.3. Physical properties of pan bread samples fortified with eggplant peels

Baking quality and color attributes of the crust and crumb of the pan bread sample fortified with EPP are presented in Table (4). Addition of EPP slightly increased loaves weight, but overall, there were no significant differences ($p > 0.05$) among all samples. Control pan bread had the highest volume, and the volume reduction increased as the level of EGP increased. Consequently, the specific volume of pan bread decreased as the addition level of EPP increased. This could be attributed to the replacement of wheat proteins with EPP, which weakens the gluten network. As a result, the diluted gluten structure has a reduced ability to trap fermentation gases. In practice, the standard leavening time for the dough should be shortened, and the dough pieces should be placed in a preheated oven at the point of maximum volume [49].

Color parameters of pan bread crust are presented in Table 4. It is observed that the replacement of wheat flour with EPP flour resulted in a lightness decrease with increasing the level of replacement with a significant difference ($p<0.05$). The color of the crust turned to a lighter brown in EGP samples. Additionally, the replacement led to an increase in the yellowness of the crust and a decrease in its redness. That may be due to the natural pigmentation of EPP flour or may be due to increasing the amount of protein can enhance the Maillard reaction which could make the crust browner [50, 51]. The crumb of pan bread samples fortified with EPP at 2.5, 5, 7.5, and 10% exhibited significantly ($p < 0.05$) decreased L* values compared to the control. The dark shade of the crumb exhibited a significant rise throughout all treatments as the content of EPP increased. The yellowness (b* value) of the crumb of bread samples also exhibited a significant increase as the level of EPP flour increased. This could be attributed to the natural pigmentation of EPP [51]. The darkness or brown color of EPP containing samples can be noticed in their crumb that appear more brownish compared to the control. Also, the total color difference (ΔE) was significantly increased with increasing the level of replacement. Bread incorporated with 10% EPP showed the highest dissimilar in color (29.20).

Table (4): Physical properties of pan bread as affected by eggplant peels flour addition

Parameter	Control	Eggplant fortified bread			
		EPP 2.5%	EPP 5%	EPP 7.5%	EPP 10%
Baking quality of pan bread samples					
Weight (g)	$89.4^a\pm0.30$	$89.9^a\pm0.42$	$90.1^a\pm0.50$	$91.0^a\pm0.46$	$91.7^a\pm0.25$
Volume (cm^3)	$420^a\pm3.61$	$405^b\pm2.08$	$345^c\pm2.52$	$325^d\pm1.73$	$240^e\pm2.65$
Specific volume (cm^3/g)	$4.70^a\pm0.02$	$4.50^b\pm0.01$	$3.83^c\pm0.03$	$3.55^d\pm0.02$	$2.62^e\pm0.01$
Crust color of pan bread samples					
Lightness (L*)	$39.2^a \pm0.01$	$37.2^b\pm0.01$	$34.0^d \pm 0.01$	$32.5^e \pm 0.02$	$36.2^c \pm 0.11$
Redness (a*)	$14.2^a \pm0.02$	$12.9^b\pm0.01$	$12.4^c\pm0.12$	$11.3^e \pm 0.03$	$12.1^d \pm 0.05$
Yellowness (b*)	$12.9^a\pm0.1$	$18.0^c\pm0.01$	$18.2^b\pm0.03$	$17.9^d\pm 0.03$	$17.1^e \pm 0.03$
Color differences (Δ E)	0	$4.60\ ^d\pm0.07$	$6.60^b \pm0.10$	$8.40^a\pm0.21$	$6.01^c\pm0.24$
Crumb color of pan bread samples1					
Lightness (L*)	$72.7^a \pm 0.03$	$59.3^b \pm 0.20$	$53.3^c \pm 0.17$	$51.2^d\pm0.03$	$43.9^e\pm0.03$
Redness (a*)	$0.08^d \pm 0.01$	$1.0^c \pm 0.02$	$2.4^b \pm 0.01$	$2.7^b\pm0.34$	$4.2^a\pm0.12$
Yellowness (b*)	$14.7^c \pm 0.01$	$15.4^b \pm 0.02$	$15.4^b \pm 0.25$	$16.2^a\pm0.02$	$16.1^a\pm0.11$
Color differences (Δ E)	0	$13.45^d\pm 0.31$	$19.54^c\pm 0.18$	$21.78^b\pm 0.11$	$29.20^a\pm 0.31$

Values with different superscript letters in the same raw are significantly different ($P\leq0.05$).

