Research Article

Valorization of Pea Pods and Faba Bean Hulls as Novel Sources of Polyphenols and Fibers: Various Formulations and their Impact on the Biscuit Quality

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Abstract
This research studied the opportunity to enrich biscuits with pea pods and faba bean hulls (seed coat) powder. Chemical composition, polyphenol content, flavonoid content, and antioxidant activity of pea pod and faba bean hulls powders were investigated. To assess their effect on biscuit color, hardness, and sensory characteristics, these powders separately replaced wheat flour at 2.5, 5, and 10% levels. The resultant composite flours were then utilized to prepare biscuits. In addition, the effects of these powders on Mixolab parameters of the resultant composite flour doughs and their correlation with biscuit hardness and texture were investigated. Total phenolics of pea pods and faba bean hulls ethanolic extracts were 44.66 ± 3.65 and 34.55 ± 0.65 mg GAE/g DW and flavonoid content was 3.68 ± 0.14 and 9.11± 0.88 mg QE/g DW, respectively. The main polyphenolic compounds in faba bean hulls extract were Benzoic acid, Rosmarinic acid and p- Hydroxy benzoic acid while the main compounds in pea pods extract were Resveratrol and Benzoic acid. The faba bean hull extract had higher antioxidant activity against DPPH than the pea pod extract. The hardness of fortified biscuits was not affected by the added powder level, but their color became darker and higher in redness and yellowness. Mixolab parameters of the resultant composite flour doughs were significantly affected by adding powders. Pea pods and faba bean hulls can be used as a source of bioactive constituents in many bakery products.

Keywords: Antioxidant, Biscuits, Faba bean hulls, Mixolab parameters, Pea pods, Polyphenols

1 Introduction

Vegetable processing industries produce a huge quantity of agro-industrial wastes causing economic and environmental problems [1]. de Brito Nogueira *et al*., [2] reported that losses of food waste and residues were estimated at 680 and 310 billion US dollars annually in developed and developing countries, respectively. They also added that around 40–50% of the annual production of fruits and vegetables is wasted. Ozcan *et al*., [3] mentioned that the world's food waste carbon footprint is estimated to be 3300 megatons of CO_2 equivalent annually, and around 1400 million hectares are cultivated to produce food that is subsequently wasted. The sustainability of food processing aims to decrease the destructive environmental impact of these wastes and achieve economic profit by valorizing these wastes in food production.

The non-edible industrial by-products from plant parts comprise peels, skins, shells, husks, pods, pits, stones, straws, stems, and leaves [4]. Vegetal residues contain many significant amounts of active compounds that promote health benefits and can be useful ingredients in fortified foods [5]. Due to their content of phytochemicals, fibers, and proteins, including certain peptides, pea and faba beans, in addition to their byproducts, have shown potential health benefits in the prevention and management of certain cancers, cardiovascular problems, diabetes, and several degenerative diseases [6], [7]. Legume beans contain many nutrients, such as protein, starch, dietary fibers, fats, vitamins and trace minerals. Their coats (seed hulls) are rich in phenolic compounds, which are considered a defense system for seeds against environmental factors, such as light, oxygen, free radicals, and metal ions [8].

Pea (*Pisum sativum*) is a green pod-shaped vegetable belonging to the *Fabaceae* family. It grows in the winter season. Pea pods are by-products of the frozen or fresh peas processing industry, commonly used as fertilizer or for animal feeds [9]. Pea pods are a great source of essential compounds such as fibers, minerals, proteins, and polyphenols [10]. They were recently utilized as a dietary fiber supplement in addition to recovering polysaccharides and carbohydrates [11]. Under optimal water extraction conditions, the recovery of polysaccharides from pea pods was 16.21% by weight, and the main identified monosaccharides were galactose, xylose, and arabinose [12]. Empty pea pods comprise 30–67% of the weight of the harvested product (whole pods) [13]. Faba bean (*Vicia faba* L.) is a versatile legume crop. It is a flowering plant that belongs to the *Fabaceae* family [14]. The hulls represent approximately 10–15% (w/w) of the total beans dry matter. These hulls are usually removed from fresh faba beans before consumption or from dry beans, which are usually dehulled by industrial or small-scale milling [15]–[17]. Faba bean hulls are a valuable source of dietary fibers such as pectin and phenolic compounds characterized by good antioxidant activity [18], [19].

Functional foods are defined as foods that are fortified with nutrients that lead to good biological metabolic activity effects and enhance general health benefits [6]. Many studies were conducted on the possibility of implementing pea pods or faba bean hulls to fortify various food products. For instance, Pooja *et al*., [20] utilized pea pod powder as a source of dietary fiber and protein to prepare fortified muffins and achieve environmental concept of “zero waste” in the vegetable processing industries. Also, Kaya *et al*., [21] fortified the Turkish noodles with hulls of faba beans to enhance the noodles’ nutritional value and textural characteristics. Daliani *et al*., [22] also incorporated faba bean hulls into bread as a source of dietary fibers. In addition, faba bean hulls were added to burger patties to improve cooking properties, delay lipid and protein oxidation, prevent color changes, and decrease the microbiological load [23].

