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Ginger (*Zingiber officinale* Roscoe): A potential source of fibre and antioxidant, and its effect on rheological characteristics of soft wheat dough, and physicochemical properties of cookies

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Abstract

Ginger is the fresh rhizome of the ginger plant (*Zingiber officinale* Roscoe), and known to have various health benefits including anti-inflammatory, antioxidant, anti-bacterial, hypoglycaemic, and gastrointestinal-protecting effects. In the present work, the effects of partially substituting soft wheat flour with ginger powder (GP) on the rheological characteristics of dough, and physicochemical properties of cookies were investigated. Results illustrated that partial substitution with GP had significant impact on rheological properties of soft wheat dough, especially at 4% or higher; the development time, energy, and resistance to extension of the dough were significantly different from the control ($p < 0.05$). LF-NMR measurements indicated that the mobility and distribution of immobilised water influenced gluten strength, and dough stability. Sensory evaluation by panellists indicated that cookies incorporated with up to 2% GP were acceptable. Moreover, cookies prepared with incorporation of 2% GP had 1.60 ± 0.06 g/100 g crude fibres, 0.92 ± 0.05 mg/g total phenolics, 1.11 ± 0.01 mg/g total flavonoids, and 13.97 ± 0.04% $ABTS^+$ radical scavenging activity, all of which were significantly different from the control ($p < 0.05$). Overall, the results supported the potential application of GP in cookies as a functional food ingredient.

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Introduction

Cookies are a commonplace bakery product popular among all age groups globally (Yang *et al*., 2020). Typically, they are made from soft wheat flour which has soft kernel texture and low protein content (Ma and Baik, 2018). While cookies have various advantages such as being cost efficient, having various flavours, and possessing long shelf life, they are considered to provide only 'empty calories' rather than nutrition because of their lack of fibres, proteins, vitamins, and minerals (Bolek, 2020). In recent years, researchers have attempted to diversify cookies, by enhancing their nutritional value and health benefits through the addition of functional ingredients. For example, hog plum bagasse was found to increase the total phenolic and fibre contents of cookies, as well as improve their antioxidant activity when consumed (Oladunjoye *et al*., 2021); burdock root flour was identified as an effective prebiotic substitute to flour, significantly increasing the total dietary fibre and fructooligosaccharide contents in cookies (Moro *et al*., 2018); Bolek (2020) also demonstrated that replacing up to 15% of wheat flour with high-fibre olive stone powder could increase antioxidant properties, as well as fat and fibre contents of cookies without negatively affecting their sensory evaluation.

Culinary ginger is the fresh rhizome of the perennial herbaceous plant *Zingiber officinale* Roscoe from the family Zingiberaceae, originating in tropical areas of Southeast Asia. It is known to contain various biologically active compounds, of which monoterpenes, sesquiterpenes, diphenylheptanes, phenolics, and flavonoids; have various health benefits, including anti-inflammatory, antioxidant, anti-bacterial, blood-sugar-reducing, and gastrointestinal-protecting effects (Si *et al*., 2018). The ginger residue is a by-product of commercial processes that crush the rhizome of ginger to extract juices, which still contains a variety of functional

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components. Due to the high moisture content in ginger residue, it is difficult to preserve, thus often discarded. How to effectively utilise the ginger residue is of great significance for improving the utilisation value and resource utilisation rate of the ginger residue. Recently, ginger residue has been reported to be used in the preparation of products such as ginger residue brandy (Chu *et al*., 2021) and spent ginger yeast cultures (Liu *et al*., 2022). On the other hand, drying and crushing ginger residue and preparing it into ginger powder is expected to be a food ingredient with functional components. At present, information on the application of ginger powder in pre-packaged snack foods such as cookies remains limited. Also, the addition of new ingredients can change the characteristics of the dough, and affect the quality of the baked product. For instance, Khoozani *et al*. (2020) discovered that replacing wheat flour with whole green banana flour could increase the viscoelasticity of the dough, which made bread denser, harder, and chewier. Li *et al*. (2012) reported that adding purple yam powder to wheat flour decreased the agitation stability and extensibility of the dough, resulting in a significant increase in the cooking loss of salted noodles. Sharma *et al*. (2013) added *Tinospora* leaf powder to wheat flour, and found that the stability, cohesiveness, and springiness of the dough all decreased, and those changes also resulted in decreased spread ratio and increased breaking strength of the cookies.

Based on these premises, the present work aimed to evaluate how the partial substitution of soft wheat flour with powdered ginger may affect the rheology, pasting properties, water mobility, and microstructure of dough, as well as the physicochemical characteristics and sensory evaluation of cookies.