3.4. Texture analysis of pan bread samples fortified with eggplant peels

Texture profile analyses of the control and pan bread samples fortified with EPP are presented in Table (5). The hardness of fortified bread samples gradually increased with increasing the addition level of EPP from 2.91 for the control sample to 13.67 for EPP 10% sample. These results confirm the result of baking quality, which reveals that the increase in crumb hardness can be explained by the decrease in the bread volume. Additionally, these findings agree with the findings of [52, 53], who demonstrated that the lower hardness values are directly linked to the increased bread volume.

The higher level of fiber changes the gluten structure, hence altering the structure of the bread [54], as well as its texture. This may be due to the lack of gluten hydration, which leads to reduced ability of the dough to retain gas. Thereby, these changes lead to a harder texture of the bread [55, 56]. The interna resistance of bread crumbs is evaluated through its cohesiveness, which is a property of the chewing process.

Table (5): Effects of eggplant peels flour on the texture profile of pan bread

Parameter	Control	Eggplant fortified bread			
		EPP 2.5%	EPP 5%	EPP 7.5%	EPP 10%
Hardness (N)	2.91	4.08	6.98	10.06	13.67
Cohesiveness	0.87	0.83	0.82	0.90	0.97
Gumminess (N)	2.53	3.39	5.69	9.06	13.35
Chewiness (g.cm)	252.27	329.72	531.07	883.48	1300.34
Springiness (mm)	9.78	9.51	9.14	9.56	9.55

The measure of cohesiveness is determined by the product's ability to withstand a second deformation compared to its behavior during the initial deformation [57].

Cohesiveness appeared to be a better indicator of staling it ranged from 0.82 to 0.97. Cohesiveness recorded the highest value in EPP 10%, whereas EPP 2.5 and 5% bread samples recorded the lowest. High cohesiveness is generally preferred in bread because it allows the bread to form a bolus instead of disintegrating when masticating [58].

Concerning springiness, the results indicate that the control had the highest values of springiness (9.78 mm) and EGP 5% had the lowest springiness (9.14 mm). The chewiness and gumminess values followed a similar trend of hardness. The results presented here agree with the findings of Ibrahim [59], who indicated that chewiness and gumminess could be affected by hardness.

3.5. Sensory evaluation of pan bread samples fortified with eggplant peels flour

The organoleptic properties of bread samples are presented in Table (6). It can be observed that, except for crust and crumb color, there were no significant differences between the bread sample fortified with 2.5% EPP and the control sample

Symmetry of shape scores of fortified bread samples decreased with increasing the level of EPP addition. Among the tested characteristics, the crust and crumb color of EPP fortified brad was the most affected character. Color scores confirmed the instrumental result of color parameters which reflect that with increasing EPP level the crust and crumb became darker. This could explain the decreased color score of fortified samples.

Break & shred showed, and mouth feels characteristics a non-significant difference between bread samples fortified with EPP at 2.5, 5, and 7.5%, while bread samples fortified with 10% EPP recorded significantly lower scores for both characters. Crumb texture scores decline from 14 for the control sample to 10.43 for the bread sample containing 10% EPP. These results are in good accordance with the result of the texture profile analysis (Table 5), which indicated that the addition of EPP increased the hardness of the bread sample.

All fortified samples gained acceptable scores regarding the taste and aroma characteristics. Our findings indicate that the addition of different percentages of EPP had varying effects on the sensory qualities of the pan bread. When 2.5% EPP was added, the acceptability was recorded at 90.64%. Similarly, when 5% EPP was added, the acceptability was slightly lower (85.87%). Finally, when 7.5% EGP was added, the acceptability decreased further to 80.15%. The acceptability of the EGP 10% was found to be the lowest, with a recorded percentage of 70.87%. In general, the addition of EPP in pan bread affected how consumers evaluated the product. However, it is significant that even though this effect, consumers still showed acceptance towards all processed products.

