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Original Article

The effect of pineapple core fiber on dough rheology and the quality of mantou

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ABSTRACT

The consumption of dietary fiber offers the health benefit of lowering the risk of many chronic diseases. Pineapple core fiber (PCF) in this study was extracted and incorporated into dough and mantou (i.e., steamed bread). The effects of PCF substitution and fiber size on textural and rheological properties of dough and mantou were evaluated by a texture analyzer. The substitution of wheat flour by PCF resulted in a stiffer and less extensible dough with or without fermentation. The hardness and gumminess of mantou significantly increased as the PCF substitution increased from 0% to 15%, but the cohesiveness, specific volume, and elasticity significantly decreased with the fiber substitution. Ten percent PCF-enriched dough and mantou with various fiber sizes had similar rheological and textural properties, except for the k_1 and k_2 values. By sensory evaluation, 5% PCF-enriched mantou and the control bread had better acceptability in texture, color, odor, and overall acceptability, compared to mantous enriched with 10% or 15% PCF. Significant correlations existed between the rheological properties of dough and textural parameters of mantou and between the sensory quality and textural parameters of mantou. Therefore, we suggest that fiber-enriched mantou can be prepared with 5% PCF substitution to increase the intake of dietary fiber and maintain the quality of mantou.

1. Introduction

Mantou (i.e., steamed bread) is an important staple food in Asia. Southern-style Chinese mantou has a soft, elastic, and uniformly fine-textured crumb. These characteristics are significantly affected by ingredients and processing variables [1–3]. Rubenthaler et al [1] reported that wheat flour with 10–11% protein and medium gluten strength is best suited for steamed bread. The low-steam generation rate significantly reduces the quality of bran-enriched steamed bread [3].

Dietary fiber (DF) is a group of food components that are resistant to hydrolysis by human digestive enzymes. Dietary fiber intake offers health benefits such as a lower risk for coronary heart disease, type 2 diabetes, obesity, and constipation [4,5]. The additions of some soluble DFs strengthens

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the structure of dough and improves the quality of bread [6], but excess amounts of insoluble DFs have an adverse effect on the formation of the gluten network [7,8] and reduces the quality of bread [9–12] because of a gluten dilution effect or because of gluten–fiber interaction. The addition of apple pomace [13] and insoluble wheat fiber [14] results in a stiffer dough, probably through a filler-like effect in the dough matrix. Ahmed et al [8] report that dough incorporated with insoluble date fiber predominately exhibits solid-like behavior. Potato fiber, which contains a high level of insoluble DF, increases the hardness and gumminess of bread [11]. The addition of 11% apple pomace decreased the quality of bread by sensory evaluation [9]. Wu et al [3] reported that steamed bread enriched with 10% and 20% wheat bran had a similar sensory quality as the control bread, but 30% bran-enriched steamed bread had the lowest sensory quality, which was significant. Increasing the DF intake may be achieved by consuming fiber-enriched mantou. Few studies exist on the properties of dough and mantou enriched with fiber.

Pineapple is one of the most important fruits in the world. In Taiwan, the annual yield of pineapple is more than 400,000 metric tons. In addition to being eaten fresh, pineapples are usually processed into canned fruit, juice, and jam. Pineapple core, the high-fiber part of the pineapple fruit, is a potential DF source [15,16]. The fruit and its pomace contain abundant phytochemicals such as fiber, polyphenols, and flavonoids; it furthermore has good antioxidant activity [17,18]. Prakongpan et al [19] report that purified pineapple core powder contains 99.8% total DF content. Hence, pineapple core is a good DF source for food enrichment.

The aim of this study was to investigate the rheological and textural properties of dough and mantou enriched with different amounts and particle sizes of pineapple core fiber (PCF). Another purpose was to observe the correlations between dough and mantou properties.

2. Methods

2.1. Materials

Wheat flour with medium gluten strength was a gift from Chia-Fha Enterprise Co. Ltd. (Taichung, Taiwan). The approximate composition of wheat flour on a wet basis, as analyzed by the AACC [20] methods, were 12.1% moisture, 11.0% crude protein, 0.6% crude fat, and 0.4% ash contents. Commercial instant dried yeast and sodium stearoyl 2-lactylate were obtained from S. I. Lesaffre Co. (Marcq, France) and Danisco Ingredients (Penang, Malaysia), respectively. Food-grade sucrose and shortening were purchased from Taiwan Sugar Co. (Tainan, Taiwan).