This paper aimed to cover the literature's scarcity in relation to phytochemical compounds of faba bean hulls and pea pods and their effect on the quality and acceptance of biscuits containing them. The chemical composition and polyphenol content, and antioxidant activities were determined. The possibility of fortifying biscuits using various levels of either pea pods or faba bean hull powders was investigated by monitoring their influences on the sensory, color, and textural characteristics of the produced biscuits. Finally, the ability to predict the influences of these powders on the hardness and texture of the biscuits was studied by determining the correlation between these attributes and Mixolab® parameters.

2 Materials and Methods

2.1 *Plant materials*

Pea *(Pisum sativum* L.) pods were manually separated and dried at 50 °C, while dried faba bean (*Vicia faba* L.) hulls were supplied by the Crop Department, Faculty of Agriculture, Cairo University, Egypt. Either pea pods or faba bean hulls were pulverized to 50 mesh, then packed in polyethylene bag and kept at 5 °C. Wheat flour, butter, egg, salt, yeast, and sugar were obtained from the local market.

2.2 *Chemicals and reagents*

DPPH (1,1-diphenyl-2-picrylhydrazyl radical), Folin–Ciocalteu reagent, aluminum chloride, quercetin, sodium nitrite, gallic acid, methyl alcohol, ethyl alcohol, sodium carbonate, and sodium hydroxide were bought from Sigma–Aldrich Co., St. Louis, USA.

2.3 *Chemical composition*

Moisture, crude protein, ether extract, ash and crude fiber contents were determined according to AOAC [24]. The total carbohydrates were calculated by difference.

2.4 *Extraction of polyphenols*

The pulverized waste material powders were added to ethanol (80%) at the solid-to-solvent ratio of 1/20 (*w/v*). Then, the mixture was stirred using a benchtop lab stirrer (Heidolph, Germany) at the highest speed for 30 min, according to Hammad *et al*., [25]. The extracts were concentrated under a vacuum at 45 °C via the EYELA Rotary Evaporator (Tokyo Rikakikai Co., LTD, Japan).

2.5 *Total phenolic content (TPC)*

TPC of various extracts was estimated via the Folin-Ciocalteu assay as outlined in Singleton *et al*., [26]. The results were expressed as mg Gallic acid equivalent per gram dry weight of wastes (mg GAE/g DW).

2.6 *Total flavonoid content (TFC)*

Aluminum chloride colorimetric method was implemented to determine the TFC of various extracts [27]. The results were articulated as milligrams of Quercetin equivalent per gram of dry weight wastes (mg QE/g DW).

2.7 *Identification of polyphenol compounds by HPLC*

Agilent 1260 Infinity || LC System (Agilent, USA) fitted with a Kineted® 5µm EVO C_{18} column (100 mm × 4.6 mm; Phenomenex, USA) was utilized to identify the profile of various phenolic compounds. The fractionation was performed using a mobile phase containing (A) HPLC grade water with 0.2% H_3PO_4 (v/v), (B) methanol and (C) acetonitrile at a flow rate of 0.7 mL/min. Before injecting the samples, they were first filtered through a 0.45 µm filter syringe, and then 20 µL was injected. The column was maintained at a constant temperature (30 °C) and phenolic compounds were detected at 284 nm. The retention times of authentic standards and their calibration curves were used to identify and quantify various phenolic compounds, respectively. All authentic standards listed in Table 1 were bought from Sigma–Aldrich Co., St. Louis, USA.

2.8 *DPPH radical Scavenging activity*

The antioxidant activity of ethanolic extracts of either pea pods or faba bean hulls was carried out using a DPPH radical scavenging assay [28]. The absorbance was measured at 515 nm using a spectrophotometer (UNICO Instruments Co., LTD, USA). The antioxidant activity was expressed as a percentage of inhibition according to this equation:

$$\text{DPPH Inhibition (\%)} = \frac{Ab - As}{Ab} \; x \; 100$$

Where (Ab) is the absorbance of the DPPH solution and (As) is the absorbance of the sample after reaction with the DPPH solution. In addition, the concentration of the studied extracts that resulted in a DPPH inhibition percentage of 50% (IC_{50}) was determined as illustrated in Figure 1(a).

2.9 *Ferric reducing antioxidant power (FRAP) assay*

The reducing power of the pea pods and faba bean hulls extracts was determined according to Yen and Chen [29] with mild modification as follows: 1 mL of different concentrations of the studied extracts reacted with 2.5 mL phosphate buffer (0.2 M, pH 6.6) and 2.5 mL potassium ferricyanide (10%), for 20 min at 50 °C. After cooling the reaction mixture, it was mixed with 2.5 mL of TCA (10%). Then, 2.5 mL of the previous solution was mixed with 2.5 ml of distilled water and 0.5 mL of freshly prepared $FeCl_3$ solution (0.1%) in the same sequence. The absorbance was measured at 700 nm. The FRAP IC_{50} of various samples was determined according to El-Roby *et al*., [30]. They defined FRAP IC_{50} as the extract concentration (µg GAE/mL) that corresponds to an absorbance of 0.5 for reducing power. This value was derived from the graph plotting absorbance at 700 nm against extract concentration, as illustrated in Figure 1(b).