Table (6): Sensorial properties of pan bread fortified eggplant peels flour

Parameter	Control	Eggplant fortified bread			
		EPP 2.5%	EPP 5%	EPP 7.5%	EPP 10%
Symmetry of shape (5)	$4.85^{a} \pm 0.08$	$4.79^{a} \pm 0.08$	$4.00^{b}\pm0.12$	$3.00^{c}\pm0.22$	$2.86^{c}\pm0.22$
Crust color (10)	$9.71^{a}\pm0.10$	$9.00^{b}\pm0.17$	$8.00^{c}\pm0.24$	$7.43^{c} \pm 0.20$	$6.43^{d}\pm0.29$
Crumb color (10)	$9.86\ ^{a} \pm0.36$	$8.71^{b}\pm1.01$	$7.86^{c}\pm1.06$	$6.86^{d}\pm0.85$	$6.00^{e} \pm1.22$
Break & shred (10)	$9.29^{a}\pm0.16$	$8.43^{b}\pm0.26$	$8.16^{b}\pm0.20$	$8.14^{b} \pm 0.19$	$7.00^{c}\pm 0.12$
Crumb texture (15)	$14.00^{a}\pm0.24$	$13.14^{ab}\pm0.35$	$12.57^{bc}\pm0.23$	$11.71^{c}\pm0.31$	$10.43^{d} \pm0.44$
Mouth feel (10)	$9.43^{a} \pm0.51$	$8.86^{ab} \pm0.85$	$8.43^{b}\pm0.93$	$8.29^{b}\pm0.90$	$6.86^{c}\pm1.49$
Aroma (20)	$19.29^{a}\pm0.90$	$18.57^{ab}\pm1.21$	$18.14^{b}\pm1.60$	$16.86^{c}\pm2.41$	$15.29^{d}\pm1.79$
Taste (20)	$19.28^{a} \pm0.72$	$19.14^{a} \pm1.15$	$18.71^{ab}\pm1.71$	$17.86^{b} \pm1.60$	$16^{c} \pm2.05$
Overall acceptability (100)	$95.71^{a}\pm2.43$	$90.64^{b}\pm5.01$	$85.87^{c}\pm4.22$	$80.15\ ^{d}\pm5.88$	$70.87^{e} \pm5.78$

Values with different superscript letters in the same raw are significantly different ($P\leq0.05$).

3.6. Microstructure of pan bread samples fortified with eggplant peel flour

Scanning electron microscopy (SEM) analysis of fortified pan bread samples at a magnification of 3000X are presented in Fig. (1). Photomicrographs revealed the bi-continuous system of gluten with embedded starch, where the gluten formed a fibrous, web-like structure in gluten bread. The control bread has a clear gluten structure and a uniform distribution of gluten matrix. The porous sponge-like microstructure indicates that the gluten structure takes a solid form. In addition, the control sample exhibited a well-developed gluten network, characterized by a limited number of noticeable starch particles.

At the same time, while mixing, the gas battery initially introduces dough [60]. The cell structure of bread containing 2.5 and 5% EPP was like the control sample. It was also observed that the integrity of gluten structure decreases with the increase in EPP level. These findings agree with the results of Tang et al. [61], who reported a decrease in both the volume and density of bread cells when incorporating 20% and 25% of lychee juice by-product dietary fiber. This may be due to the reduction or dilution in gluten concentration following the addition of fiber. Furthermore, the stability of the dough's aggregation network is significantly influenced by the secondary structure of the gluten protein. Dietary fiber will directly compete with gluten protein for water. Due to its superior hydration capability compared to gluten, dietary fiber attracts the water present in the dough, leaving insufficient water for gluten to form bonds. Over time, the secondary arrangement of gluten protein molecules becomes delicate, making the gluten matrix highly susceptible to breaking. Therefore, the cells of the bread get a reduction in size and an increase in density [62, 63].

It is observed that the air chamber of the bread in the control group had a consistent structure and a veil-like appearance [64]. The surface was slightly uneven, but the gluten protein created a smooth, continuous network structure where the starch particles were almost entirely gelatinized and hard to distinguish between the control and EPP 2.5 and 5%.