The core of fresh pineapple (*Ananas comosus* L. Merr.) was obtained as a byproduct from a local fruit processing factory. Pineapple core fiber was prepared in accordance with the method proposed by Chien and Kang [16], with some modifications. In brief, pineapple cores were washed, cut (<1 cm thick), blanched (100°C for 15 minutes), drained, air-dried (50°C for 24 hours), and crushed. The crushed samples were then extracted by 80% ethanol for 12 hours. The residues after centrifugation were air-dried (50°C for 24 hours) and milled to a particle size of less than 0.42 mm. Three fractions of PCF with different particle sizes were collected by sieving with 40 mesh, 60 mesh, and 100 mesh. Total, insoluble, and soluble DFs of the PCF were analyzed by AOAC methods [21]. Functional properties (e.g., swelling power and water-holding capacity) were measured by the method of Huang et al [22], with some modifications. The PCF (1 g) was hydrated with 20 mL of distilled water in a calibrated cylinder at room temperature. After equilibration (24 hours), the bed volume was recorded and the swelling power was expressed as milliliters of swollen sample per gram of dry sample. Furthermore, PCF (1 g) was soaked in 10 mL of distilled water for 24 hours and then centrifuged at 1000*g* for 20 minutes. The supernatant was decanted into a graduated cylinder and the volume of excess water was read. Hence, Water-holding capacity was expressed as milliliters of water held by 1 g of PCF.

2.2. Preparation of dough and mantou

Dough and mantou were both prepared with 0–15% PCF by the method of Wu et al [3]. Unless stated otherwise, the basic 10% fiber-enriched dough constituents were wheat flour (90%), PCF (10%), water (54%), yeast (1.5%), sucrose (8%), shortening (5%), and sodium stearoyl 2-lactylate (0.5%). In brief, all ingredients were mixed and kneaded to form dough. The dough was then fermented, sheeted, rolled, divided, proofed, steamed, and cooled. Rheological and quality tests of the dough and mantou were performed at room temperature (approximately 26°C) as soon as possible.

2.3. Extension test of unfermented or proofed dough

A texture analyzer (TA-XT2i; Stable Micro Systems, Surrey, UK) was equipped with a probe of Kieffer dough and gluten extensibility rig, and operated in tension mode. The pretest and test speeds were both set at 2.0 mm/s to avoid vibrations that may occur at high speed. The resistance to the extension (mN) and extensibility (mm) of dough without yeast and proofed dough were determined by recording the maximum force and the distance at rupture. The measurements were conducted in six repetitions.

2.4. Stress relaxation of mantou

The stress relaxation of mantou was measured according to the method proposed by Wu et al [3]. In brief, the center crumb sample ($3 \times 3 \times 4$ cm^3) was removed by cutting. Stress relaxation test of the sample was executed by using a textural analyzer equipped with a P20 cylindrical probe (20-mm diameter). The sample was deformed by penetration to a constant strain of 20% with a test speed of 0.5 mm/s. The data acquisition rate was 10 points per second. The residual force was continuously recorded as a function of time for 480 seconds. The measurements were conducted in triplicate.

The stress relaxation data were analyzed by using the Peleg–Normand model (Equation 1), proposed by Peleg and Normand [23].

$$\frac{F_0 t}{F_0 - F(t)} = k_1 + k_2 t \qquad (1)$$

in which F_0 is the initial force, F(t) is the momentary force at time t, and k_1 and k_2 are constants. The k_1 and k_2 values are the intercept and slope of regressive straight line plotted by normalized force and time, respectively. Furthermore, the percent stress relaxation (%SR) was calculated by the following equation [24]:

$$\%SR = \frac{F_0 - F_{t=20}}{F_0} \times 100 \qquad (2)$$

in which F_0 is the initial force and $F_{t\,=\,20}$ is the force at 20 seconds after the initial strain was achieved.

2.5. *Texture of mantou*

Texture profile analysis of the center crumb sample was measured by a textural analyzer equipped with the P20 adapter moving at a rate of 2 mm/s; the penetration depth into the crumb sample was 20 mm. Hardness, cohesiveness, gumminess, and springiness were calculated using the texture profile analysis curve. The measurements were conducted in triplicate.

2.6. *Specific volume of mantou*

The cooled mantou was weighed and its volume was determined by seed displacement in a loaf volume meter. The specific volume was expressed as milliliters per gram (mL/g).

2.7. *Color of mantou*

The color of the mantou crust and crumb was measured using a HunterLab ColorFlex colorimeter (Hunter Associates Laboratory Inc., Reston, Virginia, VA), which was controlled by a computer that calculated color ordinates from the reflectance spectrum and was calibrated with a white standard tile. The mantou samples were placed in Petri dishes, and the color was recorded using the CIELab uniform color space at room temperature. Color determined by Commission Internationale l'Eclairage (CIE) classifies color in three dimensions: *L*, brightness; *a*, red to green color; and *b*, yellow to blue color. The measurements of every treatment were performed in six replicates.

2.8. *Sensory evaluation*

Fresh prepared mantou samples with 0–15% PCF substitutions were refrigerated for less than 2 days at 4°C. The reheated and cooled mantous were served at room temperature (26°C ± 2°C) under normal lighting conditions. Consumers' sensory evaluation of mantou was performed by 30 panelists, which consisted of students, employees, and visitors of Tajen University (Pingtung, Taiwan). Color, odor, texture and the overall preference of the mantou samples were evaluated by a seven-point hedonic scale: 1, "very unacceptable"; 2, "unacceptable"; 3, "mildly unacceptable"; 4, "neither unacceptable nor acceptable"; 5, "mildly acceptable"; 6, "acceptable"; and 7, "very acceptable."

