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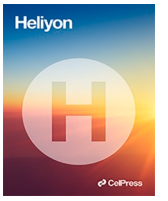

Research article

Dietary fiber-and antioxidant-enriched cookies prepared by using jackfruit rind powder and ascorbic acid

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ABSTRACT

The demand for dietary fiber-rich cookies has increased due to customer awareness about the importance of dietary fiber in human health. In addition, the urge of creating food sustainability has led to the need to reuse food by-products. In this study, dietary fiber-rich cookies were developed by incorporating jackfruit rind (JFR) powder, a by-product of jackfruit processing, as a replacement for wheat flour. The study aimed to evaluate the effects of different replacement levels (0, 10, 20, 30 and 40 %) on the proximate composition, physical properties and overall sensory acceptability of the cookies. While JFR powder addition led to a significant increase in dietary fiber and antioxidant (phenolics, flavonoids and carotenoids) contents of the cookies, the physical properties and overall acceptability of the cookies were adversely affected. The total dietary fiber and total phenolic content of the cookies at 40 % JFR powder addition were 5 and 5.5 times as much as those of the cookies with 0 % JFR powder addition. To address the adverse effects of JFR addition, various concentrations of ascorbic acid (AA), a dough improver agent, were added to the blended dough, and their effects on dough and cookie properties were investigated. With the addition of ascorbic acid at concentrations of 200 mg ascorbic acid per 100 g of the blend flour, the cookie density and cookie hardness reduced by 16 % and 31 %, respectively while the overall acceptability increased by 37 % compared to those of the cookies without ascorbic acid addition.

1. 1. introduction

Cookies are one of the most popular baked goods worldwide that are consumed by people of all ages. In recent years, there has been growing interest in incorporating plant-based materials into cookies to enhance their dietary fiber content [1]. This is due to increasing awareness of the importance of dietary fiber in human health, leading consumers to search for food that is rich in dietary fibers. Numerous studies have demonstrated the ability of dietary fiber to decrease blood pressure, lower serum cholesterol levels and mitigate the chances of developing conditions such as obesity, diabetes, cardiovascular diseases, cancer, and intestinal diseases [2].

Extensive research has been conducted on using of various natural material sources such as lemon basil and scent leaf powders [3],

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pineapple pomace [4], white grape pomace [5], mushroom [6], wheat malt [7], and *Murraya koenigii* leaves [8] to produce fiber-enriched cookies. One source of natural dietary fibers that has received a lot of attention from food scientists and producers is food by-products such as coffee skin powder [9], soybean residue [10,11] *Sargassum fusiform* residue [12] and corncob [13] since using food by-products to produce value-added goods can help to reduce food waste, avoid environmental damage, and achieve food sustainability [14]. Furthermore, antioxidants present in food by-products have also gained attention for their ability to serve as natural antioxidant for food preservation [15] and mitigate oxidative damages caused by free radicals in human body [16]. Additionally, using food by-products can be economically beneficial for food producers.

Jackfruit (*Artocarpus heterophyllus*) is a tropical fruit originating from South Asia. It is the largest known edible fruit which is rich in dietary fiber, vitamins, and minerals [17]. The unutilized fruit parts of jackfruit including the peel, rind and core are the predominant portion of the fruit, accounting for approximately 60 % of the entire fruit [18]. The rind of the jackfruit is considered as by-products and often discarded by food industries and vendors, but it is rich in functional ingredients including dietary fiber [19], pectin [20] and antioxidants such as phenolic acids and flavonoids [16,18]. Therefore, it can be a potential material to make value-added food products such as dietary fiber and antioxidants-enriched breads [21] and cookies [22]. Adding jackfruit rind (JFR) to cookie formula should increase dietary fiber content of the product, which can contribute to enhancing human gut health and lowering the risk of chronic diseases [23]. The large amounts of phenolics and flavonoids in JFR can also bring many health benefits such as anti-inflammatory, anti-aging, and neurodegenerative diseases [24,25].

However, preparation of fiber-rich cookies presents certain technological difficulties. Fibers can negatively impact gluten networks, the rheological properties of the dough, the textural properties and the overall acceptability of consumers on the resulting baking products [26]. To overcome these problems, appropriate technological solutions are required to be developed. Different additives, such as redox agents (i.e. ascorbic acid, cysteine, sodium meta-bisulfite, potassium bromate) [27] and commercial enzymes [28] have been shown to be able to improve the dough properties and the texture of final products, and are considered as potential solutions. Among the redox agents, ascorbic acid is widely used as an additive in bakery industry because of its dual role as a functional vitamin and an antioxidant [27].

Previously, a study has shown the impacts of JFR addition on the dimensional properties and sensory characteristics of cookies [22]. However, the influence of JFR addition on the textural properties of the dough and the resulting cookie products, as well as the effect of ascorbic acid addition on the properties of the JFR-incorporated cookies, have not been investigated thus far. The aim of this work was to study the effects of different levels of JFR powder addition on the chemical constituents, antioxidant contents (total phenolic, flavonoid and carotenoid contents), antioxidant activities, physical and textural attributes and overall acceptability of cookies. The study also investigated the effect of different ascorbic acid doses on the physical and textural attributes and overall acceptability of cookies. The results of this study will provide valuable information about the properties of fiber-rich cookies using jackfruit rind and ascorbic acid. The results could also help to develop new and improved recipes for JFR added cookies.

2. Materials and methods

2.1. Materials

Jackfruit (*Artocarpus heterophyllus)* rind was supplied by a local jackfruit drying plant (Dong nai province, Vietnam). Wheat flour was purchased from Dai Phong Flour Co. (Ho Chi Minh City, Vietnam). Other ingredients used in cookie making were bought from a local supermarket in Ho Chi Minh city (Vietnam).

Commercial enzymes including protease, α-amylase, amyloglucosidase used in the determination of dietary fiber content were bought from Novozyme Inc. (Bagsvaerd, Denmark). All chemicals were of analytical grade and purchased from Sigma-Aldrich Co. (Saint Louis, MO, US).