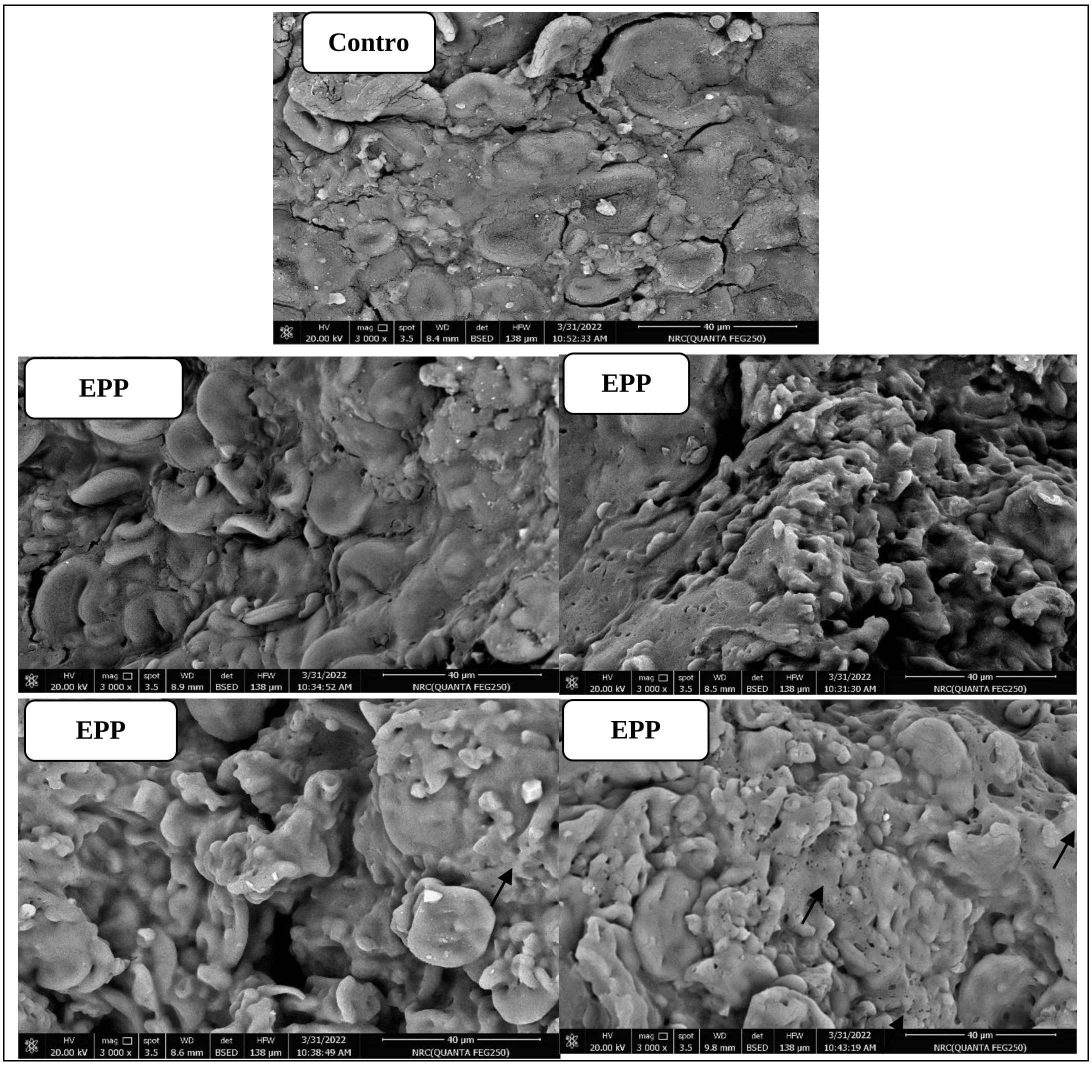

Fig. (1): SEM images of control and fortified pan bread samples

The increase in dietary fiber content revealed the presence of numerous oval and spherical starch particles, some of which were non-gelatinized or partially gelatinized**.**

Furthermore, the bread's air chamber wall progressively became uneven and rough, and starch particles partially or partially aggregated the gluten matrix and perforated as indicated by the black arrows in Fig. 1D and E).

3.7. Staling properties of pan bread samples fortified with eggplant peels flour

Bread quality deteriorates with storage time after baking. Bread staling has been defined as a decrease in quality that is not due to microbial spoilage and is determined by consumer acceptability [65]. For over a century, it has been stated that bread staling is still causing significant economic losses for both the industry of baking and the consumer. Bread staling is a multifaceted procedure that goes on during the storage of bread. Despite bread, staling has been the subject of research for 150 years, and the mechanism behind it remains unclear [66]. The alkaline water retention capacity (AWRC) of the pan bread loaves can be defined as an indicator of their rate of staling and freshness. Hence, the estimation was done for each sample at the initial time and after storage durations of 24 and 72 hours, as shown in Figure 2. The results illustrate that the control pan bread samples had the highest staling rate after 24h. While, all fortified pan bread samples showed almost the same staling rate at the same time. During a 72-hour of room temperature storage, eggplant peels shown significant effects in delaying the staling of baked pan bread. Furthermore, it was shown that increased levels of EPP resulted in a decrease in the rate of staling.