2.9. *Statistical analysis*

Using SPSS software 13.0 (SPSS Chicago, IL), the data in triplicate, unless stated otherwise, were analyzed for different treatments by one-way ANOVA and Duncan's new multiple range tests to determine the statistical significance of differences among the values. Pearson's simple correlation analysis was also conducted for observing correlations between dough and mantou properties.

3. Results and discussion

The particle size of PCF used in this study was 104–149 μm (small), 149–250 μm (medium), and 250–420 μm (large). The total, insoluble, and soluble DFs of the PCF were 53.59%, 51.14%, and 2.45% (dry weight basis), respectively. This indicated that insoluble DF was the major fiber in PCF. Different fiber sizes did not affect the DF content of PCF. The swelling power of wheat flour and the three PCF fractions with small, medium, and large particle size was 2.23 ± 0.01 mL/g, 8.98 ± 0.03 mL/g, 11.44 ± 0.01 mL/g, and 11.96 ± 0.05 mL/g, respectively. The water-holding capacity was 1.32 ± 0.01 mL/g, 4.59 ± 0.01 mL/g, 7.58 ± 0.12 mL/g, and 7.65 ± 0.21 mL/g, respectively. The results indicated that the PCF had a higher swelling power and water-holding capacity than wheat flour, and that PCF with a small fiber size had a lower swelling power and water-holding capacity than PCF with a large fiber size. Our results were in agreement with the results in the study of Chien and Kang [16] that showed that small-particle pineapple pomace had a low swelling power and water-holding capacity.

3.1. *Dough rheology*

Table 1 lists the resistance to extension (R value) and extensibility (E value) of proofed and unfermented doughs enriched with various substitution levels and particle sizes of PCF. The R value was higher in the unfermented dough enriched with 15% PCF than in the dough enriched with 0–5% PCF. The E value of the dough without yeast decreased as the PCF substitution increased (0–15%). Hence, the addition of excessive PCF resulted in a stiffer and less extensible dough. The effect of PCF on the rheological properties of dough without yeast was consistent with previous research using different DFs, such as 30% apple pomace [13], 3% date flesh fiber concentrate [25], and 15–35% apple pomace [26]. In addition, insoluble wheat fiber resulted in a stiffer dough, probably through a filler-like effect in the dough matrix [14]. The negative effect on the formation of the gluten network by excess amounts of insoluble DF may be because of the dilution of gluten protein [7,8].

Substitution by PCF increases the R value and decreases the E value in proofed dough (Table 1). Because of the fermentation of yeast, the proofed dough generally had lower R and E values than dough without yeast. However, the particle size of the PCF did not significantly affect the R and E values of unfermented and proofed doughs (Table 1). The farinograph properties were not significantly affected by the particle size of barley fiber-rich fractions [27] and wheat bran [12]. However, Noort et al [12] also reported that dough with

Table 1 – The effect of pineapple core fiber on the resistance to extension and extensibility of dough.

PCF		Dough without yeast		Proofed dough	
Amount (%)	Particle size (μm)	R (mN)	E (mm)	R (mN)	E (mm)
0	250–420	408 ± 39[b]	28.78 ± 2.52[a]	240 ± 26[c]	26.21 ± 2.44[a]
5	250–420	411 ± 31[b]	22.73 ± 0.84[b]	330 ± 29[b]	19.36 ± 0.40[b]
10	250–420	454 ± 39[a,b]	19.97 ± 0.67[c]	354 ± 29[b]	18.97 ± 1.36[b]
15	250–420	489 ± 16[a]	15.80 ± 0.85[d]	421 ± 12[a]	13.31 ± 0.57[c]
10	250–420	454 ± 39[a]	19.97 ± 0.67[a]	354 ± 29[a]	18.97 ± 1.36[a]
10	149–250	426 ± 40[a]	18.44 ± 0.93[a]	336 ± 14[a]	16.51 ± 1.33[a]
10	104–149	429 ± 25[a]	18.50 ± 1.55[a]	362 ± 13[a]	17.77 ± 1.99[a]

The values are expressed as the mean ± standard deviation ($n = 3$). The mean values with different superscripted letters in the same column and section are significantly different ($p < 0.05$).
E = extensibility; PCF = pineapple core fiber; R = resistance to extension.

fine wheat bran had lower ability for the gluten protein to re-aggregate (i.e., gluten yield), compared to dough with coarse bran. Because no work in the literature has described the rheological properties of proofed dough with added fiber, it is impossible to compare our data with the results of other research studies.

3.2. *Texture of mantou*

Texture is an important mantou quality. Gluten protein is a main contributor to the strength of Chinese steamed bread [2]. Fig. 1 shows the effect of PCF on the texture and specific volume of mantou. The hardness and gumminess of mantou significantly increased with increasing the PCF substitution, but the cohesiveness, springiness and specific volume significantly decreased with the substitution.