Table 1
Formula for cookie samples added with different ratios of jackfruit rind powder.

	Jackfruit rind powder-incorporated cookies at different addition levels				
Ingredients	0 % addition ratio (Control cookies)	10 % addition ratio	20 % addition ratio	30 % addition ratio	40 % addition ratio
Wheat flour (g)	120	108	96	84	72
JFR powder (g)	0	12	24	36	48
Isomalt (g)	37.28	37.28	37.28	37.28	37.28
Raw whole egg (g)	37.28	37.28	37.28	37.28	37.28
Unsalted butter (g)	56	56	56	56	56
Sodium bicarbonate (g)	1.28	1.28	1.28	1.28	1.28
Table salt (g)	0.53	0.53	0.53	0.53	0.53
Acesulfame potassium (g)	0.08	0.08	0.08	0.08	0.08
Vanilla extract (g)	0.48	0.48	0.48	0.48	0.48
Water (g)	10.4	10.4	10.4	10.4	10.4

2.2. Methods

2.2.1. Preparation of jackfruit rind powder

The jackfruit rind was dried at 60 °C by a convective dryer (DL12-PTN, Tung Viet Ltd, Vietnam) to reach a final moisture content less than 12 %, ground in a crusher (A18, Tan Minh Ltd, Vietnam) and then passed through a 40-mesh sieve. The dried JFR powder was preserved in polyethylene bags at 4 °C for use.

2.2.2. Cookie preparation

To investigate the effects of addition ratios of jackfruit rind powder on the quality of cookie dough and cookie product, the formula for all cookie samples is given in Table 1.

To prepare the cookie dough, a handheld mixer (HR1456, Philips Co., Zhuhai, Guangdong, China) was used to combine acesulfame potassium, table salt, isomalt, chicken egg and water at a speed of 200 rpm for 4 min. Then, butter, vanilla flavor, and sodium bicarbonate were added, and the mixture was further mixed for 4 min at the same speed. In a separate process, a mixture of wheat flour and JFR powder was prepared using a stand mixer (SM8005, Ichiban Ltd., Tokyo, Japan) at a speed of 60 rpm for 3 min. The two mixtures above were combined and mixed together at a speed of 100 rpm for 2 min before being allowed to rest for 15 min. The dough was manually rolled to a thickness of 4 mm, shaped using a circular cutter with a diameter of 35 mm, and then baked. The baking process involved an initial temperature of 175 °C for the first 15 min, followed by a temperature of 150 °C for an additional 10 min using a GL-1126 oven (Gali Co., Ho Chi Minh City, Vietnam). After baking, the freshly prepared biscuits were cooled to room temperature for 30 min and then sealed in airtight containers for subsequent physical property analysis and sensory evaluation. For other analyses, the biscuit samples were stored at room temperature for up to 2 weeks.

To improve the quality of dietary fiber- and antioxidant-enriched cookies using ascorbic acid, the formula with the highest total dietary fiber content (40 % jackfruit rind incorporated cookie, Table 1) was selected. Various dosages of ascorbic acid were added to the 40 % addition ratio cookie formula: 0, 40, 80, 120, 160 and 200 mg ascorbic acid per 100 g of the blend flour. The procedure of cookie preparation was similar to that described above except that ascorbic acid was added to water before mixed with other ingredients.

2.2.3. Chemical composition

Moisture content was quantified by using a moisture analyzer after drying at 105 °C (A&D Co., Tokyo, Japan). Protein was measured by Kjeldahl digestion following AOAC method 992.33. Lipid content was determined by Soxhlet extraction with diethyl ether solvent. Ash was measured by incineration at 600 °C in a muffle furnace (Lenton Co., Hope Valley, UK). Starch content was evaluated according to AOAC method 996.11. Insoluble dietary fiber (IDF), soluble dietary fiber (SDF) and total dietary fiber (TDF) were determined following AOAC method 991.43.

2.2.4. Water holding capacity and oil holding capacity

Water holding capacity (WHC) and oil holding capacity OHC were determined according to the method described by Garau et al. [29].

To determine water holding capacity (WHC), 1 g of JFR powder or wheat flour was soaked in 10 mL of distilled water for a period of 24 h. After soaking, the mixture was subjected to centrifugation at room temperature for 20 min at 3000×*g* (Sigma 3K30 centrifuge, Sigma Zentrifugen Ltd., Osterode am Harz, Germany). Subsequently, the supernatant was carefully removed by aspiration. The results were reported as the ratio of grams of water per gram of dry weight (dw) of JFR powder or wheat flour.

To determine OHC, 10.5 g of peanut oil was added to 3 g of JFR powder or wheat flour and vortexed for 1 min using a Vortex mixer (Model 250VM, Hwashin Technology Co., Seoul, South Korea). The mixture was then allowed to stand at room temperature for 30 min before being centrifuged at 1500×*g* at room temperature for 30 min. Following centrifugation, the supernatant was carefully poured off. The results were reported as the ratio of grams of oil per gram of dry weight (dw) of JFR powder or wheat flour.

2.2.5. Total carotenoid, phenolic and flavonoid contents and antioxidant activities

Total carotenoid content was determined by the method reported by Bae et al. [30] with slight modifications. About 4 g of the sample was added to 40 mL of acetone/ethanol (1/1, v/v) containing 200 mg/L butylated hydroxytoluene; the extraction was done at 30 °C and 200 rpm for 1 h. The mixture was then centrifuged at 4 °C and 10,000×*g* for 10 min. The supernatant was then filtered and filled up to 40 mL with acetone/ethanol (1/1, v/v) and the absorbance was recorded at a wavelength of 470 nm. The carotenoid content was calculated using the following formula:

$$\text{Total carotenoid content (mg / kg dw)} = \frac{A_{470\ nm} \times V \times 10^6 \times 1000}{A^{1\%} \times 100 \times m} \quad [30]$$

Where: $A_{470\ nm}$ is the absorbance at 470 nm; V (mL) is the extract volume (40 mL); $A^{1\%} = 2500$ (the extinction coefficient for a 1 % mixture of carotenoid) and m is the sample dry weight (g).