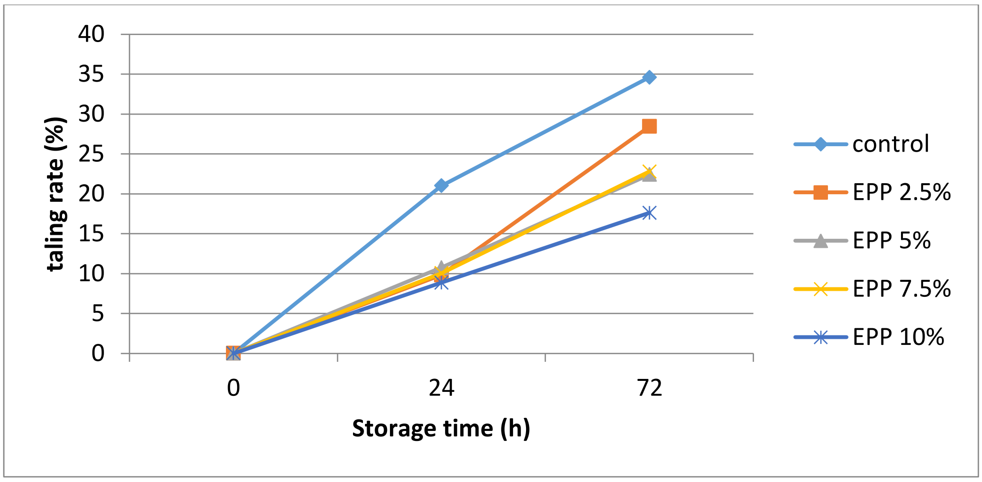

Fig. (2): staling properties of fortified pan bread samples

4. Conclusion

The chemical profile analysis rated EPP as a unique source of dietary fiber and phenolic compounds. However, it had various impacts on the rheological, texture, and sensory characteristics. The specific volume of pan bread decreased significantly by increasing the addition of EPP level. The crust and crumb color exhibited a noticeable darkening when the level of EPP was increased, in comparison to the control. The increased fiber content altered the gluten structure, resulting in a higher level of hardness and chewiness. There were no notable variations in the aroma and taste of the control, EPP 2.5%, and EPP 5% samples. The findings suggest that the addition of varying amounts of EPP resulted in different impacts on the sensory characteristics of the produced bread. However, it is significant that even despite this effect, consumers still showed acceptance towards all processed products. During 72 h of storage at room temperature, EPP showed positive effects on delaying the staling of the baked pan bread.

5. Conflicts of interest

There are no conflicts to declare

6. References

[1] Estrella-Osuna, D. E., Tapia-Hernández, J. A., Ruíz-Cruz, S., Márquez-Ríos, E., Ornelas- Paz, J. de J., Del-Toro-Sánchez, C. L., Ocaño-Higuera, V. M., Rodríguez-Félix, F., Estrada-Alvarado, M. I., & Cira-Chávez, L. A. (2022). Nanoencapsulation of Eggplant (Solanum melongena L.) Peel Extract in Electrospun Gelatin Nanofiber: Preparation, Characterization, and In Vitro Release. Nanomaterials (Basel, Switzerland), 12(13). 10.3390/NANO12132303.