Similar to the increase in the R value of the dough (Table 1), the PCF-enriched steamed bread had higher hardness and gumminess that resulted from the competition of water absorption between PCF and wheat flour components or from the rigid nature of the fiber. Because insoluble DF is the major type of DF in PCF, incorporating PCF into the dough system may interfere with the formation of the gluten network. This lowers cohesiveness, springiness, and specific volume of the PCF-enriched steamed bread.

Wu et al [3] report that hardness and springiness of 20–30% bran fiber-enriched steamed breads had higher hardness than breads with 0–10% wheat bran. Sangnark and Noomhorm [28] found that bread containing 5% fiber from rice straw had higher firmness and lower springiness, compared to the control bread. Kaack et al [11] found that the hardness of bread increased with the quantity (0–12%) of potato fiber containing a high content of insoluble DF. However, date flesh fiber concentrate added at 0–3% insignificantly decreased the bread volume. [25].

The particle size tested in this study did not affect hardness, cohesiveness, gumminess, and springiness values (data not shown); however, the specific volume (2.95 mL/g) of 10% PCF-enriched mantou with the smallest fiber size (104–149 μm) was significantly higher ($p < 0.05$) than the specific volume (2.67 mL/g and 2.75 mL/g) with the medium fiber size (149–250 μm) and large fiber size (250–420 μm). Our results were similar to the studies of bread reported by Curti et al [29], Izydorczyk et al, [27], Lai et al [10], and Chien and Kang [16]. Different particle size of wheat bran fractions [29] and barley fiber-rich fractions [27] did not significantly affect the hardness of bread. Coarse pineapple pomace [16] and bran [10] had adverse effects on bread volume. However, the impact of the fiber size on baked bread quality is contentious at present. de Kock et al [30] found that coarse bran particles produced better baking results than finely ground bran. Noort et al [12] report that bread volume is higher when the particle size of wheat bran is increased. Hence more study using various fiber sources and sizes is needed to explain the

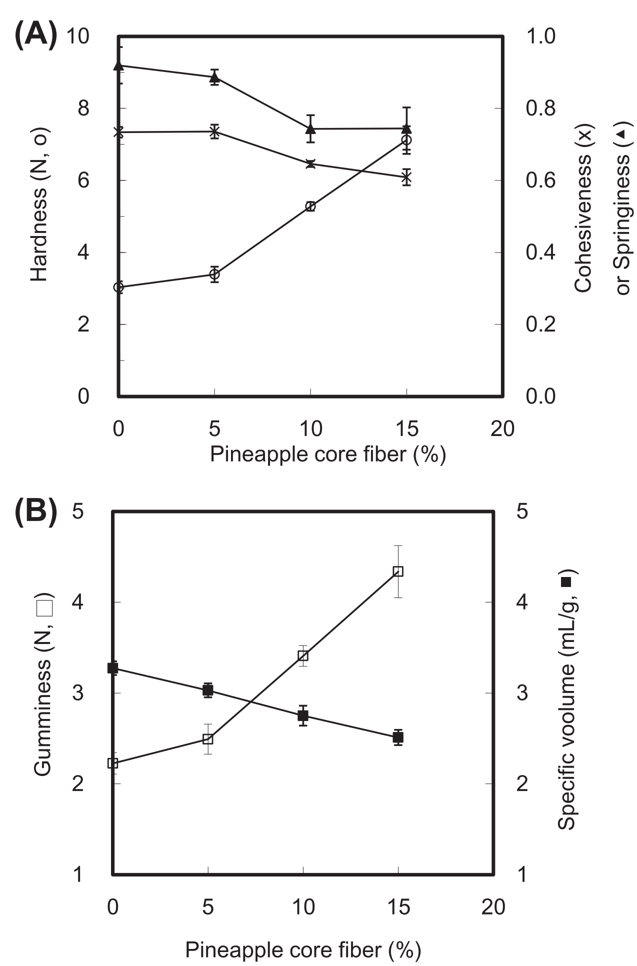

Fig. 1 – The effect of pineapple core fiber on (A) the textural properties and (B) the specific volume of mantou.

Table 2 – The effect of pineapple core fiber on the stress relaxation parameters of mantou.

PCF amount (%)	PCF particle size (μm)	%SR	F_0 (N)	k_1 (s)	k_2	R^2
0	250–420	22.05 ± 0.85[c]	0.97 ± 0.04[c]	49.6 ± 1.9[a]	2.65 ± 0.08[a]	0.998
5	250–420	23.14 ± 1.16[c]	0.88 ± 0.03[c]	48.7 ± 2.8[a]	2.58 ± 0.09[a]	0.997
10	250–420	27.06 ± 1.19[b]	1.21 ± 0.06[b]	40.9 ± 2.4[b]	2.32 ± 0.04[b]	0.998
15	250–420	29.62 ± 1.18[a]	1.48 ± 0.12[a]	36.0 ± 2.5[c]	2.17 ± 0.06[c]	0.998
10	250–420	27.06 ± 1.19[a]	1.21 ± 0.06[b]	40.9 ± 2.4[b]	2.32 ± 0.04[b]	0.998
10	149–250	26.02 ± 1.02[a]	1.25 ± 0.09[b]	42.2 ± 2.0[b]	2.43 ± 0.08[b]	0.998
10	104–149	24.96 ± 1.28[a]	1.38 ± 0.09[a]	47.6 ± 2.8[a]	2.62 ± 0.05[a]	0.998

Values are expressed as the mean ± standard deviation ($n = 3$). The mean values with different superscripted letters in the same column and section are significantly different ($p < 0.05$).
F_0 = initial force; k_1, and k_2 = constant parameters in the Peleg–Normand model; PCF = pineapple core fiber; R^2 = coefficient of determination; %SR = percent stress relaxation.

mechanism related to the effect of fiber size on dough and mantou properties.