Materials and methods

Materials

Soft wheat flour and other baking ingredients were purchased from local supermarkets (Tai'an, China). Ginger residue was obtained from Shandong Qingzhou Yijiakang Food Company (Qingzhou, China). The ginger residue was spread evenly on a tray, and baked in an oven at 60°C for 24 h. The dried ginger residue was crushed in batches in a high-speed grinder (DE-100, Rhodiola, Zhejiang, China) into ginger powder (GP), and then collected and passed through a 100-mesh sieve (0.150 mm). The composition of soft wheat flour and GP was as follows: 100 g of soft wheat flour contained 12.7 g of moisture, 8.5 g of protein, 74.6 g of starch, and 1.2 g of dietary fibre; 100 g of GP contained 9.4 g of moisture, 7.68 g of protein, 4.00 g of fat, 15.75 g of crude fibre, 39.50 g of starch, and 5.23 g of ash; 1 g of GP contained 25.44 mg of total phenolics and 21.99 mg of total flavonoids. All chemical reagents used were of analytical or HPLC grade, and obtained from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China).

Preparation of cookies

Cookies were prepared following a generic recipe: per 100 g of soft wheat flour, 20.0 g sugar, 16.0 g vegetable oil, 6.0 g whole milk powder, 1.0 g salt, 0.5 g baking soda, 15.0 g egg liquid, and 20.0 g water were used. The baking ingredients were first mixed and then added to flour mixes with different proportions of ginger powder. For the control, 100% soft wheat flour was used, whereas different proportions were substituted with ginger powder (1.0, 2.0, 4.0, 6.0, and 8.0%) in the treatment groups. The ingredients were mixed using a stirrer until dough formed, then, a tablet press (JMTD-168/140, Beijing Dongfu Jiuheng Instrument, China) was used to roll the formed dough three times, with folding and rotating 90° in between, and finally the dough was pressed to 3 mm in thickness. The dough pieces were cut out with a rectangular mould (2 × 3 cm), and baked at 180°C for 10 min to make cookies, which were then cooled to room temperature (25°C), and packaged in sealed polyethylene bags for further analyses.

Analysis of dough

Farinograph properties

The farinograph properties of dough were determined using a farinograph (JFZD, Beijing Dongfu Jiuheng Instrument, China) with a 300 g kneading bowl following AACC method 54-21.02 (AACC, 2000). Briefly, the temperature of the kneading bowl was controlled at 30°C, and then the flour blend (300 g, 14% moisture), sodium chloride (6 g), and a certain amount of water were added to produce dough samples with a consistency of 500 BU (Brabender units). The parameters obtained were the percentage of water to yield consistency of 500 BU (water absorption), time to reach up to 500 BU (development time), and time that dough remained at a consistency of 500 BU (stability time).

Extensograph properties

Dough samples were prepared as specified in farinograph test, and formed into a uniform cylinder before being placed in the waking chamber of an extensograph (JMLD150, Beijing Dongfu Jiuheng Instrument, China) at 30°C for 45 min. Energy value (area under the curve, cm^2), resistance to extension (R, BU), dough extensibility (E, mm), and R/E ratio (BU/mm) were determined following AACC method 54-10.01 (AACC, 2000).

Low-field nuclear magnetic resonance (LF-NMR)

To evaluate the effect of ginger powder substitution on water mobility and distribution in the dough, transverse relaxation time (T_2) was recorded using an LF-NMR (NMI20-015V-1, Niumag Electronics Technology, Shanghai, China) equipped with a 60 mm probe. Dough samples (1.0 g) were placed in LF-NMR tubes, which were then sealed to prevent moisture loss. The relaxation curves were acquired using a Carr-Purcell-Meiboom-Gill (CPMG) pulse sequence. Data from 2,000 echoes were obtained through 16 scan repetitions. The repetition time between two successive scans was 1 s (Peng *et al*., 2017; Yang *et al*., 2020).

Scanning electron microscopy (SEM)

The dough was freeze-dried using a freeze-drier (SCIENTZ-10N, SCIENTZ, China). Microstructure of the dough was observed using a scanning electron microscope Sigma 300 (ZEISS, Germany). Freeze-dried samples were cut into cubes with dimensions of 1 × 1 × 1 cm. Cubes were separately secured onto the sample holder using double-sided scotch tape, and then coated with gold. Finally, the samples were transferred to the microscope where they were observed at an accelerating voltage of 5 kV.

Analysis of cookies

Nutritional analysis

Nutritional analysis of cookies was conducted following the standard methods of analysis (AOAC, 2005). The moisture, protein (conversion factor: 6.25), fat, and crude fibre contents were assessed.

Colour measurement

The colour parameters (CIE L* a* b*) of the cookies were determined using a colorimeter (Chroma meter CR-400, Konica Minolta, USA). L* defines lightness, and its values range from 0 (black) to 100 (white), while a* and b* denote green (-a) to red (+a) and blue (-b) to yellow (+b), respectively.