[2] Schieber, A., Stintzing, F. C., & Carle, R. (2001). By-products of plant food processing as a source of functional compounds—recent developments. Trends in food science & technology, 12(11), 401-413.
[3] Mauro, R. P., Agnello, M., Rizzo, V., Graziani, G., Fogliano, V., Leonardi, C., & Giuffrida, F. (2020). Recovery of eggplant field waste as a source of phytochemicals. Scientia Horticulturae, 261, 109023.
[4] Gürbüz, N., Uluişik, S., Frary, A., Frary, A., & Doğanlar, S. (2018). Health benefits and bioactive compounds of eggplant. Food chemistry, 268, 602-610.
[5] Dranca, F., & Oroian, M. (2016). Optimization of ultrasound-assisted extraction of total monomeric anthocyanin (TMA) and total phenolic content (TPC) from eggplant (Solanum melongena L.) peel. Ultrasonics Sonochemistry, 31, 637–646.
[6] Niño-Medina, G.; Urías-Orona, V.; Muy-Rangel, M.D. and Heredia, J.B. (2017). Structure and content of phenolics in eggplant (Solanum melongena)-a review. South African Journal of Botany, 111:161-169.
[7] García-Salas, P., Gómez-Caravaca, A. M., Morales-Soto, A., Segura-Carretero, A., & Fernández-Gutiérrez, A. (2014). Identification and quantification of phenolic compounds in diverse cultivars of eggplant grown in different seasons by high-performance liquid chromatography coupled to diode array detector and electrospray-quadrupole-time of flight-mass spectrometry. Food Research International, 57, 114–122. https://doi.org/10.1016/j.foodres.2014.01.032
[8] Karimi, A., Kazemi, M., Samani, S. A., & Simal-Gandara, J. (2021). Bioactive compounds from by-products of eggplant: Functional properties, potential applications and advances in valorization methods. Trends in Food Science & Technology, 112, 518–531. https://doi.org/10.1016/J.TIFS.2021.04.027
[9] Sudha, M. L., Rajeswari, G., Venkateswara-Rao, O. (2011). Effect of wheat and oat brans on the dough rheological and quality characteristics of instant vermicelli. Journal of Texture Studies, 43: 195–202
[10] Li, Y. O., Komarek, A. R. (2017). Dietary fibre basics: health, nutrition, analysis, and applications. Food Quality and Safety, 1: 47–59.
[11] Makhlouf, S., Jones, S., Ye, S. H., Sancho-Madriz, M., Burns-Whitmore, B., & Li, Y. O. (2019). Effect of selected dietary fiber sources and addition levels on physical and cooking quality attributes of fiber-enhanced pasta. Food Quality and Safety, 3(2), 117-127.
[12] Dahm, C.C., Keogh, R.H., Spencer, E.A., Greenwood, D.C., Key, T.J., Fentiman, I.S., Shipley, M.J., Brunner, E.J., Cade, J.E., Burley, V.J. and Mishra, G., 2010. Dietary fiber and colorectal cancer risk: a nested case–control study using food diaries. Journal of the National Cancer Institute, 102(9), pp.614-626.
[13] Zhang, Z., Xu, G., Liu, D., Zhu, W., Fan, X., Liu, X. (2013). Dietary fiber consumption and risk of stroke. European Journal of Epidemiology, 28: 119–130.
[14] U. S. Department of Agriculture, U. S. Department of Health and Human Services (USDA and USHHS). (2015). Dietary Guidelines for Americans (8th edn). United States Government Printing Office, Washington, DC. https://health.gov/dietaryguidelines/2015/guidelines/. Accessed 10 January 2019.
[15] Rana, K., Ghimire, P., Chimoriya, R., & Chimoriya, R. (2021). Trends in the prevalence of overweight and obesity and associated socioeconomic and household environmental factors among women in Nepal: findings from the Nepal demographic and health surveys. Obesities, 1(2), 113-135.
[16] Onipe, O. O., Jideani, A. I., & Beswa, D. (2015). Composition and functionality of wheat bran and its application in some cereal food products. International Journal of Food Science & Technology, 50(12), 2509-2518.
[17] Lin, S. (2022). Dietary fiber in bakery products: Source, processing, and function. Advances in food and nutrition research, 99, 37-100.
[18] Zhou, Y., Dhital, S., Zhao, C., Ye, F., Chen, J., & Zhao, G. (2021). Dietary fiber-gluten protein interaction in wheat flour dough: Analysis, consequences and proposed mechanisms. Food Hydrocolloids, 111, 106203.
[19] Grigor, J. M., Brennan, C. S., Hutchings, S. C., & Rowlands, D. S. (2016). The sensory acceptance of fibre-enriched cereal foods: a meta-analysis. International Journal of Food Science & Technology, 51(1), 3-13.
[20] Biduski, B., Maçãs, M., Vahedikia, N., O'Connor, P.M., Hussey, K., Simpson, J.C., Mysior, M.M. and Gallagher, E., 2024. Dough rheology and internal structure of bread produced with wheat flour partially substituted by buckwheat flour: A step towards enhancing nutritional value. Food Structure, 39, p.100364.
[21] AOAC (2000): Association of Official Analytical Chemists. Official Methods of Analysis (18thEd.) Maryland, USA
[22] Yousif ES., Yaseen A., Abdel-Fatah AF., Shouk AA., Gdallah M. & Mohammad AA. (2022a). Antioxidant and anticancer properties of nano and fermented-nano powders of wheat and rice by-products. Discover Food 2, 33. https://doi.org/10.1007/s44187-022-00032-6
[23] Hwang, S. J., Yoon, W. B., Lee, O. H., Cha, S. J., & Dai Kim, J. (2014). Radical-scavenging-linked antioxidant activities of extracts from black chokeberry and blueberry cultivated in Korea. Food Chemistry, 146, 71-77.
[24] Yaseen AA., Al-Okbi SY., Hussein AMS., Mohamed DA., Mohammad AA., Fouda KA., Mehaya FM. (2019). Potential protection from Alzheimer's disease by wheat germ and rice bran nano-form in rat model. Journal of Applied Pharmaceutical Science, 9(S1), 067-076.
[25] ICC. 2006. Approved Standard 173. International Association for CerealScience and Technology: Vienna.
[26] AACC. 2002. Approved Methodsofthe AACC, 8th Ed. Method 10-10B. American Association of Cereal Chemists, St. Paul, MN.
[27] Hunter, R.S. and Harold, R.W. The measurement of appearance. Hoboken, NJ: Wiley-Interscience, (1987).
[28] Yousif ES., Yaseen A., Abdel-Fatah AF., Shouk AA., Gdallah M. & Mohammad AA. (2022b). Pan bread quality as affected by some nano and fermented-nano food industries by-products. Bulletin of the National Research Centre, 44:61. https://doi.org/10.1186/s42269-020-00315-x
[29] Yamazaki W.T. 1953. An alkaline water retention capacity test for the evaluation of cookie baking potentialities of soft winter wheat flours. Cereal Chem. 30, 242-246
[30] Licciardello, F., Cipri, L., & Muratore, G. (2014). Influence of packaging on the quality maintenance of industrial bread by comparative shelf life testing. Food Packaging and Shelf Life, 1(1), 19-24.
[31] SPSS (2001): Statistical Software Package for the Social Sciences, Version 13 for Windows. Inc., Chicago, IL.