3.3. *Stress relaxation of mantou*

Fundamental viscoelastic properties of foods have frequently been measured by stress relaxation. Table 2 lists the fitting parameters of the Peleg–Normand model for mantou with various amounts and particle sizes of PCF. Results showed that the stress relaxation data of mantou in this study were well fitted ($R^2 > 0.99$) to the Peleg–Normand model (Equation 1). Thus we could obtain the F_0, k_1, and k_2 parameters by regression. A high k_1 value indicates a pronounced elastic behavior. The k_2 value is representative of the degree of solidity and it varies from 1 (for a material that is truly a liquid) to infinity (for an ideal elastic solid in which the stress does not relax) [23].

The F_0 (i.e., initial force) parameter of mantou increases with the increased PCF substitution. However, the k_1 and k_2 parameters of mantou significantly reduces with increased PCF substitution (Table 2). Hence, 10–15% PCF-enriched mantous were more rigid and less elastic than mantous with 0–5% PCF. The increasing and decreasing patterns of mantou in F_0, k_1, and k_2 in the Peleg–Normand model (Table 2) were consistent with hardness and springiness, respectively (Fig. 1). The result of stress relaxation in this study was similar to the study of Wu et al [3], which showed that increasing the substitution of wheat flour by wheat bran resulted in less elasticity of steamed bread. Li et al [31] indicate that the relaxation properties of dough depend on gluten protein. Zhang et al [32] found a moderate correlation coefficient ($r = 0.55$–0.61) between stress relaxation of steamed bread and gluten in a fraction of wheat cultivar.

Furthermore, 10% PCF-enriched mantou with a small fiber size (104–149 μm) had significantly higher k_1 and k_2 values and a lower F_0 value than PCF-enriched mantou with medium and large fiber size (149–420 μm) (Table 2). At present, no work was found in the literature in appropriating the Peleg–Normand model to describe the viscoelastic properties of fiber-enriched mantou or bread with different fiber size.

The %SR is a convenient and informative parameter to understand the viscoelastic properties of food products, and is obtained directly from the plot of stress relaxation versus time plot at an arbitrary time [24]. The %SR is 0 for an ideal elastic solid, and the %SR is 100 for an ideal liquid. The results showed that %SR of mantou tested ranged 22.05–29.62 (Table 2). Thus, mantou was classified as a viscoelastic solid. Furthermore, the %SR of mantou obviously increased with increasing amount of PCF. Wu et al [3] report that the addition of wheat bran increased the %SR value of steamed bread. Dough from strong wheat cultivars exhibited slower rates of stress relaxation and higher storage modulus, compared to moderate, weak, and very weak cultivars [33]. However, the particle size of PCF did not significantly affect the %SR of mantou (Table 2).

3.4. *Color of mantou*

Color is an important quality indicator for food products. Table 3 shows the effect of PCF on the color of mantou. The White index and Hunter L value, which indicate the luminosity of the sample, were significantly lower in the crust and crumb of mantou with PCF than in the control. Both *a* (redness) and *b* (yellowness) values of the crust and crumb of mantou increased with the substitution by PCF. However, the particle size of PCF tested did not significantly affect the *L*, *a*, and *b* values of mantou crust and crumb ($p > 0.05$). Therefore, the color of mantou was primarily affected by the amount of PCF. Chien and Kang [16] found that bread crumb with pineapple pomace had lower *L* and higher *b* values and that the color of the crumb was not influenced by the particle size of pineapple pomace. Borchani et al [25] reported that bread with 3% date flesh fiber concentrate was darker, redder, and less yellow in comparison to the control bread.

3.5. *Sensory evaluation of mantou*

Pineapple core fiber substitution or particle size significantly affected the quality of mantou, as measured instrumentally (Tables 1–3 and Fig. 1). In general, objective instrumental measurements have higher sensitivity, compared to subjective sensory evaluation. Table 4 shows the result of the consumers' sensory assessment of mantou with PCF. The sensory scores of the 5% PCF-enriched mantou and the control mantou were not significantly different ($p > 0.05$). The mantou enriched with 10% PCF and 15% PCF substitutions had significantly ($p < 0.05$) lower sensory scores in color, odor, texture and overall acceptability, compared to the 5% PCF-enriched