For evaluation of total phenolic and flavonoid contents and antioxidant activities, about 2 g of the sample was added to 20 mL 70 % aqueous acetone and the extraction was conducted at 30 °C and 200 rpm for 1 h. The mixture was subsequently centrifuged at 4 °C and 10,000×*g* for 10 min and the supernatant was used to determine total phenolic and flavonoid contents and antioxidant activities.

Total phenolic content (TPC) was measured by spectrophotometric method with Folin–Ciocalteu reagent as described previously

[31]. First, 0.2 mL of the sample extract (or gallic acid standard solution) was added to a test tube. Then, 1 mL of the Folin-Ciocalteu reagent was added and thoroughly mixed. Next, 0.8 mL of 10 % Na_2CO_3 solution and 3 mL of distilled water were added and well mixed. The resulting mixture was incubated in the dark at room temperature for 2 h, the absorbance at a wavelength of 760 nm was then recorded. The results were shown as mg gallic acid equivalent (GAE) per 100 g dry weight (dw) of the sample.

The total flavonoid content (TFC) was determined using the aluminum chloride colorimetric method. In a test tube, 4 mL of distilled water was added, followed by 1 mL of the sample extract (or quercetin standard solution) and 0.3 mL of 5 % $NaNO_2$. The mixture was vortexed and left to stand for 5 min. Then, 0.3 mL of 10 % $AlCl_3$ was added, and the mixture was vortexed again and left to stand for 6 min. Finally, 2 mL of 1 M NaOH and 2.4 mL of distilled water were added, and the absorbance at 415 nm was measured. The TFC was expressed as mg quercetin equivalent (QE) per 100 g dw of the sample.

Antioxidant activities were evaluated using ferric reducing antioxidant power (FRAP) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity assays, which were presented by Xu & Chang [32]; the results were expressed in μmol Trolox equivalent (TE)/g dw.

2.2.6. SS/total SH ratio

The concentrations of free SH and total SH were determining using the method described by Chen et al. [33] with slight modifications.

For the analysis of free SH concentration, about 100 mg freeze-dried dough sample was suspended in 15.0 mL of a buffer consisting of 8 M urea, 3 mM EDTA, 1 % SDS, and 0.2 M Tris-HCl at pH 8.0. After vortexing for 30 s, the samples were left to mix at room temperature for 60 min. Subsequently, 0.4 mL of a buffer containing 10 mM DTNB, 0.2 M Tris-HCl, pH 8.0 was added to each 4 mL of the above mixture and mixed for another 60 min. The resulting mixture was then centrifuged at 13,600×*g* for 15 min at room temperature, and the absorbance was recorded at 412 nm.

To determine the concentration of total SH groups, 40 mg of dough samples were mixed with 4.0 mL of a buffer consisting of 3 mM EDTA, 1 % SDS, 0.2 M Tris-HCl, 0.1 M sodium sulfite, pH 9.5, and 0.5 M 2-nitro-5-thiosulfobenzoate (NTSB). After vortexing for 30 s, the samples were incubated in a shaker in the dark for another 60 min. Following centrifugation at 13,600×*g* for 15 min, the supernatant (0.4 mL) was diluted with 3.6 mL of a buffer containing 3 mM EDTA, 1 % SDS, 0.2 M Tris-HCl, 0.1 M sodium sulfite, pH 9.5. The absorbance of the resulting solution was then measured at 412 nm.

The SH content (C_{SH}) was calculated as follows: $C_{SH} = \frac{A_{412\ nm}}{\varepsilon \times l}$ (where $A_{412\ nm}$ is the absorbance at 412 nm, ε is the extinction coefficient obtained from the standard curve using L-cysteine as the standard, and l is the cell path length) [33].

The disulfide content (C_{ss}) was calculated as follows: $C_{ss} = \frac{C_{total\ SH} - C_{free\ SH}}{2}$ [33]

The SS/total SH ratio is the ratio of sulphur atoms involved in the disulfide bonds (SS bonds) to the total number of thiol groups present in the gluten proteins within the dough. The SS/total SH ratio was calculated as follows:

$$\text{SS} \Big/ \text{total SH ratio} = \frac{2 \times C_{ss}}{C_{total\ SH}} \quad [33]$$

2.2.7. Physical properties

Textural attributes of the dough and cookie samples were evaluated with TA-XT plusC texture analyzer (Stable Micro Systems Co., Godalming, UK) and Windows version of Exponent Connect Lite 7.0 software (Texture Technologies Co., Hamilton, MA, USA). A three-point break test with a cell load of 5 kg was used. Hardness, cohesiveness and resilience of cookie dough samples and hardness of cookie samples were obtained from the force-time curves.

Diameter and thickness of cookie samples were determined following the method previously described; spread factor of cookie samples were calculated as ratio of diameter to thickness [34].

Instrumental color parameters including L* (lightness), a* (redness), and b* (yellowness) in CIELAB color space were determined with Konica Minolta CR400 chromameter (Osaka, Japan). The color difference (ΔE) between the JFR-added cookies and the control cookies was calculated by the following formula:

$$\Delta E = \sqrt{\left(L_0^* - L^*\right)^2 + \left(a_0^* - a^*\right)^2 + \left(b_0^* - b^*\right)^2}$$

Where: L_0*, a* and b* are the color values of the control cookies; L*, a* and b* are the color values of the JFR-incorporated cookies.