Texture and density analyses

Hardness was determined using a texture analyser (TA-XT2i, Stable Micro Systems, UK) with three-point bending rig (HDP/3PB). 5 g trigger force and 25 kg load cell were used. The tests were conducted by first placing the cookie on two supporting beams spaced 30 mm apart, with a pre-test speed of 1.0 mm/s, a test speed of 2.0 mm/s, a post-test speed of 5.0 mm/s, and a distance of 5 mm. Analysis was performed on ten cookies for each group. Hardness was defined as the maximum peak force. The resistance to bend, which is related to fracturability, was defined as the distance at the point of break. The densities of cookies were measured according to the method described by Sulieman *et al*. (2019).

Total phenolic content

The TPC was determined using the Folin-Ciocalteu method as described by Wu *et al*. (2021), and expressed as mg of gallic acid equivalent (GAE) per g of sample. Briefly, 1 mL of the extract, 1 mL of 10% Folin, and 4 mL of 75% (w/v) sodium carbonate solution were mixed, and the total volume was adjusted to 10 mL with distilled water. The mixture was kept in a water bath at 75°C for 10 min, after which the absorption was read using a spectrophotometer (UV755B, Shanghai Youke Instrument, China) at 765 nm wavelength. A calibration curve was established using the gallic acid standard solution (y = 0.9140x + 0.0026; R^2 = 0.9998).

Total flavonoid content

The TFC was determined using methods slightly modified from those by Wu *et al*. (2021), and expressed as mg of rutin equivalents (RE) per g of sample. Briefly, 0.3 mL of 5% (w/v) sodium nitrate was mixed with 2 mL of the extract. After 6 min, 0.3 mL of 10% (w/v) aluminium nitrate solution was added to the mixture. After another 6 min, 4.0 mL 4% (w/v) sodium hydroxide solution was added, and then 60% ethanol solution was added until the total volume reached 10 mL. After 15 min, absorption was read using a spectrophotometer at the wavelength of 510 nm. A calibration curve was constructed using the rutin standard solution (y = 0.9168x - 0.0065; R^2 = 0.9995).

Antioxidant capacity

The DPPH free radical clearance rate was analysed according to methods modified from Oladunjoye *et al*. (2021). Briefly, 2 mL of DPPH ethanol solution (100 μM) was mixed with 200 μL of extract, and then the mixture was incubated at ambient temperature in the dark. After 30 min, the absorbance of the mixture was measured using a spectrophotometer at a wavelength of 517 nm.

The $ABTS^+$ free radical clearance rate was determined according to methods described by Sladana *et al*. (2016). Firstly, the same amount of ABTS (7 mmol/L) solution and potassium persulfate solution (2.45 mmol/L) were mixed and kept in the dark for 12~16 h at room temperature to prepare the $ABTS^{+}•$ solution. The absorbance of the $ABTS^{+}•$ solution at 734 nm was determined to be 0.70 ± 0.02 when the solution was diluted with anhydrous ethanol. Then, 5 mL of the diluted $ABTS^{+}•$ solution was mixed with 50 μL of the extract, and the absorbance was measured at 734 nm after reaction for 20 min at room temperature in the dark. Antioxidant activity was expressed as percent capacity of scavenging the DPPH and ABTS radical using Eq. 1:

$$scavenging\ rate(\%) = 1 - \frac{A_1 - A_2}{A_O} \times 100 \quad \text{(Eq. 1)}$$

where, A_0 = absorbance of the control reaction, A_1 = absorbance of the test samples, and A_2 = absorbance of the sample itself.

Sensory evaluation

Cookies were subjected to sensory evaluation by 11 semi-trained panellists selected from within the university community. Cookie samples were served at room temperature on white paper plates, and white fluorescent lights were used to illuminate the sensory booth. Purified water was provided to rinse the mouth between samples. During testing, each panellist received six coded cookie samples, and had no prior information about the coded test products. The ratings were given on a 9-point hedonic scale ranging from 9 (like extremely) to 1 (dislike extremely), following methods described by Meilgaard *et al*. (2016). Cookies were evaluated for their appearance, colour, taste, texture, and overall acceptability.

Statistical analysis

All results were expressed as mean ± standard deviation. IBM SPSS Statistics 25 software was used for One-way analysis of variance (ANOVA) and multiple comparisons (LSD test). The differences of experimental results were considered to be significant at 95% confidence level ($p < 0.05$). The mean values of at least three replicates were reported.