Table 3 – Effect of pineapple core fiber on the color of mantou

PCF Amount (%)	PCF Particle size (μm)	Position	L	a	b	White index
0	250–420	Crust	69.29 ± 0.57^{a}	−0.09 ± 0.09^{d}	11.97 ± 0.43^{d}	67.04 ± 0.65^{d}
5	250–420	Crust	65.74 ± 0.47^{b}	1.19 ± 0.19^{c}	14.70 ± 0.56^{c}	62.70 ± 0.45^{c}
10	250–420	Crust	62.86 ± 0.19^{c}	2.69 ± 0.15^{b}	17.49 ± 0.23^{b}	58.86 ± 0.22^{b}
15	250–420	Crust	59.03 ± 0.12^{d}	3.63 ± 0.23^{a}	18.09 ± 0.16^{a}	55.07 ± 0.11^{a}
10	250–420	Crust	62.86 ± 0.19^{a}	2.69 ± 0.15^{a}	17.49 ± 0.23^{a}	58.86 ± 0.22^{a}
10	149–250	Crust	62.63 ± 0.43^{a}	2.87 ± 0.17^{a}	17.88 ± 0.16^{a}	57.99 ± 0.41^{a}
10	104–149	Crust	63.53 ± 0.40^{a}	2.54 ± 0.25^{a}	17.67 ± 0.31^{a}	58.59 ± 0.56^{a}
0	250–420	Crumb	68.94 ± 0.53^{a}	0.14 ± 0.22^{d}	12.92 ± 0.41^{d}	66.36 ± 0.59^{d}
5	250–420	Crumb	68.73 ± 0.47^{a}	1.44 ± 0.10^{c}	14.61 ± 0.27^{c}	65.45 ± 0.46^{c}
10	250–420	Crumb	62.93 ± 0.58^{b}	2.81 ± 0.17^{b}	16.15 ± 0.35^{b}	59.46 ± 0.59^{b}
15	250–420	Crumb	60.24 ± 0.70^{c}	3.53 ± 0.18^{a}	17.14 ± 0.60^{a}	56.55 ± 0.65^{a}
10	250–420	Crumb	62.93 ± 0.58^{a}	2.81 ± 0.17^{a}	16.15 ± 0.35^{a}	59.46 ± 0.59^{a}
10	149–250	Crumb	63.28 ± 0.42^{a}	2.91 ± 0.10^{a}	16.47 ± 0.30^{a}	59.50 ± 0.52^{a}
10	104–149	Crumb	62.50 ± 0.41^{a}	3.07 ± 0.15^{a}	16.64 ± 0.23^{a}	58.99 ± 0.51^{a}

Values are expressed as the mean ± standard deviation ($n = 3$). The mean values with different superscripted letters in the same column and section are significantly different ($p < 0.05$).
a = redness value; b = yellowness value; L = brightness value; PCF = pineapple core fiber.

and control mantous. The mantou enriched with the highest substitution (i.e., 15% PCF) had the lowest sensory scores in color, odor, texture and overall acceptability. However, the tested fiber sizes did not significantly affect the consumers' sensory assessment of mantou. Therefore, we suggest fiber-enriched mantou can be prepared with 5% PCF to increase the intake of DF and maintain sensory acceptability by consumers. Steamed bread with 0–20% wheat bran had higher sensory scores than bread with 30% bran [3]. Compared to the control bread, all breads containing various amounts (3–6%) and particle sizes of pineapple pomace had similar sensory scores in texture, flavor, and overall acceptability [16]. Borchani et al [25] report that the addition of 0–3% date flesh fiber concentrate did not significantly affect the overall acceptability of the bread.

3.6. *Correlation coefficients between dough and mantou properties*

Table 5 lists the correlation coefficients between dough and mantou properties. The R_p and R_u values (resistance to extension) of the proofed and unfermented doughs, respectively, were positively correlated with hardness and the %SR, and was negatively correlated with a specific volume, sensory texture, and overall scores. The extensibility (E_p and E_u) of the proofed and unfermented doughs were positively correlated with the specific volume, and negatively correlated with hardness and %SR. The results showed that the extensibility of dough is crucial to the specific volume and elasticity of fiber-enriched mantou. The hardness of mantou was positively correlated with R_u, R_p, %SR, and F_0; and negatively correlated with E_u, E_p, specific volume, k_1, k_2, and sensory texture, and overall scores. The springiness of mantou was positively correlated to E_u, and specific volume. The fitting parameters (k_1 and k_2) were positively correlated with the specific volume, and negatively correlated with R_u, hardness, $F_{0,}$ and %SR. The sensory texture and overall scores were negatively correlated with R_u, R_p, hardness, and %SR. The results indicate a good relationship between rheological properties of dough and textural parameters of mantou and between sensory quality and textural parameters of mantou. Significant correlations existed between the textural

Table 4 – Consumers' sensory evaluation of mantou enriched with different amounts and particle sizes of pineapple core fiber.