[32]Nisha, P., Nazar, P. A., & Jayamurthy, P. (2009). A comparative study on antioxidant activities of different varieties of Solanum melongena. Food and Chemical Toxicology, 47(10), 2640-2644.
[33]Hussain S, Maqsood MA, Miller LV (2011) Bioavailable zinc in grains of bread wheat varieties of Pakistan. Cereal Res Commun. doi:10.1556/CRC.2011.003
[34]Mohamed, M., Zeitoun, A., & Abdalla, A. E. (2019). Assessment of chemical composition and bioactive compounds in the peel, pulp and whole Egyptian eggplant flour. Journal of the Advances in Agricultural Researches, 24(1), 14-37.
[35]Scorsatto, M., Pimentel, A. D. C., Silva, A. J. R. D., Sabally, K., Rosa, G., & Oliveira, G. M. M. D. (2017). Assessment of bioactive compounds, physicochemical composition, and in vitro antioxidant activity of eggplant flour. International Journal of Cardiovascular Sciences, 30, 235-242.
[36]Kadivec, M., Kopjar, M., Žnidarčič, D., & Požrl, T. (2015). Potential of eggplant peel as by-product. Acta alimentaria, 44(1), 126-131.
[37]Helmja, K., Vaher, M., Gorbatšova, J., & Kaljurand, M. (2007, December). Characterization of bioactive compounds contained in vegetables of the Solanaceae family by capillary electrophoresis. In Proceedings of the Estonian academy of sciences, Chemistry (Vol. 56, No. 4).
[38]Kwon, Y. I., Apostolidis, E., & Shetty, K. J. B. T. (2008). In vitro studies of eggplant (Solanum melongena) phenolics as inhibitors of key enzymes relevant for type 2 diabetes and hypertension. Bioresource technology, 99(8), 2981-2988.
[39]Saura-Calixto, F. (2011). Dietary fiber as a carrier of dietary antioxidants: an essential physiological function. Journal of agricultural and food chemistry, 59(1), 43-49.
[40]Viuda-Martos, M.; Ruiz-Navajas, Y.; Martin-Zanchez, A.; Sanchez-Zapata, E.; Fernandez-Lopez, J.; Sendra, E.; Sayas-Barbera, E.; Navarro, C. and Perez-Alvarez, J. A. (2012). Chemical, physico-chemical and functional properties of pomegranate (Punica granatum L.) bagasses powder co-product. Journal of Food Engineering 110: 220-224.
[41]Begum, H. A., Tanni, T. R., & Shahid, M. A. (2021). Analysis of water absorption of different natural fibers. Journal of Textile Science and Technology, 7(4), 152-160.
[42]Krekora, M., Miś, A., & Nawrocka, A. (2021). Molecular interactions between gluten network and phenolic acids studied during overmixing process with application of FT-IR spectroscopy. Journal of Cereal Science, 99, 103203.
[43]Sivam, A. S.; Sun-Waterhouse, D.; Quek, S. Y. and Perera, C. O. (2010). Properties of bread dough with added fiber polysaccharides and phenolic antioxidants: A Review. Journal of Food Science, 75: R163-R174.
[44]Zhang, D. and Moore, W.R. (1997). Effect of wheat bran particle size on dough rheological properties. Journal of the Science of Food and Agriculture, 74: 490-496.
[45]Rosell, C. M. and Santos, E. (2010). Impact of fibers on physical characteristics of fresh and staled bake-off bread. Journal of Food Engineering, 98: 273-281.
[46]Wang, Y., Pan, Y., Zhou, C., Li, W., & Wang, K. (2024). Effects of Kiwifruit Dietary Fibers on Pasting Properties and In Vitro Starch Digestibility of Wheat Starch. Nutrients, 16(5), 749.
[47]Zhu, F., Cai, Y. Z., Sun, M., & Corke, H. (2008). Effect of phenolic compounds on the pasting and textural properties of wheat starch. Starch-Stärke, 60(11), 609-616.
[48]Maaruf, A. G., Man, Y. C., Asbi, B. A., Junainah, A. H., & Kennedy, J. F. (2001). Effect of water content on the gelatinisation temperature of sago starch. Carbohydrate Polymers, 46(4), 331-337.