2.2.8. Overall acceptability

Overall acceptability of cookie samples was evaluated using a nine-point hedonic test on a scale from 1 (extremely dislike) to 9 (extremely like) and a panel of 60 people (30 men and 30 women) aged from 18 to 50. The panelists were selected based on the criteria that they use cookies at least once a week. All panelists signed an informed consent statement to participate in this study. The test was approved by the Ethics Review Board at the University of Social Sciences and Humanities, Vietnam National University – Ho Chi Minh City, with the approval number 01/GCN-XHNV-HDDDNC. Each cookie sample was labeled with a random three-digit number and the cookie samples were presented in a monadic and randomized order. Water was provided for mouth cleansing between samples.

2.2.9. Statistical analysis

Each cookie sample was performed in three batches. The results were shown as mean ± standard deviation. One-way analysis of

variance (ANOVA) and Tukey's comparison test with significance level set at $p \leq 0.05$ were done with Statgraphics Centurion 18.1.12 (Statgraphics Technologies, Inc., VA, USA).

3. Results and discussion

3.1. Chemical composition and functional properties of jack fruit rind powder and wheat flour

To evaluate the potential of JFR powder as a material source to increase fiber and antioxidant content for cookie products, the chemical constituents and functional properties of JFR powder and wheat flour were first characterized and compared (Table 2). The JFR powder had a higher lipid and ash content but a lower protein and starch content than the wheat flour. Remarkably, the total dietary fiber (TDF) and TPC contents of JFR powder were 8 and 9 times higher than those of wheat flour, respectively. The IDF/SDF ratio of JFR powder was 3.3 which is relatively low compared to that of other food by-products such as corncob (IDF/SDF ~ 9.6) [35], wheat bran (IDF/SDF ~ 7) [36], and grape pomace (IDF/SDF ~ 10.2) [5]. The high solubility of fibers is often associated with their high fermentability in the human intestine [37]. The flavonoid and carotenoid contents of JFR powder were 8.3 mg QE/100 g dw and 28.8 mg/kg dw, respectively. JFR powder had significantly higher antioxidant activity than wheat flour, with the DPPH radical scavenging activity being 22 times higher and the ferric reducing power being 16 times higher. These comparisons on chemical constituents and antioxidant properties of JFR powder and wheat flour indicate that JFR powder is a potential ingredient to make cookie products with high fiber and antioxidant level.

The WHC and OHC of the JFR powder were 2.6 and 3.0 times higher than those of the wheat flour due to their differences in chemical composition and porous structure. The difference between the WHC of JFR powder and wheat flour can affect the hydration of the gluten network [38] when wheat flour was replaced by JFR powder in the cookie recipe.

3.2. Effects of JFR powder incorporation levels on the cookie dough and cookies

3.2.1. Effects on chemical composition of the cookies

The impacts of different levels of JFR powder addition on chemical constituents of JFR-incorporated cookies are presented on Table 3. The lipid and ash contents gradually increased while the protein, starch and total carbohydrate contents decreased as the addition level increased from 0 to 40 %. These changes in the proximate compositions of JFR-incorporated cookies were ascribed to the differences in the proximate compositions of wheat flour and JFR powder (Table 2). In comparison to wheat flour, the JFR powder displayed higher lipid and ash contents, while exhibiting lower protein and starch contents. As expected, the inclusion of higher ratio of JFR powder in the cookie formula resulted in notable enhancement in the dietary fiber content (Table 3). At 40 % addition level, the IDF, SDF and TDF content of JFR-incorporated cookies were approximately 5, 3, and 4 times as much as that of the control sample, respectively. The IDF/SDF ratio (Table 3) of the JFR-incorporated cookie at 40 % addition level was 2.7 which falls within the recommend ratio of IDF/SDF between 2.3 and 3 by Federation of American Society of Experimental Biology [39]. Compared to the control sample, cookies with 40 % JFR addition level showed approximately 5.5 times and 8 times higher in TPC and TFC, respectively. The carotenoid content was marginal in the control sample while this content was 5.8 mg/kg dw in the JFR-incorporated cookie at 40 % addition level. The antioxidant activities of cookies with 40 % JFR powder were 12 times and 15 times higher than those of the control cookies, as quantified by DPPH and FRAP assays using Trolox as the standard, respectively. Similar improvement in dietary fiber and antioxidant contents of the fortified cookies is recently reported when food processing by-products such as pitaya peel [40] or

Table 2
Chemical composition, and functional properties of jackfruit rind powder and wheat flour.

	Jackfruit rind powder[i]	Wheat flour[i]
Protein (%, dw)	8.7 ± 0.0^{a}	10.2 ± 0.2^{b}
Lipid (%, dw)	8.9 ± 0.1^{b}	2.5 ± 0.2^{a}
Ash (%, dw)	6.0 ± 0.0^{b}	0.8 ± 0.2^{a}
Starch (%, dw)	34.1 ± 2.5^{a}	81.3 ± 0.9^{b}
Total sugar content (% dw)	5.3 ± 0.1^{b}	0.4 ± 0.1^{a}
IDF (%, dw)	18.2 ± 0.2^{b}	1.7 ± 0.0^{a}
SDF (%, dw)	5.5 ± 0.2^{b}	1.3 ± 0.1^{a}
TDF (%, dw)	23.9 ± 0.2^{b}	3.0 ± 0.1^{a}
IDF/SDF ratio	3.3 ± 0.1^{b}	1.3 ± 0.1^{a}
TPC (mg GAE/100 g dw)	11.1 ± 0.5^{b}	1.2 ± 0.3^{a}
TFC (mg QE/100 g dw)	8.3 ± 0.5^{b}	0.4 ± 0.1^{a}
Carotenoid (mg/kg dw)	28.8 ± 0.3^{b}	1.6 ± 0.3^{a}
DPPH radical scavenging activity (μmol TE/100 g dw)	24.5 ± 1.9^{b}	1.1 ± 0.4^{a}
Ferric reducing power (μmol TE/100 g dw)	18.6 ± 1.9^{b}	1.2 ± 0.3^{a}
WHC (g water/g dw)	3.1 ± 0.1^{b}	1.2 ± 0.0^{a}
OHC (g oil/g dw)	2.4 ± 0.1^{b}	0.8 ± 0.0^{a}

[i] that do not share a same letter (a-b) within the same row are significantly different (Tukey's comparison test, $p < 0.05$). Abbreviations: dw: dry weight; IDF: insoluble dietary fiber; SDF: soluble dietary fiber; TDF: Total Dietary Fiber; TPC: Total phenolic content; TFC: Total flavonoid content; GAE: gallic acid equivalent; QE: quercetin equivalent; TE: Trolox equivalent.