PCF Amount (%)	PCF Particle size (μm)	Color	Odor	Texture	Overall
0	250–420	5.40 ± 1.28^{a}	4.97 ± 1.35^{a}	5.53 ± 1.01^{a}	5.23 ± 1.17^{a}
5	250–420	4.97 ± 1.19^{ab}	4.87 ± 1.28^{a}	5.40 ± 1.04^{a}	4.97 ± 1.03^{a}
10	250–420	4.50 ± 1.17^{b}	4.13 ± 1.22^{b}	4.57 ± 1.36^{b}	4.33 ± 1.21^{b}
15	250–420	4.34 ± 1.08^{b}	4.07 ± 0.91^{b}	3.82 ± 1.16^{c}	4.25 ± 1.15^{b}
10	250–420	4.50 ± 1.17^{a}	4.13 ± 1.22^{a}	4.57 ± 1.36^{a}	4.33 ± 1.21^{a}
10	149–250	4.57 ± 1.08^{a}	4.60 ± 1.25^{a}	5.03 ± 1.35^{a}	4.97 ± 1.19^{a}
10	104–149	4.70 ± 1.21^{a}	4.61 ± 1.16^{a}	4.90 ± 1.37^{a}	4.57 ± 1.28^{a}

The mean values with the same superscripted letter within the same column and section are not significantly different at the 5% level.
PCF = pineapple core fiber.

Table 5 – Correlation coefficients between dough and mantou properties.

	R_u	E_u	R_p	E_p	Hardness	Cohesiveness	Springiness	Sp. V	%SR	F_0	k_1	k_2	Texture	Overall
R_u	1.000													
E_u	−0.733	1.000												
R_p	0.829*	−0.949**	1.000											
E_p	−0.731	0.976**	−0.953**	1.000										
Hardness	0.935**	−0.892*	0.888*	−0.873*	1.000									
Cohesiveness	−0.812*	0.875*	−0.786	0.800	−0.948**	1.000								
Springiness	−0.586	0.851*	−0.675	0.772	−0.802	0.909*	1.000							
Sp. V	−0.834*	0.910*	−0.865*	0.917*	−0.938**	0.883*	0.870*	1.000						
%SR	0.956**	−0.866*	0.881*	−0.852*	0.985**	−0.912*	−0.787	−0.954**	1.000					
F_0	0.781	−0.832*	0.773	−0.750	0.907*	−0.958**	−0.783	−0.759	0.834*	1.000				
k_1	−0.929**	0.758	−0.769	0.769	−0.936**	0.846*	0.745	0.941**	−0.971**	−0.726	1.000			
k_2	−0.929**	0.697	−0.750	0.725	−0.885*	0.755	0.651	0.903*	−0.943**	−0.624	0.985**	1.000		
Texture	−0.993**	0.800	−0.876*	0.789	−0.964**	0.858*	0.642	0.860*	−0.970**	−0.839*	0.921**	0.905*	1.000	
Overall	−0.891*	0.775	−0.871*	0.711	−0.838*	0.767	0.590	0.735	−0.866*	−0.759	0.758	0.762	0.907*	1.000

* Indicates a significant difference at $p < 0.05$.

** Indicates a significant difference at $p < 0.01$.

E_p and E_u, extensibility of proofed dough and unfermented dough, respectively; F_0, k_1, and k_2 = the fitted parameters of the Peleg–Normand model; R_p and R_u = resistance to extension of proofed dough and unfermented dough, respectively; Sp. V = specific volume; Texture = the textural score in sensory evaluation.

characteristics and stress relaxation parameters of bran-enriched steamed bread [3].

4. Conclusion

Pineapple core fiber substitution made unfermented and proofed doughs stiffer and less extensible. The hardness, gumminess, F_0, and %SR of mantou significantly increased with increased PCF substitution (0–15%); however, the cohesiveness, springiness, specific volume, k_1, and k_2 significantly decreased with the substitution. Pineapple core fiber with a small fiber size had lower swelling power and water-holding capacity, compared to the large fiber size; however, 10% PCF-enriched dough and mantou with various fiber sizes had similar rheological and textural properties, except for the k_1 and k_2 values. Based on colorimetry, the color of mantou was darker, redder, and more yellow with the enrichment by PCF. The sensory quality of mantou with 5% PCF was similar to that of the control bread. Therefore, PCF could be supplied as a potential source of DF, and a good-quality fiber-enriched mantou could be produced by the substitution of 5% PCF in wheat flour.

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REFERENCES

[1] Rubenthaler GL, Pomeranz Y, Huang ML. Steamed bread. IV. Negative steamer-spring of strong flours. Cereal Chem 1992;69:334–7.

[2] Zhu J, Huang S, Khan K, O'Brien L. Relationship of protein quantity, quality and dough properties with Chinese steamed bread quality. J Cereal Sci 2001;33:205–12.

[3] Wu MY, Chang YH, Shiau SY, Chen CC. Rheology of fiber-enriched steamed bread: stress relaxation and texture profile analysis. J Food Drug Anal 2012;20:133–42.

[4] Anderson JW, Baird P, Davis Jr RH, Ferreri S, Knudtson M, Koraym A, Waters V, Williams CL. Health benefits of dietary fiber. Nutr Rev 2009;67:188–205.

[5] Lupton JR. From basic science to dietary guidance: dietary fiber as an example. J Food Drug Anal 2012;20(Suppl. 1):S346–9.