Results and discussion

Farinograph and extensograph properties

The influence of ginger powder (GP) on farinograph and extensograph properties in soft wheat flour is presented in Table 1. Partial substitution with GP increased the water absorption capacity of cookies in a dose-dependent manner. This result could be related to the existence of higher amounts of fibres in GP, which contain a large number of hydroxyl groups, and are more likely to interact with water molecules to form hydrogen bonds (Sudha *et al*., 2007). Our results were consistent with those obtained by Pourabedin *et al*. (2017) who determined that the addition of fibre sources increased the water absorption capacity of dough. When GP was substituted at 4% or higher, it was observed that the development time of the dough was all dramatically prolonged to more than 5 min, which was significantly different from that of the control (1.6 min), whereas the development time of the 1 and 2% substituted dough was not significantly different from that of the control. These results may be attributed to the high substitution levels of GP limiting the water absorption of soft wheat flour, which negatively affected protein hydration, and led to prolonged dough development time. In addition, the stabilisation time increased drastically in GP-mixed dough, peaking at 5.3 min in 1% substituted dough compared to 1.5 min in the control. With further increases in GP substitution, stabilisation time gradually decreased, but stabilisation time in all treatment groups was longer than that of the control. These phenomena could be attributed to how small particles introduced from GP could fill the matrix in gluten network structures, thus stabilising them (Zhou *et al*., 2021). On the other hand, at higher concentrations, GP also diluted the glutenin in soft wheat flour, which reduced the formation of gluten during the kneading process, thus resulting in a decreased stabilisation time (Meng *et al*., 2019).

Extensograph properties reflect the elasticity, plasticity, and gas holding capacity of dough. As shown in Table 1, the values of energy, resistance to extension, and R/E ratio exhibited a similar trend of variation. More specifically, values peaked at 1%

substitution of GP (58 cm^2, 456 BU, and 4.9 BU/mm, respectively), and were higher ($p < 0.05$) than the control (55 cm^2, 358 BU, and 3.5 BU/mm), then began to decrease with further GP substitution. When GP addition exceeded 4%, the energy, resistance to extension, and R/E ratio significantly decreased compared to the control ($p < 0.05$). These results suggested that high amounts of GP (≥ 4%) would weaken the gluten strength, thus decreasing elasticity and gas holding capacity of the dough. This phenomenon has also been observed when olive stone powder was added to wheat flour (Bolek, 2020). In contrast to other properties, there was no significant difference in extensibility between the GP-mixed dough and the control, indicating that the addition of GP had little effect on the plasticity of the dough (Li *et al*., 2020).

Table 1. Effects of ginger powder substitution on farinograph and extensograph properties of dough.

Substitution level	Farinograph			Extensograph[1]			
	Water absorption (%)	Development time (min)	Stabilisation time (min)	Energy (cm^2)	Extensibility (mm)	Resistance to extension (BU)	Ratio R/E (BU/mm)
0%	57.0 ± 0.1^d	1.6 ± 0.0^c	1.5 ± 0.1^d	55 ± 3^a	102 ± 2^{abc}	358 ± 9^b	3.5 ± 0.0^b
1%	57.5 ± 0.1^c	1.4 ± 0.1^c	5.3 ± 0.1^a	58 ± 6^a	99 ± 5^{bc}	456 ± 9^a	4.9 ± 0.4^a
2%	57.6 ± 0.2^c	1.5 ± 0.0^c	4.8 ± 0.1^b	50 ± 1^a	98 ± 1^c	373 ± 2^b	3.8 ± 0.1^b
4%	58.3 ± 0.1^b	5.1 ± 0.0^b	4.7 ± 0.2^b	40 ± 0^b	110 ± 4^{abc}	288 ± 5^c	2.7 ± 0.2^c
6%	58.6 ± 0.1^b	5.3 ± 0.1^{ab}	4.5 ± 0.1^b	28 ± 2^c	112 ± 3^{ab}	177 ± 11^d	1.6 ± 0.1^d
8%	59.3 ± 0.3^a	5.5 ± 0.1^a	3.5 ± 0.1^c	22 ± 2^c	113 ± 7^a	135 ± 8^e	1.2 ± 0.0^d

[1]Extensograph results after 45 min. Means within a row followed by different lowercase superscripts are significantly different ($p < 0.05$).

Water mobility and distribution in doughs

LF-NMR is a widely applied method that estimates the water mobility in food by measuring transverse relaxation time (T_2), and expressing the relative water content in each part as peak area. The distribution of T_2 values from soft wheat dough at different GP substitution levels is shown in Figure 1. The three peaks, T_{21} (0.1 - 2 ms), T_{22} (2 - 60 ms), and T_{23} (60 - 230 ms) represent bound water, immobilised water, and free water, respectively.

It was found that the addition of GP had no significant effect on bound water, while for immobilised water, the relaxation time (T_{22}) decreased significantly when more than 4.0% GP was added. In wheat dough, T_{22} is interpreted as water on starch granule surfaces or surrounding gluten strands (Lu and Seetharaman, 2013). The decrease in T_{22} implies decreased water availability to gluten matrices and weakened gluten strength (Xiong *et al*., 2017). Moreover, the peak area (A_{22}) increased when GP was substituted at 1 and 2%, but decreased with further substitutions. The decrease in A22 indicated that there was less water distributed across the hydration sites on the gluten and starch surfaces, resulting in a reduction in dough stability (Li *et al*., 2020). These results were consistent with the observed changes in farinograph and extensograph properties.