Table 3
Chemical composition of cookies with different addition level of jackfruit rind powder.

	Jackfruit rind powder-incorporated cookie samples at different addition levels (%)[i]				
	0 %	10 %	20 %	30 %	40 %
Crude protein (%, dw)	6.2 ± 0.0^{d}	5.9 ± 0.0^{cd}	5.7 ± 0.3^{bc}	5.5 ± 0.2^{ab}	5.2 ± 0.2^{a}
Lipid (%, dw)	22.2 ± 0.2^{a}	22.8 ± 0.1^{b}	23.1 ± 0.2^{bc}	23.5 ± 0.4^{cd}	23.9 ± 0.4^{d}
Starch (%, dw)	59.4 ± 2.1^{a}	55.7 ± 0.6^{b}	51.0 ± 2.1^{c}	46.3 ± 0.2^{d}	42.2 ± 0.2^{e}
Ash (%, dw)	1.1 ± 0.1^{a}	1.5 ± 0.0^{b}	1.8 ± 0.0^{c}	2.0 ± 0.1^{d}	2.3 ± 0.0^{e}
Total carbohydrate (%, dw)	67.8 ± 0.4^{c}	66.4 ± 0.1^{b}	66.0 ± 0.4^{ab}	65.6 ± 0.7^{ab}	65.3 ± 0.5^{a}
TDF	1.8 ± 0.2^{a}	2.9 ± 0.2^{b}	4.7 ± 0.3^{c}	6.1 ± 0.3^{d}	7.4 ± 0.3^{e}
IDF	1.1 ± 0.1^{a}	1.9 ± 0.1^{b}	3.3 ± 0.2^{c}	4.5 ± 0.2^{d}	5.4 ± 0.2^{e}
SDF	0.7 ± 0.1^{a}	1.0 ± 0.1^{b}	1.4 ± 0.1^{c}	1.6 ± 0.1^{d}	2.0 ± 0.1^{e}
IDF/SDF ratio	1.5 ± 0.1^{a}	1.8 ± 0.2^{b}	2.3 ± 0.1^{c}	2.7 ± 0.1^{d}	2.7 ± 0.1^{d}
Total phenolic content (mg GAE/100 g dw)	0.9 ± 0.1^{a}	2.0 ± 0.1^{b}	2.9 ± 0.1^{c}	4.0 ± 0.1^{d}	5.0 ± 0.2^{e}
TFC (mg QE/100 g dw)	0.2 ± 0.0^{a}	0.5 ± 0.1^{b}	1.0 ± 0.1^{c}	1.2 ± 0.1^{d}	1.6 ± 0.2^{e}
Carotenoid (mg/kg dw)	0.3 ± 0.1^{a}	2.3 ± 0.1^{b}	3.4 ± 0.1^{c}	4.5 ± 0.1^{d}	5.8 ± 0.2^{e}
DPPH radical scavenging activity (μmol TE/100 g dw)	0.8 ± 0.2^{a}	5.9 ± 0.1^{b}	7.6 ± 0.2^{c}	8.8 ± 0.2^{d}	10.3 ± 0.2^{e}
Ferric reducing power (μmol TE/100 g dw)	0.8 ± 0.1^{a}	5.3 ± 0.1^{b}	7.6 ± 0.1^{c}	10.0 ± 0.2^{d}	12.2 ± 0.5^{e}

[i] Values that do not share a same letter (a-e) within the same row are significantly different (Tukey's comparison test, $p \leq 0.05$). Abbreviations: dw: dry weight, TDF: Total Dietary Fiber; IDF: insoluble dietary fiber; SDF: soluble dietary fiber; TPC: Total phenolic content; TFC: Total flavonoid content; QE: quercetin equivalent; GAE: gallic acid equivalent; TE: Trolox equivalent.

spent green tea leaves [41] are added into cookie recipes.

3.2.2. *Effects on textural properties of the cookie dough*

The effects of JFR addition on the cookie dough are presented in Table 4. The increase in addition level led to an increase in hardness while the dough cohesiveness and resilience decreased. The increase in dough hardness could be ascribed to the high water holding capacity of JFR powder, which influenced the hydration of gluten proteins and starch granules. The decrease in the dough cohesiveness and resilience indicates that the addition of JFR powder detrimentally affected the gluten matrix [42]. There are different mechanisms by which JFR powder can negatively affect the gluten matrix. First, the addition of JFR may dilute the gluten content, leading to a weaker gluten strength [42]. Second, the high water holding capacity of JFR powder can lead to the dehydration of gluten proteins, resulting in changes in secondary structure of gluten proteins [38]. In addition, the fiber particles can also pose steric hindrance to the formation of gluten network [26,43]. Collectively, the addition of JFR powder could result in a weaker and less developed gluten matrix, leading to the decrease in the dough cohesiveness and resilience.

3.2.3. *Effects on physical and textural properties of the cookies*

The thickness of cookie products gradually decreased with increasing addition level (Table 4). At 40 % addition level, the thickness

Table 4
Effects of addition level of jackfruit rind powder on physical properties of the doughs, physical and textural properties, and overall acceptability of the cookies.