2.10 *Biscuits preparation*

Biscuits were prepared according to the methods of Ronoh *et al*., [31]. Part of wheat flour in the biscuit formula (control) (100 gm) was partially replaced with different levels of either faba bean hulls or pea pods powder at 2.5, 5, and 10 levels. Other ingredients shown in Table 2 were mixed in a dough mixer for 1 min at low speed, then further mixed for 3 min at high speed. The dough was then sheeted and cut into pieces (15 gm). The biscuits were baked at 170 °C to 180 °C for 12 min, then cooled and kept at room temperature for further evaluation.

Table 1: HPLC analysis of the pea pods and faba bean hulls ethanolic extracts.

Compounds (mg/g sample DW)	Pea Pods	Faba Bean Hulls
Phenolics		
Pyrogallol	ND	0.35
Gallic acid	0.01	0.05
p- Hydroxy benzoic acid	0.73	3.16
Chlorogenic acid	0.04	0.37
Vanillic acid	0.14	0.44
Caffeic acid	0.11	0.04
Syringic acid	0.11	0.18
p- Coumaric acid	0.07	0.36
Benzoic acid	3.38	5.07
Ferulic acid	0.07	0.07
o- Coumaric acid	0.19	0.20
Resveratrol	6.84	ND
Cinnamic acid	0.60	0.12
Rosmarinic acid	ND	3.39
Ellagic acid	0.06	0.63
Flavonoids		
Myricetin	ND	1.03
Kaempferol	ND	0.83
Catechin	0.01	0.18
Rutin	0.19	ND
Quercetin	ND	0.18

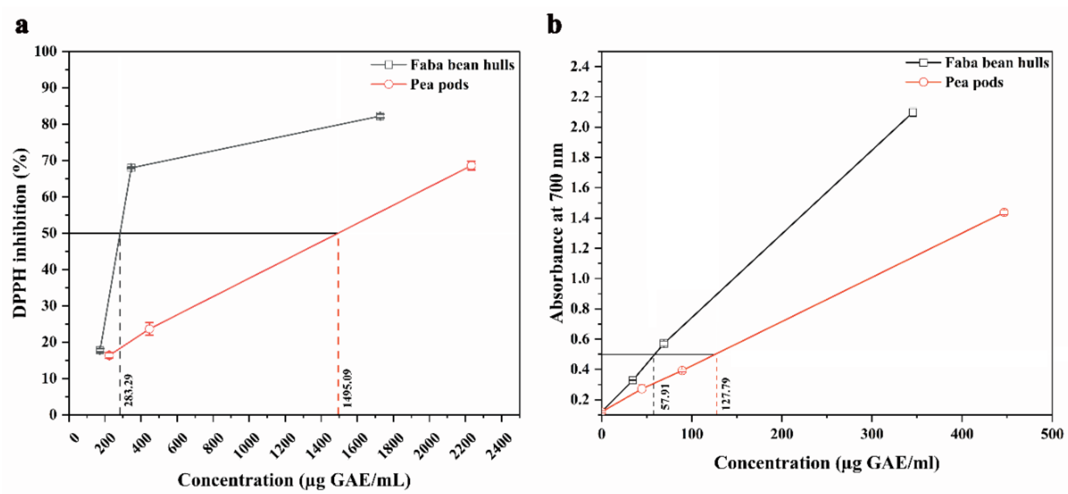

Figure 1: DPPH radical scavenging activities (a) and FRAP (b) assays of either pea pods or faba bean hull extract.

Table 2: Ingredients of various biscuit samples with different replacement percentages.

Ingredients (gm)	Biscuit Sample						
	Control	T1	T2	T3	T4	T5	T6
Wheat flour	100	97.5	95.0	90.0	97.5	95.0	90.0
Faba bean hulls	0.00	2.50	5.00	10.0	0.00	0.00	0.00
Pea pods	0.00	0.00	0.00	0.00	2.50	5.00	10.0
Sugar	34.00	34.00	34.00	34.00	34.00	34.00	34.00
Shortening	27.00	27.00	27.00	27.00	27.00	27.00	27.00
Sodium carbonate	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Ammonium bicarbonate	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Skim milk powder	11.20	11.20	11.20	11.20	11.20	11.20	11.20
Vanilla	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Water	27.00	27.00	27.00	27.00	27.00	27.00	27.00
Total	204.2	204.2	204.2	204.2	204.2	204.2	204.2

Control: Wheat flour 100%, T1, T2, and T3: Biscuits with 2.5, 5, and 10% faba bean hulls, respectively, T4, T5, T6: Biscuits with 2.5, 5, and 10% pea pods, respectively.