[49]Benam, N. S., Goli, M., Ardebili, S. M. S., & Vaezshoushtari, N. (2021). The quality characteristics of dough and toast bread prepared with wheat flour containing different levels of Portulaca oleracea leaf powder. Food Science and Technology http://dx.doi.org/10.1590/fst.60820.
[50]Gómez, M., Ronda, F., Blanco, C. A., Caballero, P. A., & Apesteguía, A. (2003). Effect of dietary fibre on dough rheology and bread quality. European Food research and technology, 216, 51-56.
[51]Levent, H., Bilgiçli, N., & Ertaş, N. (2015). The assessment of leavened and unleavened flat breads properties enriched with wheat germ. Quality assurance and safety of crops & foods, 7(3), 321-326.
[52]Wanga J., Rosella C.M., Barbera C.B. (2002): Effect of the addition of different fibres on wheat dough perfor-mance and bread quality. Food Chemistry, 79: 221–226
[53]Yamsaengsung R., Schoenlechner R., Berghofer E. (2010): The effects of chickpea on the functional proper-ties of white and whole wheat bread. International Journal of Food Science and Technology, 45: 610–620.
[54]Eshak NS (2016) Sensory evaluation and nutritional value of balady flat bread supplemented with banana peels as a natural source of dietary fiber. Ann Agric Sci 61:229–235
[55]Ghoshal G, Shivhare US, Banerjee UC (2016) Thermo-mechanicaland micro-structural properties of xylanase containing wholewheat bread. Food Sci Hum Wellness 5:219–229
[56]Aydogdu A, Sumnu G, Sahin S (2018) Effects of addition of differentfibers on rheological characteristics of cake batter and quality ofcakes. J Food Sci Technol 55:667–677
[57]Boz H.,Karaoğlu M.M. (2013): Improving the quality of whole wheat bread by using various plant origin materials. Czech J. Food Sci., 31: 457–466
[58]Onyango C., Mutungi C., Unbehend G., Meinolf G., Lindhauer M.G. (2010): Rheological and baking char-acteristics of batter and bread prepared from pregelati-nised cassava starch and sorghum and modified using microbial transglutaminase. Journal of Food Engineering, 97: 465–470.
[59]Ibrahim, M.A.K. (2011) Chemical and biological studies on some bakery products. Ph.D. Thesis, Food Science Dep. Fac. Agric., Moshtohor, Banha Univ., Egypt, 184 p
[60]Scanlon, M. G., & Zghal, M. C. (2001). Bread properties and crumb structure. Food research international, 34(10), 841-864
[61]Tang, S., Su, T., Huang, Z., Huang, F., Zhang, R., Dong, L., Deng, M., Shen, Y. and Su, D., 2022. Impact of replacing wheat flour with lychee juice by-products on bread quality characteristics and microstructure. LWT, 165, p.113696.

[62] Goesaert, H., Brijs, K., Veraverbeke, W. S., Courtin, C. M., Gebruers, K., & Delcour, J. A. (2005). Wheat flour constituents: how they impact bread quality, and how to impact their functionality. Trends in food science & technology, 16(1-3), 12-30.

[63] Zhou, Y., Dhital, S., Zhao, C., Ye, F., Chen, J., & Zhao, G. (2021). Dietary fiber-gluten protein interaction in wheat flour dough: Analysis, consequences and proposed mechanisms. Food Hydrocolloids, 111, 106203.

[64] Rojas, J. A., Rosell, C. M., Benedito de Barber, C., Pérez-Munuera, I., & Lluch, M. A. (2000). The baking process of wheat rolls followed by cryo scanning electron microscopy. European Food Research and Technology, 212, 57-63.

[65] Martin, M. L.; Zeleznak, K. J. and Hoseney, R. C. (1991). A mechanism of bread firming. I. Role of starch swelling. Cereal Chemistry, 68:498-503.

[66] Xie, F.; Dowell, F. E. and Sun, X. S. (2004). Using visible and near-infrared reflectance spectroscopy and differential scanning calorimetry to study starch, protein and temperature effects on bread staling. Cereal Chemistry, 81: 249–54.