Dough properties	Jackfruit rind powder-blended doughs at different addition levels (%)[i]				
	0 %	10 %	20 %	30 %	40 %
Hardness (g)	728.6 ± 45.7^{a}	1481.9 ± 51.4^{b}	1901.0 ± 71.2^{c}	3100.5 ± 70.4^{d}	3518.5 ± 144.7^{e}
Cohesiveness	0.53 ± 0.02^{e}	0.45 ± 0.02^{d}	0.32 ± 0.01^{c}	0.24 ± 0.03^{b}	0.18 ± 0.00^{a}
Resilience	0.045 ± 0.005^{d}	0.040 ± 0.003^{cd}	0.037 ± 0.003^{bc}	0.031 ± 0.003^{ab}	0.028 ± 0.003^{a}
Cookie properties	**Jackfruit rind powder-incorporated cookie samples at different addition levels (%)[i]**				
	0 %	**10 %**	**20 %**	**30 %**	**40 %**
Dimension					
Diameter (mm)	35.3 ± 0.2^{c}	35.1 ± 0.2^{b}	34.9 ± 0.2^{ab}	34.9 ± 0.3^{a}	34.8 ± 0.1^{a}
Thickness (mm)	5.43 ± 0.07^{d}	5.34 ± 0.03^{cd}	5.24 ± 0.03^{c}	5.05 ± 0.06^{b}	4.87 ± 0.03^{a}
Spread ratio (D/T)	6.50 ± 0.08^{a}	6.58 ± 0.03^{ab}	6.67 ± 0.04^{b}	6.90 ± 0.08^{c}	7.14 ± 0.05^{d}
Volume (cm^3)	5.30 ± 0.07^{e}	5.16 ± 0.03^{d}	5.02 ± 0.03^{c}	4.82 ± 0.06^{b}	4.63 ± 0.03^{a}
Weight (g)	3.85 ± 0.06^{a}	3.92 ± 0.02^{b}	3.99 ± 0.01^{c}	4.06 ± 0.02^{d}	4.16 ± 0.02^{e}
Density (g/cm^3)	0.73 ± 0.02^{a}	0.76 ± 0.00^{b}	0.79 ± 0.00^{c}	0.84 ± 0.01^{d}	0.90 ± 0.01^{e}
Fracture strength					
Hardness (g)	940.8 ± 52.1^{a}	1041.3 ± 62.8^{a}	1219.9 ± 58.1^{b}	1325.8 ± 74.5^{b}	1520.2 ± 98.5^{c}
Color					
L*	73.4 ± 0.3^{e}	62.1 ± 0.5^{d}	56.3 ± 0.3^{c}	51.7 ± 0.4^{b}	49.1 ± 0.6^{a}
a*	1.3 ± 0.2^{a}	4.0 ± 0.3^{b}	5.2 ± 0.3^{c}	6.2 ± 0.1^{d}	6.4 ± 0.1^{e}
b*	31.9 ± 0.5^{e}	29.8 ± 0.4^{d}	27.6 ± 0.2^{c}	25.9 ± 0.3^{b}	23.1 ± 0.4^{a}
ΔE	0.0 ± 0.0^{a}	11.9 ± 0.3^{b}	18.1 ± 0.3^{c}	23.1 ± 0.7^{d}	26.4 ± 0.6^{e}
Overall acceptability	6.1 ± 1.6^{cd}	6.4 ± 1.4^{d}	5.8 ± 1.8^{bc}	5.2 ± 1.7^{b}	4.1 ± 1.5^{a}

[i] Values that do not share a same letter (a-e) within the same row are significantly different (Tukey's comparison test, $p \leq 0.05$).

of cookie was dropped by 10 % as compared to that of the control cookie. The diameter of cookie samples was marginally affected by the JRR addition level, showing only a slight decrease when addition level increased from 0 to 10 % and was insignificantly different as the addition level was increased from 20 to 40 % (Table 4). The spread ratio slightly increased from 6.50 to 7.14 as the addition level increased from 0 to 40 % (Table 4). This suggests that the adding of JFR powder to cookie formula reduced the rising ability of cookies (Cheng & Bhat, 2016). Corresponding to the decrease of diameter and thickness, the volume of cookie products decreased with the increased JFR addition level (Table 4). These observations could be ascribed to the impacts of dietary fiber on the gluten network and dough properties which are mainly responsible for the expansion of cookies during baking [26]. Dietary fiber addition was typically reported to reduce the dimensional parameters and volume of baked products [44,45]. The dough cohesiveness and resilience were reduced with the addition of JFR powder (Table 4), which should lead to a lower gas retention ability of the dough. Consequently, the cookie volume decreased as the dough cohesiveness and resilience decreased (Table 4) with the increasing of JFR addition level. In addition, the high water binding ability of JFR powder can also reduce the cookie expansibility during baking [46]. The diameter of cookie is mainly controlled by the dough viscosity [34]. Addition of dietary fibers to the bakery dough was shown to make the dough become more solid-like, reducing its spread ability during the subsequent baking and diameter of the final product [34].

The density of cookie products increased with increasing JFR addition. At 40 % addition level, the density of cookie increased by 23 % compared to that of the control cookie. The increase in cookie density is the result of both the reduction in cookie expansion and the increase in cookie weight due to difference in the density of JFR powder and wheat flour (Table 4).

The increase of addition level resulted in the sharp increase in the cookie hardness (Table 4). Cookie samples with addition of 40 % JFR powder showed 62 % higher in hardness compared with the control samples. This result is comparable with previous studies in which the cookie hardness was increased with the incorporation of fiber-rich materials such as corncob [13], wheat and rice bran [47], and lemon fiber [48]. The increase of hardness could be attributed to the decrease in the cookie volume resulting in denser structures as the JFR addition increased.

3.2.4. Effects on color of the cookies

As the JFR powder addition level increased, the lightness (L*) of the JFR-incorporated cookie samples substantially decreased (Table 4). At 40 % addition level, L* value reduced by 33 % as compared to that of the control sample. This darkening effect could be attributed to natural pigments such as carotenoids available in JFR powder and the oxidation of phenolics which usually results in brown quinone and polymerized compounds [49]. As the addition level rose from 0 to 40 %, the redness (a*) gradually increased from 1.3 to 6.4 while the yellowness (b*) dropped from 31.9 to 23.1 (Table 4).