In addition, T_{23} values significantly decreased, whereas A_{23} significantly increased with increasing GP substitution. These results demonstrated that while GP introduced more free water, it also reduced the mobility of free water. We speculate that this might be due to GP having stronger interactions with water molecules compared to gluten, resulting in the release of water surrounding gluten strands (immobilised water) into free water. On the other hand, GP substitution resulted in the diluting of gluten and starch, which decreased the number of water molecules around them. Yu *et al*. (2019) also previously reported that free water has a crucial influence on the processing characteristics of dough, and the texture of baked products.

To summarise, LF-NMR results suggested that substitution of soft wheat flour with GP mainly caused the migration of immobilised water into free water in the dough. Changes in the mobility and distribution of immobilised water then influenced gluten strength, and the stability of the dough.

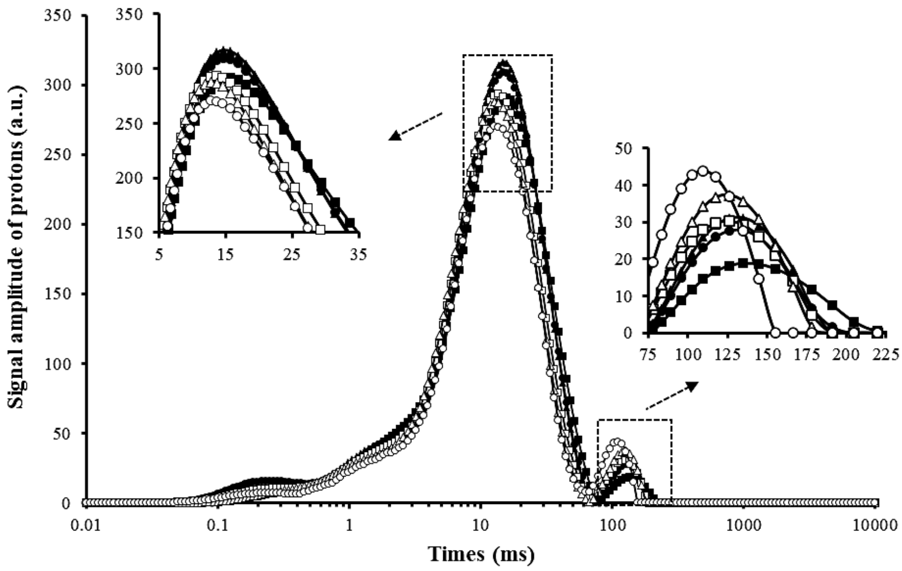

Figure 1. Transverse relaxation time (T_2) in dough mixtures with different amounts of ginger powder substitution (■: 0.0%; ▲: 1.0%; ●: 2.0%; □: 4.0%; △: 6.0%; and ○: 8.0%).

Microstructure of doughs

The microstructure images of dough with different GP contents are shown in Figure 2. The small and large starch granules of soft wheat dough (control) were surrounded by continuous and compact gluten network structures (Figure 2a), which were similar to previous findings (Torbica *et al*., 2012). Substitution with GP at 1% did not appear to significantly influence the gluten network, and caused formation of a denser network structure similar to that in the control (Figure 2b). With further substitution with GP (Figures 2c and 2d), dough samples began to bear holes, suggesting a reduced gas holding capacity, but gluten-starch networks still formed. However, dough samples with GP contents of 6 and 8% were characterised by discontinuous gluten structures, containing larger holes, and had loosely distributed starch granules that were not wrapped into the gluten network (Figures 2e and 2f). This might have been due to the large size and unevenness of GP granules. Moreover, the reduced gluten protein, and the addition of crude fibre from GP reduced the continuity and integrity of the gluten network, which increased the difficulty of forming a continuous gluten skeleton (Cao *et al*., 2019). SEM imaging supported this explanation, showing that the GP substitution weakened interactions between gluten and starch matrices, and revealing the reason for the decrease in gluten strength and gas holding capacity of the dough as described earlier.

Physicochemical characteristics of cookies

The physicochemical properties of the cookies are shown in Table 2. Substitution with GP decreased the lightness (L*) while increasing yellowness (b*) of the cookies, as visible in Figure 3. Several reasons could have contributed to this change: Firstly, the oxidation reaction of phenolics in GP produced quinones which might have caused the colour of cookies to darken (Jan *et al*., 2016); Secondly, the increased reducing sugar from GP might have contributed to browning through Maillard reactions during baking (Usman *et al*., 2020); Furthermore, increased yellowness in the cookies could have been attributed to an increase in curcumin which was found in GP.