2.11 *Hardness of biscuits*

The hardness of the biscuits was measured as a maximum force **(**kgf) required to break biscuit fingers using a digital force gauge (SHIMPO-FGC-50, Japan). The analysis was carried out using a chisel knife adapter.

2.12 *Color of biscuits*

Various biscuit samples were subjected to a chromameter Minolta CR-400 144 (Minolta. Inc., Tokyo, Japan) to measure their color in terms of CIE color parameters L*, a*, and b*.

2.13 *Sensory evaluation*

A panel of fifty (20 females and 30 males, aged between 19–45 years) untrained students and staff members (Food Science Department, Agriculture Faculty, Cairo University) were enrolled to evaluate the color, odor, taste, texture, and overall acceptability of biscuit samples. A horizontal 10-point hedonic scale was used to measure the degree of liking (from 1 'Dislike Extremely' to 10 'Like Extremely'). Several biscuit samples were coded with blinded digits and were randomly served to panelists to evaluate their color, odor, taste, texture, and overall acceptability. The obtained data were statistically analyzed using a completely randomized design ($p \leq 0.05$) followed by Tukey's test to compare the mean of various organoleptic attributes. The absence of food allergies or intolerances to sample ingredients was also considered. Water was served to cleanse the palate between samples.

2.14 *Rheological characteristics of wheat-waste powders composite flour dough using Mixolab®*

The influence of partial substitution of wheat flour by either pea pods or faba bean hulls powder (2.5, 5.0, and 10 %) on the rheological behavior of various wheat-waste powder composite dough was investigated using Mixolab (Chopin, Tripette et Renaud, Paris, France). The standard Chopin^{+} protocol, which simultaneously determines dough characteristics during mixing at constant temperature and during constant heating and cooling periods, was followed [32]. This protocol held the temperature at 30 °C for the initial 8 min. Afterwards, the temperature was raised to 90 °C over 15 min and kept at this temperature for 7 min. Finally, the temperature was lowered to 50 °C over 10 min and held at this temperature for 5 min. The temperature was increased or decreased throughout the preceding steps with a constant heating/ cooling rate of 4 °C/min. The mixing blades were held at a constant speed of 80 rpm.

2.15 *Statistical analysis*

The data are presented as mean values ± SD of three replicates. The data were subjected to analysis of variance (ANOVA) followed by Tukey's test using a significance level of 0.05 (XLSTAT, Addinsoft, USA).

3 Results and Discussion

3.1 *Chemical composition*

Pea pods are elongated outer shells covering the seeds and their combined seed covers (hulls), while the faba bean hulls are the outer covering surrounding the seeds. The chemical composition of these wastes is shown in Table 3. The moisture, ash, lipids, fiber, protein and carbohydrates content of pea pods powder was 6.7 ± 0.17, 6.55 ± 0.17, 4.67 ± 0.18, 4.68 ± 0.20, 16.36 ± 0.97, and 61.04% while for faba bean hulls powder was 5.77 ± 0.15, 12.4 ± 0.25, 4.8 ± 0.17, 6.50 ± 0.25, 9.1 ± 0.70 and 61.43 %, respectively. These results reveal that faba bean hulls exhibited higher fiber and ash contents than pea pods, whereas the latter showed high protein content. These results are comparable to previously published data on the chemical composition of pea pods and faba bean hulls. Hanan *et al*., [10] reported that the chemical composition of pea pods was 11.99 % protein, 3.88 % fat, and 4.61%. Ash. Pooja *et al*., [20] reported that pea pod powder's protein and ash content were 15.80 and 6.53%, respectively. In addition, Mejri *et al*., [11] showed that the crude fiber of pea pods was 7.86 %. Krenz *et al*., [17] reported that the protein, crude fiber, fat, and ash content of faba bean hulls were 8.1, 4.57, 0.6, and 3.1%, respectively.

3.2 *Total phenolic and flavonoid content of pea pods and faba bean hulls*

The total phenolic content (TPC) of pea pods and faba bean hull extracts is listed in Figure 2. The results reveal that the TPC of faba bean hulls and pea pod extracts was 34.55 ± 0.65 and 44.66 ± 3.65 mg GAE/g DW, respectively. The total flavonoid content (TFC) of faba bean hull extract was 9.11 ± 0.88 mg QE/g DW and was 3.68 ± 0.14 mg QE/g DW for pea pods extract. Our results are consistent with those previously reported by Mejri *et al.*, [11] and kumari and deka [17]. They found that TPC and TFC of pea pod extract were 32 (mg GAE/g extract) and 21 (mg QE/g extract), respectively. Chaieb *et al.*, [33] reported that the TPC of different faba bean seed coat genotypes ranged from 45.5 to 107.65 (mg GAE/g sample), while their TFC ranged from 5.31 to 17.58 (mg RE/g sample).