3.2.5. Effect on overall acceptability of the cookies

The 10 % JFR cookies demonstrated a similar overall acceptability compared to the 0 % cookies. This observation could be

Table 5
Effects of the addition of various ascorbic acid concentrations on physical properties of the blend doughs, physical and textural properties, and overall acceptability of the cookies.

Dough properties	Control dough[a]	40 % jackfruit rind-incorporated doughs supplemented with ascorbic acid at different concentrations (ppm)[i,j]					
		0	40	80	120	160	200
Hardness (g)	728.6 ± 45.7[a]	3518.5 ± 144.7[g]	3086.9 ± 74.5[f]	2712.4 ± 146.9[e]	2282.4 ± 131.1[d]	2015.3 ± 151.1[c]	1732.4 ± 106.4[b]
Cohesiveness	0.53 ± 0.02[g]	0.18 ± 0.00[a]	0.22 ± 0.02[b]	0.26 ± 0.01[c]	0.31 ± 0.01[d]	0.35 ± 0.02[e]	0.42 ± 0.02[f]
Resilience	0.045 ± 0.005[e]	0.028 ± 0.004[a]	0.032 ± 0.003[ab]	0.035 ± 0.002[bc]	0.037 ± 0.002[bcd]	0.039 ± 0.002[cd]	0.041 ± 0.003[de]
SS/total SH ratio	0.491 ± 0.001[e]	0.476 ± 0.003[a]	0.481 ± 0.001[b]	0.484 ± 0.000[c]	0.485 ± 0.000[c]	0.488 ± 0.001[d]	0.490 ± 0.001[de]
Cookies properties	**Control cookies[a]**	**40 % jackfruit rind powder-incorporated cookie samples supplemented with ascorbic acid at different concentration (ppm)[i,j]**					
		0	**40**	**80**	**120**	**160**	**200**
Dimension							
Diameter (mm)	35.3 ± 0.2[d]	34.8 ± 0.1[a]	34.8 ± 0.2[a]	35.0 ± 0.2[ab]	35.0 ± 0.2[bc]	35.1 ± 0.2[bc]	35.2 ± 0.1[cd]
Thickness (mm)	5.43 ± 0.07[c]	4.87 ± 0.03[a]	4.97 ± 0.06[a]	5.15 ± 0.13[b]	5.21 ± 0.04[b]	5.26 ± 0.04[b]	5.39 ± 0.05[c]
Spread ratio (D/T)	6.50 ± 0.08[a]	7.14 ± 0.05[d]	7.00 ± 0.09[d]	6.79 ± 0.17[c]	6.73 ± 0.05[c]	6.67 ± 0.05[bc]	6.53 ± 0.06[ab]
Volume (cm^3)	5.30 ± 0.07[d]	4.63 ± 0.03[a]	4.74 ± 0.06[a]	4.94 ± 0.12[b]	5.01 ± 0.04[bc]	5.09 ± 0.04[c]	5.23 ± 0.05[d]
Weight (g)	3.85 ± 0.06[a]	4.16 ± 0.02[e]	4.13 ± 0.01[e]	4.09 ± 0.01[d]	4.06 ± 0.01[cd]	4.03 ± 0.01[c]	3.99 ± 0.01[b]
Density (g/cm^3)	0.73 ± 0.02[a]	0.90 ± 0.01[f]	0.87 ± 0.01[e]	0.83 ± 0.02[d]	0.81 ± 0.01[cd]	0.79 ± 0.01[c]	0.76 ± 0.01[b]
Fracture strength							
Hardness (g)	940.8 ± 52.1[a]	1520.2 ± 98.5[d]	1446.9 ± 74.8[cd]	1329.6 ± 69.3[c]	1168.1 ± 95.0[b]	1140.5 ± 82.5[ab]	1047.5 ± 43.3[ab]
Overall acceptability	6.1 ± 1.6[e]	4.1 ± 1.5[a]	4.6 ± 1.2[b]	4.8 ± 1.2[bc]	5.1 ± 1.3[bc]	5.2 ± 1.0[cd]	5.6 ± 1.1[d]

[i] Values that do not share a same letter (a-g) within the same row are significantly different (Tukey's comparison test, $p \leq 0.05$).
[j] To prepare jackfruit rind-incorporated cookie, 40 % wheat flour was replaced by jackfruit rind powder.
[a] The control dough and cookies are the dough and cookies without jackfruit rind and ascorbic acid addition (Formula of the control dough and cookies is shown in Table 1).

explained by a similar in the hardness of the 0 % cookies and 10 % JFR cookies. The overall acceptability of cookies incorporated with 20–40 % JFR powder was lower than that of the control cookie and significantly decreased with the increased addition level (Table 4). The decline in overall acceptability at higher ratios could be attributed to the changes in cookie textural properties and colors. As the addition level increased, the hardness and density of the cookies significantly increased while the color became darker. A previous study has shown that the addition of cereal bran to cookie recipe resulted in darker and harder cookies, which also led to a decrease in sensory quality regarding the color and texture [47].

3.3. Effects of ascorbic acid addition on the dough properties and quality of jackfruit rind incorporated cookies

3.3.1. Effects of ascorbic acid concentration on textural properties of cookie dough

Ascorbic acid (AA) was added to the blended dough with final concentration varying from 0 to 200 ppm. The effects of ascorbic acid addition on textural properties of the blended dough are shown in Table 5. Generally, the addition of AA reversed the negative effects of JFR powder on the dough textural properties. As the AA concentration rose from 0 to 200 ppm, the dough hardness decreased by 51 %, but was still 2.4 times higher than that of the control dough. Nevertheless, a previous study reported that the addition of AA led to an increase in hardness of wheat flour dough [50], which was attributed to the increase in the disulphide bonds through the SH/SS exchange induced by AA. Difference in the result between this study and the previous study was probably due to the difference in the dough ingredients. In the previous study, the dough hardness increased with the addition of AA comprised only wheat flour and water, whereas in this study, additional ingredients such as JFR powder, fat, and egg were incorporated into the dough preparation along with wheat flour and water. AA may alter the interactions between cookie ingredients especially the interactions between starch, proteins, and fibers, leading to reduction in the dough hardness. However, the effects of AA on these interactions need to be further investigated.