Generally speaking, the moisture content of cookies, which is affected by the water absorption properties of the dough (Bolek, 2020), should be limited (< 5%) in order to extend shelf life (Cauvain and Young, 2008). In the present work, the moisture content of cookies increased from 3.26 to 3.84% with increasing levels of GP substitution, and was consistent with the change trends of dough water absorption as expected (Table 1). The hardness of the GP-mixed cookies ranged from 2713 to 1346 g when GP was substituted at 2~8%, significantly lower than that of the control group (3083 g). The fracturability of the cookies was also significantly lower than that of the control (0.35 mm), reaching 0.28 and 0.26 mm, respectively, when 6 and 8% GP substitution were

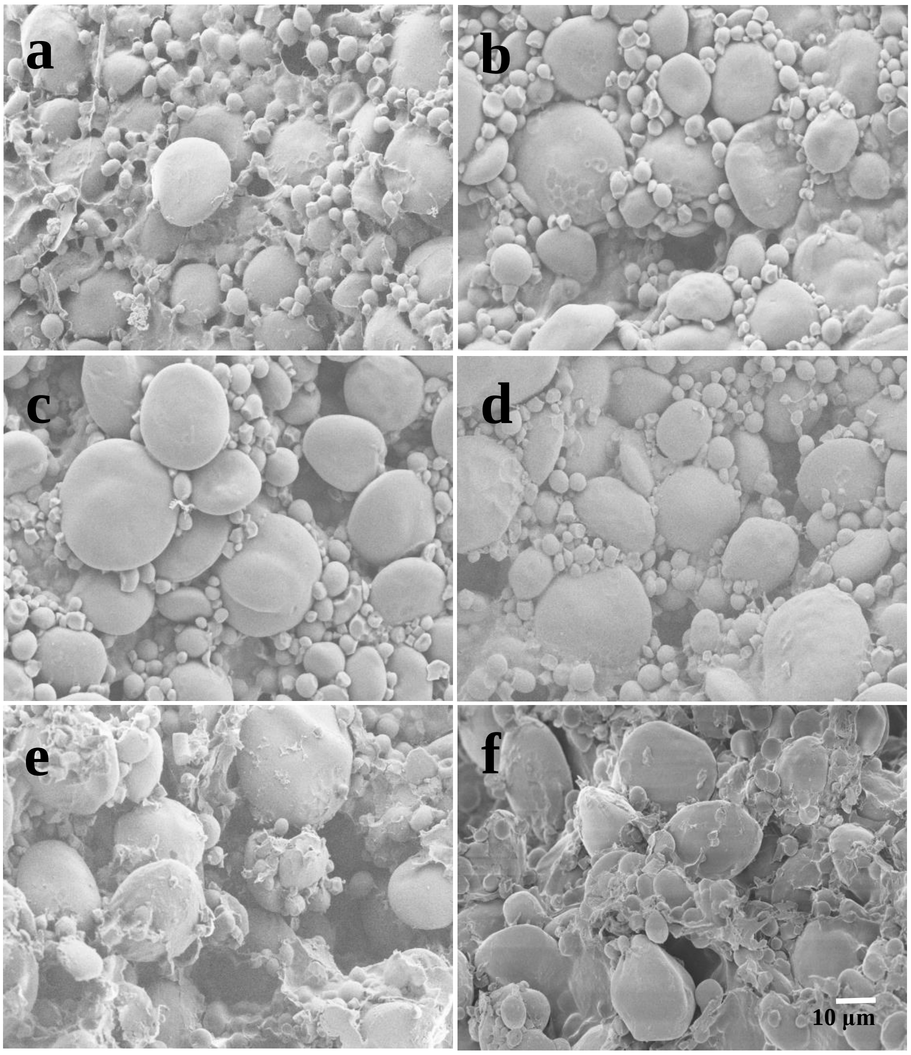

Figure 2. Scanning electron microscopy of dough with different amounts of ginger powder substitution (a: 0.0%; b: 1.0%; c: 2.0%; d: 4.0%; e: 6.0%; and f: 8.0%).

Table 2. Physicochemical parameters of cookies with different proportions of ginger powder substitution.