Table 3: Chemical composition of pea pod and faba bean hull powders.

Component (%)	Pea pods	Faba Bean Hulls
Moisture	6.70 ± 0.17	5.77 ± 0.15
Ash	6.55 ± 0.17	12.40 ± 0.25
Lipids	4.67 ± 0.18	4.80 ± 0.17
Fiber	4.68 ± 0.20	6.50 ± 0.25
Protein	16.36 ± 0.97	9.10 ± 0.70
Carbohydrate	61.04	61.43

Values are the mean of three replicates ±SD.

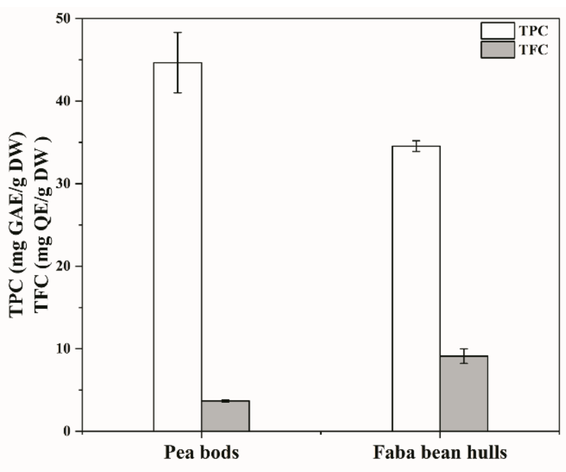

Figure 2: Total phenolic content (TPC) and Total flavonoid content (TFC) of pea pod and faba bean hull.

3.3 *Identification of polyphenol compounds of faba bean hulls and pea pods extract*

Phenolic compounds from the ethanolic extracts of faba bean hulls and pea pods are listed in Table 1. The main phenolic compounds in faba bean hulls extract were Benzoic acid, p-Hydroxy benzoic acid and Rosmarinic acid, while Myricetin and Kaempferol were dominant flavonoids. Meanwhile, the main phenolic compounds in pea pod extract were Resveratrol, Benzoic acid, and p-hydroxy benzoic acid. On the other hand, the only identified flavonoid compounds in pea pods' ethanoic extract were Rutin and Catechin. The most relevant flavonoids found in the pea pod water-based extracts were catechin and epicatechin [5]. Protocatechuic, gentisic and vanillic acids were dominantly found in the colored seed coat peas [8]. In his work, Bello *et al.*, [34] identified several phenolic compounds in pea pods, such as kaempferol, catechin, coumaric acids, caffeic acids, vanillic acids, ferulic, protocatechuic, proanthocyanidin, and tannins.

3.4 *The antioxidant activity of faba bean hulls and pea pod extract*

The antioxidant activity of either faba bean hulls or pea pods was evaluated in vitro using DPPH and FRAP assays (Figure 1). The results illustrated in Figure 1(a) confirm that both pea pods and faba bean hulls exhibited significant scavenging activity against DPPH radical. Generally, DPPH inhibition (%) increased as the extract concentration increased. The faba bean hull extract recorded the highest inhibition percentage (82.24%) at a concentration of 1700 (µg GAE/mL) compared with 68.62% for 2270 (µg GAE /mL) of pea pods extract. Moreover, the same data reveal that the DPPH IC_{50} of pea pods and faba bean hull extracts was 1495.10 and 293.29 (µg GAE /mL), respectively. This finding is consistent with that of kumari and deka [6] who found the DPPH IC_{50} of pea pod extract was 1430 ± 10 (µg GAE /mL). Boudjou *et al.*, [16] reported that the antiradical activity (% inhibition) of faba bean hulls against DPPH radicals was 92%, and they attributed this vigorous antioxidant activity to their high phenolic and tannin contents.

Reducing power assay has been used as an antioxidant ability indicator of phenolic compounds. Data in Figure 1(b) demonstrate that the ethanolic extracts of pea pods and faba bean hulls had the potential reducing power. The faba bean hull extract exhibited higher reducing power than the pea pod extract. The highest reducing power of faba bean hull extract was 2.099 at 345.53 (µg GAE/ml), while pea pod extract had a reducing power of 1.437 at 446.64 (µg GAE/ml). The IC_{50} values of faba bean hulls and pea pod extracts were 57.91 and 127.79 (µg GAE/ml), respectively. Ouis and Hariri [35] found that the highest power activity for reducing iron (1.5 ± 0.3) was obtained at 1000 (µg GAE/mL) of pea pod extract, and its IC_{50} value was 135 ± 0.2 (µg GAE/mL). Fendri *et al.*, [36] reported that the IC_{50} of the methanolic extract of pea pods was 500 (µg GAE/mL), while that of broad bean pods was 90 (µg GAE /mL). They also concluded that the antioxidant activity of studied extracts was not only correlated with the quantity of phenolic compounds but also attributed to a variety of these compounds.