The dough cohesiveness and resilience increased with the increase in AA addition concentration. The cohesiveness of the dough increased by 2.3 times when 200 ppm of AA was added compared to the dough without AA addition. The dough resilience at 200 ppm AA was increased by 46 % compared to that at 0 ppm AA and comparable to that of the control dough without JFR addition. It was hypothesized that the presence of AA in the blend dough can improve the gluten network by inducing formation of more SS bonds.

The SS/total SH ratio represents the proportion of sulphur atoms participating in disulfide bonds (SS bonds) compared to the total number of thiol groups present in the gluten proteins of the dough. In this study, as the AA concentration in the blended dough with 40 % replacement ratio increased, the SS/total SH ratio within the dough increased (Table 5). This observation supports that AA promoted the formation of a greater number of SS bonds. AA is a reducing agent which turns into dehydro-L-ascorbic acid (DHA), an oxidizing agent after adding to dough by the action of ascorbic acid oxidase enzyme [51]. DHA can oxidize low molecular thiol groups (SH) such as endogenous glutathione and cysteine thiols [27,51]. Consequently, the SH/SS exchange between low molecular thiols such as cysteine and glutathione and SS bonds of gluten protein is reduced [52], leading to a higher amount of intermolecular SS bonds in gluten proteins and strengthening the gluten [27].

3.3.2. Effects of ascorbic acid concentrations on physical properties of the cookies

As AA concentration increased from 0 to 200 ppm, the diameter slightly increased while the thickness increased by 11 % (Table 5). Both diameter and thickness of the fortified cookies at 200 ppm AA were comparable to those of the control cookies. These observations are due to enhancement effects on the gas retention ability and the gluten strength of AA supplement on the doughs [27,53] as evidenced by the observed improvements in dough cohesiveness and resilience (Table 5) leading to the increase in cookie dimensions. The increase in gas retention ability of blended dough supplemented with AA was indicated by the reduction in the weight of cookies with the increase amount of added AA (Table 5). As the cookie dough samples with different AA concentrations were prepared from the same amount of ingredients and the same volume of dough was used to produce cookie samples, the reduction in cookie mass should indicate that more gas was trapped in the dough during the baking. As a consequent of increasing in cookie volume and reducing in cookie mass, the cookie density decreased as the concentration of AA increased.

The cookie hardness significantly decreased with the increase in AA concentration, possibly due to more porous structure being produced at higher AA concentration. At 200 ppm AA concentration, the hardness was dropped by 31 % compared to that of the cookie without adding AA. The hardness at 200 ppm AA was comparable to that of the control cookie.

3.3.3. Effects of ascorbic acid concentrations on overall acceptability of the cookies

As AA concentration increased from 0 to 200 ppm, the overall acceptability score increased from 4.1 to 5.6 (Table 5). The improvement effect of AA on the overall acceptability of JFR-incorporated cookie could be attributed to its improvement effect on textural properties. AA is a well-known dough improver agent which can cause a pronounced increase in dough strength and the volume of baked goods [53]. Since AA is a vitamin, it is the most acceptable additive to improve bakery product texture [53]. Here, AA was shown that it has the ability to improve the texture and the acceptability of the fiber-rich cookie products, suggesting its potential in producing good quality fiber-rich cookies to satisfy the consumer demands for healthier cookie products.

4. Conclusion

This study highlights the potential use of jackfruit rind powder in the development of fiber- and antioxidant-enriched cookies. The incorporation of JFR powder resulted in improved dietary fiber and antioxidant content. However, compared to the control cookie, the JFR-incorporated cookies have darker color, higher density and harder texture, which reduced their overall acceptability. Ascorbic acid (AA) was successfully applied in the blended dough to mitigate the negative effects of JFR addition on the physical and textural

properties of the prepared cookies, leading to a significant improvement in the overall acceptability. The efficiency of AA addition is concentration-dependent, with an increase in the AA concentration leading to better efficiency. At 200 ppm AA concentration supplement, the overall acceptability score of JFR-incorporated cookie was increased by 1.5 points compared to the cookie without AA addition. To further enhance the potential use of JFR in the food industry, future studies should explore alternative approaches, such as varying the cookie formulation and JFR particle size, to optimize the sensory attributes of the cookies with JFR incorporation. Additionally, *in vitro* digestion and *in vivo* studies could be conducted to further investigate the health benefit effects of JFR-incorporated cookies. These efforts would contribute to the development of improved JFR-incorporated cookie products, enhance our understanding of the health benefits of these products, and pave the way for broader utilization of JFR in the food industry in the future.

Declaration

The study was covered by a general approval number 01/GCN-XHNV-HDDDNC from the Ethics Review Board at the University of Social Sciences and Humanities, Vietnam National University – Ho Chi Minh City (VNU-HCM). Participants were instructed to read an information sheet and sign a consent form. Participants gave voluntary consent and were assured that their responses would remain confidential; they were informed they could withdraw at any point without any consequences.

Data availability statement

The data that support the findings of this study will be available from the corresponding author upon reasonable request.

CRediT authorship contribution statement

Huynh Binh Giang Ngo: Methodology, Investigation, Formal analysis. **My Lam Phu:** Methodology, Investigation, Formal analysis. **Thi Thu Tra Tran:** Visualization, Validation, Resources, Data curation. **Nu Minh Nguyet Ton:** Visualization, Validation, Resources, Data curation. **Thi Quynh Ngoc Nguyen:** Writing – review & editing, Writing – original draft, Validation, Data curation. **Van Viet Man LE:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors of the submitted manuscript declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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