Substitution level	**0%**	**1%**	**2%**	**4%**	**6%**	**8%**
Moisture (%)	3.26 ± 0.00^{c}	3.40 ± 0.07^{bc}	3.53 ± 0.17^{b}	3.54 ± 0.02^{b}	3.82 ± 0.05^{a}	3.84 ± 0.10^{a}
Protein (g/100 g)	11.18 ± 0.02^{a}	11.14 ± 0.03^{a}	11.25 ± 0.04^{a}	11.21 ± 0.08^{a}	11.17 ± 0.07^{a}	11.14 ± 0.04^{a}
Fat (g/100 g)	18.93 ± 0.50^{a}	18.64 ± 0.35^{a}	19.92 ± 0.30^{a}	19.13 ± 0.70^{a}	18.97 ± 0.78^{a}	19.35 ± 0.98^{a}
Crude fibre (g/100 g)	1.37 ± 0.04^{d}	1.41 ± 0.05^{d}	1.60 ± 0.06^{c}	1.89 ± 0.07^{b}	1.97 ± 0.03^{b}	2.21 ± 0.03^{a}
TPC (GAE mg/g)	0.84 ± 0.00^{e}	0.86 ± 0.01^{e}	0.92 ± 0.05^{d}	1.16 ± 0.00^{c}	1.23 ± 0.00^{b}	1.32 ± 0.00^{a}
TFC (RE mg/g)	0.83 ± 0.02^{e}	0.81 ± 0.01^{e}	1.11 ± 0.01^{d}	1.25 ± 0.09^{c}	1.37 ± 0.02^{b}	1.77 ± 0.00^{a}
DPPH• (%)	8.20 ± 0.12^{d}	8.92 ± 0.03^{d}	9.17 ± 0.07^{d}	11.11 ± 0.04^{c}	14.16 ± 0.66^{b}	17.45 ± 0.34^{a}
$ABTS^{+}$• (%)	9.93 ± 0.28^{f}	11.44 ± 0.10^{e}	13.97 ± 0.04^{d}	15.37 ± 0.10^{c}	17.60 ± 0.18^{b}	20.61 ± 0.38^{a}
Density (cm^3/g)	1.19 ± 0.01^{a}	1.19 ± 0.02^{a}	1.17 ± 0.01^{ab}	1.15 ± 0.00^{b}	1.15 ± 0.00^{b}	1.12 ± 0.01^{c}
Hardness (g)	3083.12 ± 17.64^{a}	2932.87 ± 71.37^{a}	2712.84 ± 66.32^{b}	2220.39 ± 88.74^{c}	1759.83 ± 86.92^{d}	1346.30 ± 79.25^{e}
Fracturability (mm)	0.35 ± 0.03^{a}	0.31 ± 0.02^{ab}	0.30 ± 0.05^{ab}	0.28 ± 0.01^{ab}	0.28 ± 0.03^{b}	0.26 ± 0.03^{b}
Colour						
L*	61.00 ± 0.22^{a}	59.57 ± 0.46^{b}	58.43 ± 0.41^{c}	56.30 ± 0.08^{d}	55.83 ± 0.21^{d}	54.23 ± 0.24^{e}
a*	14.53 ± 0.40^{a}	14.60 ± 0.43^{a}	14.17 ± 0.21^{a}	14.50 ± 0.22^{a}	14.63 ± 0.17^{a}	14.70 ± 0.08^{a}
b*	34.03 ± 0.34^{d}	34.13 ± 0.09^{cd}	34.53 ± 0.12^{c}	35.13 ± 0.05^{b}	35.43 ± 0.26^{b}	36.17 ± 0.12^{a}

Means within a row followed by different lowercase superscripts are significantly different ($p < 0.05$).

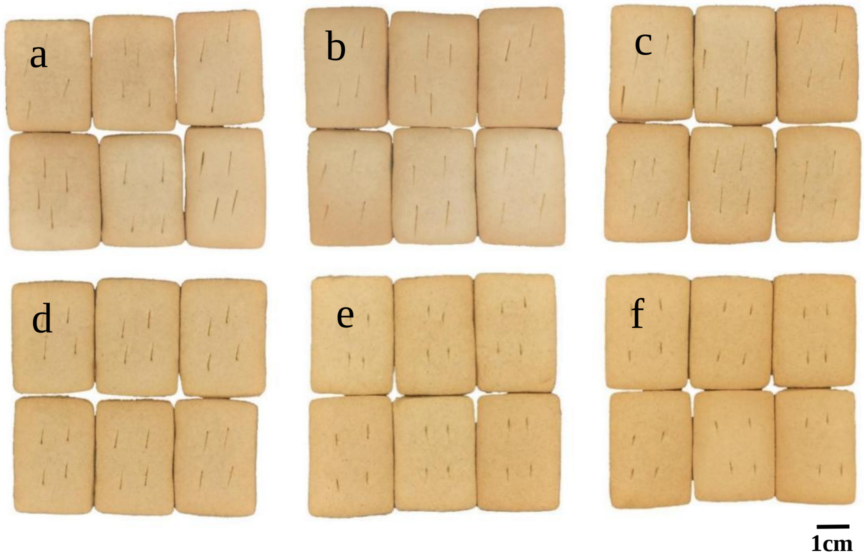

Figure 3. Images of cookies with different amounts of ginger powder substitution (a: 0.0%; b: 1.0%; c: 2.0%; d: 4.0%; e: 6.0%; and f: 8.0%).

used. Related studies have reported that dough gluten content is the main factor in determining the hardness of cookies. The higher the gluten content, the harder the cookies (Pourmohammadi *et al*., 2019). Therefore, we speculate that this decreased hardness might have been due to lower gluten content. In addition, extensograph properties of the dough suggest that gluten strength and gas holding capacity were significantly weakened when substitution with GP exceeded 4%. Decreased gluten strength reduced the stability of the gluten spatial network structure, which might have led to a decrease in the compressive resistance of the internal space of the baked cookies, resulting in a crumbly texture. Meanwhile, decreased gas holding capacity prevented the formation of holes during the baking process, resulting in a lower density of the product.