3.5 *Hardness and color parameters of biscuits*

Textural properties of the bakery products, especially their softness/hardness, play a crucial role in consumer acceptance of these product types. These textural properties are analyzed using subjective or objective methods, wherein various approaches were implemented and relied on human senses and different instruments, respectively [37]. As instrumentally determined, the hardness was defined as the maximum force required to penetrate/break the biscuit samples [38]. Despite data listed in Table 4 showing that the hardness of various biscuit samples ranged between 0.81 and 1.07 kgf, incorporating either faba bean hulls or pea pod powder had no significant effect on the hardness of the biscuit samples. These results reflect those of Pooja *et al*., [20] who also found that increasing the pea pod powder content in muffin formulation from 1.91 to 22.09 had an insignificant effect on the hardness of the muffin (from 2015.11 to 2491.25 g).

Color is another key factor that governs consumers' acceptability of any bakery product. The color of bakery products is influenced by several factors, such as the Maillard reaction, added ingredients, and sugar caramelization during baking [20]. Data listed in Table 4 reveals that incorporating either faba bean hulls or pea pods significantly affected the color of produced biscuits. In comparison to the control sample that significantly exhibited the highest L* (lightness) and b* (yellowness) values and lowest a* (redness) values, biscuit samples containing high levels of either faba bean hulls or pea pods significantly exhibited the lowest L* and b* values and highest a* values. These results agree with those obtained by Belghith-Fendri *et al*., [12] who reported that increasing the added pea bod powders levels during preparation of cake decreased its crumb L* values. Results of Kaya *et al*., [21] also confirmed that the redness of the Turkish noodles fortified with faba bean hull powder increased with increasing addition levels.

Sallam *et al*., [32] found that increasing the added level of green pea waste flour during preparation of pound cake decreased its crust L* and a* values. They attributed these reductions in L* and a* values to Maillard and caramelization reactions. In contrast, Pooja *et al*., [20] found that adding pea pod powder during muffin preparation decreased its crumbs a* values. They ascribed this reduction in a* values to added pea pod powder's chlorophyll content.

3.6 *Sensory evaluation of biscuits fortified with pea pods and faba bean hulls powders*

The sensory properties of any food product determine its acceptance. Therefore, various biscuit samples were sensorily evaluated, and the obtained results are listed in Table 5. The most exciting finding was that all biscuit samples containing faba bean hulls at all incorporation levels differed insignificantly (*p-value* > 0.05) from control samples. Indeed, increasing the faba bean hull levels decreased the sensorial characteristic score values; however, these decrements were not significant (*p-value* > 0.05). On the other hand, except for taste scores, all biscuit samples containing pea pod powder exhibited lower significant ($p < 0.05$) sensorial characteristic scores than those of control samples. In his work, Chockchaisawasdee *et. al*., [39] found that faba bean husk-enriched bread exhibited sensorial characteristics similar to control, except for texture. The obtained findings reflected the acceptance index (AI) of various biscuit samples. Adding pea pod powder at levels of 2.5 and 10% decreased the AI to lower than 70%, which is considered as a determinant AI level to differentiate between acceptable and nonacceptable products [32].

3.7 *Rheological characteristics of wheat-waste powder composite flour dough using Mixolab®*

The literature is rich with studies that have been conducted to show the influence of flour properties as measured by the Mixolab® device on the quality properties of bakery products [31], [40]–[43]. Therefore, the rheological properties of wheat flour containing various levels of either pea pods or faba bean hull powder and wheat flour without any replacement were measured using Mixolab (Table 6). C_1 is the maximum torque required to obtain an adequate consistency dough. It is used to assess water absorption. C_2 measures dough weakening due to mechanical work and increasing temperature. C_3 expresses starch gelatinization during the heating stage. C_4 indicates the stability of the hot-formed gel.

C_5 indicates starch retrogradation or re-ordering of starch molecules during the cooling phase. The correlation between the hardness and texture of various biscuit samples and the flour characteristics measured by Mixolab is illustrated in Figure 3.

Data in Table 6 reveal that as the incorporation percentage of either pea pods or faba bean hulls increased, so did the water absorption percentage and dough development time (DDT). These results align with Yağcı [43], who found that adding barley, wheat bran, Oats and bulgur to flour at 10% increased its water absorption percentage. This increase in water absorption percentage was attributed to the high content of investigated materials from dietary fibers, protein, and damaged starch from pulverization. Rasper and Walker [44] reported that gluten characteristics, flour particle size, and protein significantly influenced DDT. In contrast to the preceding results, dough stability time was decreased as the incorporation level of either faba bean hulls or pea pods was increased. These results are consistent with those of Zhang *et al.*, [45], who found that adding yellow or green pea flour significantly decreased the dough stability time. The decrement in dough stability could be ascribed to gluten dilution [32].

Table 4: Hardness and color parameters (L*, a* and b*) values of various biscuit samples.