As presented in Table 2, there were no significant differences in protein and fat contents with GP substitution. More importantly, the content of crude fibres, total phenolics, and flavonoids all increased significantly ($p < 0.05$). These ingredients have various health benefits including hypoglycaemic, hypolipidaemic, antioxidant, and anti-cancer effects (Salehi, 2019). A similar observation has been reported in cookies made from hog plum bagasse (Oladunjoye *et al*., 2021). Furthermore, the scavenging ability of DPPH• and ABTS^{+}• significantly increased ($p < 0.05$), which would give the cookies stronger antioxidant properties. Similar observations have been made by Inglett *et al*. (2015) who added amaranth flour to cookies. These findings all supported the potential application of GP in cookies as a functional food ingredient.

Sensory evaluation of cookies

The sensory evaluation of GP cookies is presented in Table 3. Statistical results indicated that no differences in appearance were noticeable between cookies. In terms of taste, the taste score of the cookies increased when GP was substituted at 1 and 2%, and the taste score (7.70) was the highest when 2% GP was added. However, taste scores decreased rapidly when GP substitution exceeded 2%. This can be attributed to the gingerol in GP giving the cookies a bitter and spicy taste (Kim *et al*., 2005). As described by Moro *et al*. (2018), tastes such as astringency and bitterness are typically a challenge to the sensory properties of cookies. In addition, the decreasing scores in cookie texture might have been due to how the cookies became softer and more easily cracked when GP was substituted at 4% or higher. Interestingly, the colour score of the cookies increased significantly, and panellists found the increased yellow colour of cookies more pleasing. This result was opposite to those from Sharma *et al*. (2013) who added *Tinospora* leaf powder to cookies, changing the colour from golden brown to green, thus resulting in a decreased colour score. Overall, sensory panellists suggested that soft wheat flour could be substituted up to 2.0% with GP without resulting in unacceptable sensory properties.

Table 3. Sensory evaluation of cookies with different proportions of ginger powder substitution by panellists.

Substitution level	Appearance	Colour	Taste	Texture	Overall acceptability
0%	6.91 ± 1.00^{a}	5.72 ± 0.74^{d}	6.00 ± 0.00^{a}	6.64 ± 0.77^{a}	6.72 ± 0.75^{a}
1%	7.00 ± 0.85^{a}	5.91 ± 0.51^{d}	6.25 ± 0.34^{a}	6.45 ± 0.78^{a}	6.82 ± 0.83^{a}
2%	7.18 ± 0.57^{a}	6.73 ± 0.75^{c}	7.70 ± 0.33^{a}	6.36 ± 0.88^{a}	6.64 ± 0.64^{a}
4%	7.09 ± 0.69^{a}	7.18 ± 0.72^{bc}	5.30 ± 0.90^{b}	5.55 ± 0.99^{b}	5.64 ± 0.88^{b}
6%	7.18 ± 0.57^{a}	7.36 ± 0.64^{ab}	3.35 ± 0.45^{c}	5.00 ± 0.74^{bc}	2.45 ± 1.08^{c}
8%	7.27 ± 0.61^{a}	7.91 ± 0.69^{a}	1.60 ± 0.20^{d}	4.45 ± 0.89^{c}	1.91 ± 0.79^{c}

Means within a row followed by different lowercase superscripts are significantly different ($p < 0.05$).

Conclusion

Results showed that partial substitution with GP had significant impact on rheological properties of soft wheat dough, especially at 4% or higher, causing decreases in gluten strength and gas holding capacity. GP substitution changed the mobility and distribution of immobilised and free water in the dough, causing immobilised water to migrate to free water, thus affecting dough characteristics. Furthermore, GP could be incorporated into cookie dough to introduce beneficial components such as crude fibres, phenolics, and flavonoids, as well as to improve the antioxidant capacity of cookies. Finally, sensory evaluations revealed that cookies incorporated with no more than 2% GP in soft wheat flour were acceptable. Based on these results, GP could have great potential as a functional ingredient. *In vitro* / *in vivo* biological assays should be undertaken in the future to confirm the positive effects of food products containing GP on human health.

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