Samples	Hardness (kg_f)	L*	a*	b*
Control	$0.81^a \pm 0.09$	$69.13^a \pm 0.22$	$5.09^d \pm 0.22$	$33.31^a \pm 0.45$
T1	$1.02^a \pm 0.05$	$62.30^b \pm 0.87$	$7.07^b \pm 0.11$	$27.25^b \pm 0.28$
T2	$1.04^a \pm 0.11$	$61.40^b \pm 0.12$	$8.13^a \pm 0.60$	$27.54^b \pm 0.28$
T3	$1.07^a \pm 0.15$	$59.41^c \pm 0.38$	$8.66^a \pm 0.10$	$25.16^c \pm 0.64$
T4	$0.81^a \pm 0.11$	$62.50^b \pm 0.44$	$5.41^{cd} \pm 0.31$	$27.29^b \pm 1.2$
T5	$0.89^a \pm 0.17$	$57.21^d \pm 0.90$	$5.81^{cd} \pm 0.27$	$22.91^d \pm 0.05$
T6	$0.92^a \pm 0.18$	$53.45^e \pm 0.68$	$6.22^c \pm 0.09$	$19.25^e \pm 1.1$

Control: Wheat flour 100%, T1, T2, and T3: Biscuits with 2.5, 5, and 10% faba bean hulls, respectively, T4, T5, T6: Biscuits with 2.5, 5, and 10% pea pods, respectively. Values are mean of three replicates ±SD. Means followed by different superscripts within the same column are significantly different at 0.05 level.

Table 5: Sensory attributes of various biscuit samples

Samples	Color	Texture	Odor	Taste	Overall	AI
Control	$9.6^a \pm 1.63$	$9.3^a \pm 2.25$	$9.4^a \pm 1.47$	$9.6^a \pm 0.47$	$9.5^a \pm 2$	$95^a \pm 20$
T1	$8.8^{ab} \pm 1.22$	$9.2^{ab} \pm 1.96$	$9.2^a \pm 2.19$	$9.2^{ab} \pm 2.19$	$9.2^{ab} \pm 2.04$	$92^{ab} \pm 20.4$
T2	$8.6^{abc} \pm 0.98$	$8.4^{abc} \pm 0.98$	$9.0^a \pm 0.8$	$8.8^{ab} \pm 0.80$	$8.3^{ab} \pm 0.81$	$83^{ab} \pm 8.1$
T3	$7.8^{abc} \pm 0.98$	$8.2^{abc} \pm 0.98$	$8.2^{ab} \pm 0.98$	$8.0^{ab} \pm 0.98$	$7.7^{ab} \pm 0.81$	$77^{ab} \pm 8.1$
T4	$6.8^{bc} \pm 0.98$	$6.6^c \pm 0.98$	$8.2^{ab} \pm 0.98$	$8.6^{ab} \pm 0.98$	$6.7^b \pm 0.81$	$67^b \pm 8.1$
T5	$6.6^c \pm 0.98$	$7.0^{bc} \pm 0.98$	$7.2^b \pm 0.98$	$8.6^{ab} \pm 0.98$	$7.8^{ab} \pm 0.81$	$78^{ab} \pm 8.1$
T6	$6.6^c \pm 0.98$	$7.0^{bc} \pm 0.98$	$7.6^b \pm 0.98$	$8.2^{ab} \pm 0.98$	$6.6^b \pm 0.81$	$66^b \pm 8.1$

Control: Wheat flour 100%, T1, T2, and T3: Biscuits with 2.5, 5, and 10% faba bean hulls, respectively, T4, T5, T6: Biscuits with 2.5, 5, and 10% pea pods, respectively. Values are mean of three replicates ±SD. Means followed by different superscripts within the same column are significantly different at 0.05 level.

Table 6: Rheological characteristics of various composite wheat-waste powder dough samples

Treatment	Water Absorption (%)	DDT (min)	Torque (Nm)					Stability (min)
			C_1	C_2	C_3	C_4	C_5	
Control	55.13	5.24	1.06	0.53	1.84	1.89	2.83	8.30
T1	54.98	5.32	1.05	0.59	1.73	1.63	2.64	6.32
T2	56.23	6.23	1.07	0.67	1.68	1.57	2.45	6.02
T3	58.38	6.83	1.08	0.69	1.61	1.51	2.41	5.56
T4	55.23	6.13	1.06	0.54	1.76	1.73	2.74	7.23
T5	58.89	6.67	1.07	0.59	1.74	1.69	2.71	6.98
T6	62.23	7.23	1.08	0.62	1.70	1.66	2.64	6.51

Control: Wheat flour 100%, T1, T2, and T3: Biscuits with 2.5, 5, and 10% faba bean hulls, respectively, T4, T5, T6: Biscuits with 2.5, 5, and 10% pea pods, respectively.

In this context, it could be noted that (Figure 3) the dough stability time is significantly (*p-value* < 0.0038) and negatively ($r = -0.9151$) correlated to biscuits hardness. These results reveal that low dough stability, which is associated with high incorporation levels of waste powder, led to harder biscuits. Moreover, it could be observed that wheat dough incorporated with pea pods generally exhibited higher water absorption, DDT, and stability than those exhibited by wheat doughs containing faba bean hulls. These increases could be attributed to the high protein content of pea pods (Table 3).

Data in Table 6 show also that the Mixolab C_2 parameter increased as incorporation levels increased indicating that increasing the addition percentages of either pea pods or faba bean hulls leads to stronger doughs. Moreover, the correlation between biscuit hardness and Mixolab C_2 parameter (Figure 3) was significant (*p-value* < 0.0069) and positive (r = 0.8925), indicating that increasing the incorporation percentage of waste powder resulted in harder biscuits. Furthermore, Mixolab C_3, C_4, and C_5 parameters were decreased as the incorporation percentage of either pea pods or faba bean hulls increased. This indicates that increasing the added levels of either faba bean hulls and pea pods powder decreased the paste viscosity, hot gel stability, and starch retrogradation of various investigated dough samples, respectively.

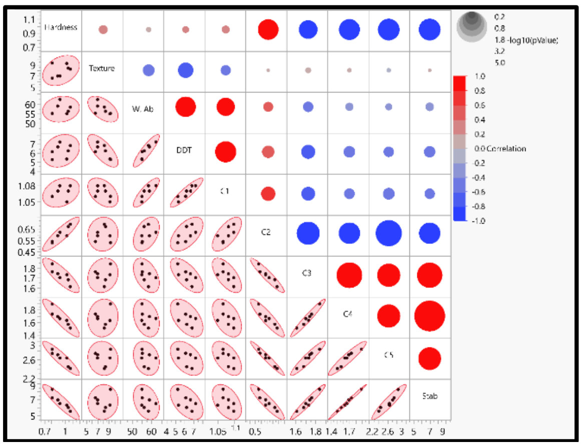

Figure 3: Correlation between the biscuit hardness, biscuit texture, water absorption percentage (W. Ab), dough development time (DDT), dough stability time (Stab) and Mixolab C_1, C_2, C_3, C_4, C_5 parameters [The lower triangular represents the scatter plot and the upper triangular represents the significant circles].

Sallam *et al*., [32] found that wheat flour dough containing 10% green pea waste flour exhibited lower Mixolab C_3, C_4, and C_5 parameters in comparison to control one (did not contain green pea waste flour). The correlations between Mixolab C_3, C_4, and C_5 parameters and biscuit hardness were significant (*p-value* < 0.0179, 0.0058, and 0.0040, respectively) and negative (r = –0.8404, –0.8993, and –0.9139, respectively). These results show the influence of the additional levels of investigated powders on Mixolab parameters of composite wheat-powder flour and, consequently, the quality of produced biscuits.

4 Conclusions

This study examined the impact of the incorporation level of either pea pods and faba bean hull powder on biscuits' color, hardness, and sensory characteristics. Also, the influence of these incorporation levels on Mixolab parameters of the composite flour (wheat flour and either pea bods and faba bean hulls powder) and their correlation to biscuit hardness and texture was determined. Before mixing wheat flour with either pea pods or faba bean hull powder, their nutritional benefits were evaluated regarding chemical composition, polyphenols content, and antioxidant activity. The total phenolic content of faba bean hulls and pea pods were 34.55 ± 0.65 and 44.66 ± 3.65 (mg GAE/g DW), while their scavenging activities against DPPH radicals in terms of IC_{50} were 283.29 and 1495.09 (µg GAE/mL), respectively. The incorporation of either pea pods or faba bean hulls insignificantly affected biscuit hardness; however, the biscuit color parameters were significantly altered, especially at high incorporation levels. These alterations in biscuit properties are reflected in consumer acceptance, as biscuits with high incorporation levels exhibited the lowest overall acceptability scores and acceptance indexes. Water absorption percentage and dough development time were increased, whereas the dough stability time was decreased as incorporation level increased. Mixolab parameters of various investigated doughs significantly correlated with biscuit hardness. In general, therefore, it seems that adding the powder of either faba bean hulls or pea pods to the biscuit formulations enriches the nutritional quality of the biscuit. This nutritional enhancement relies on the incorporation level of these powders and their combined nutrients; however, the results showed that increasing the incorporation level negatively affected the quality attributes of the biscuits. Hence, the highest incorporation level with an acceptance index above 70 was chosen to determine the best biscuit formulation. The biscuit formulation containing faba bean hulls with an incorporation level of 10% was chosen as the best formulations as it meets the specified criterion. The study results open the door for future utilizing of either faba bean hulls or pea pods powder to fortify biscuits or other food products specifically, as they are cheap, and their preparation is simple.

Author Contributions

S.S.S.: conceptualization, investigation, data curation, reviewing and editing; A.E.A.: data analysis, writing an original draft and reviewing; H.K.S.M.: investigation, methodology, data analysis, writing an original draft and reviewing. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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