[6] Sivam AS, Sun-Waterhouse D, Quek S, Perera CO. Properties of bread dough with added fiber polysaccharides and phenolic antioxidants: a review. J Food Sci 2010;75:R163–74.

[7] Wang M, Hamer RJ, van Vliet T, Gruppen H, Marseille H, Weegels PL. Effect of water unextractable solids on gluten formation and properties: mechanistic considerations. J Cereal Sci 2003;37:55–64.

[8] Ahmed J, Almusallam AS, Al-Salman F, AbdulRahman MH, Ebtihal Al-Salem E. Rheological properties of water insoluble date fiber incorporated wheat flour dough. LWT—Food Science and Technology 2013;51:409–16.

[9] Masoodi FA, Chauhan GS. Use of apple pomace as a source of dietary fiber in wheat bread. J Food Process Preserv 1998;22:255–63.
[10] Lai CS, Hoseney RC, Davis AB. Effects of wheat bran in breadmaking. Cereal Chem. 1989;66:217–9.
[11] Kaack K, Pedersen L, Laerke HN, Meyer A. New potato fibre for improvement of texture and colour of wheat bread. Eur Food Res Technol 2006;224:199–207.
[12] Noort MWJ, van Haaster D, Hemery Y, Schols HA, Hamer RJ. The effect of particle size of wheat bran fractions on bread quality—evidence for fibre protein interactions. J Cereal Sci 2010;52:59–64.
[13] Sudha ML, Baskaran V, Leelavathi K. Apple pomace as a source of dietary fiber and polyphenols and its effect on the rheological characteristics and cake making. Food Chem 2007;104:686–92.
[14] Bonnand-Ducasse M, Della Valle G, Lefebvre J, Saulnier L. Effect of wheat dietary fibres on bread dough development and rheological properties. J Cereal Sci 2010;52:200–6.
[15] Saksiri S. Acceptability of high pineapple core fiber low calorie cake. MSD thesis. Bangkok, Thailand: Mahidol University; 1992.
[16] Chien SP, Kang PT. Functional and baking properties of pineapple core for bread making. Taiwan J Agric Chem Food Sci 2008;46:7–13 [in Chinese, English abstract].
[17] Martínez R, Torres P, Meneses MA, Figueroa JG, Pérez-Álvarez JA, Viuda-Martos M. Chemical, technological and *in vitro* antioxidant properties of mango, guava, pineapple and passion fruit dietary fibre concentrate. Food Chem 2012;135:1520–6.
[18] Lou SN, Hsu YS, Ho CT. Flavonoid compositions and antioxidant activity of calamondin extracts prepared using different solvents. J Food Drug Anal 2014;22:290–5.
[19] Prakongpan T, Nitithamyong A, Luangpituksa P. Extraction and application of dietary fiber and cellulose from pineapple cores. J Food Sci 2002;67:1308–13.
[20] AACC International. Approved methods of the AACC. 10th ed. Saint Paul, MN, USA: AACC International; 2000.
[21] AOAC International. Approved methods of the AOAC. 17th ed. Washington, DC, USA: AOAC International; 2000.
[22] Huang YL, Chow CJ, Fang YJ. Preparation and physicochemical properties of fiber-rich fraction from pineapple peels as a potential ingredient. J Food Drug Anal 2011;19:318–23.
[23] Peleg M, Normand MD. Comparison of two methods for stress relaxation data presentation of solid foods. Rheol Acta 1983;22:108–13.
[24] Hatcher DW, Bellido GG, Dexter JE, Anderson MJ, Fu BX. Investigation of uniaxial stress relaxation parameters to characterize the texture of yellow alkaline noodles made from durum and common wheats. J Texture Stud 2008;39:695–708.
[25] Borchani C, Masmoudi M, Besbes S, Attia H, Deroanne C, Blecker C. Effect of date flesh fiber concentrate addition on dough performance and bread quality. J Texture Stud 2011;42:300–8.
[26] Ktenioudaki A, O'Shea N, Gallagher E. Rheological properties of wheat dough supplemented with functional by-products of food processing: brewer's spent grain and apple pomace. J Food Eng 2013;116:362–8.
[27] Izydorczyk MS, Chornick TL, Paulley FG, Edwards NM, Dexter JE. Physicochemical properties of hull-less barley fibre-rich fractions varying in particle size and their potential as functional ingredients in two-layer flat bread. Food Chem 2008;108:561–70.
[28] Sangnark A, Noomhorm A. Chemical, physical and baking properties of dietary fiber prepared from rice straw. Food Res Int 2004;37:66–74.
[29] Curti E, Carini E, Bonacini G, Tribuzio G, Vittadini E. Effect of the addition of bran fractions on bread properties. J Cereal Sci 2013;57:325–32.
[30] De Kock S, Taylor J, Taylor JRN. Effect of heat treatment and particle size of different brans on loaf volume of brown bread. LWT—Food Science and Technology 1999;32:349–56.
[31] Li W, Dobraszczyk BJ, Schofield JD. Stress relaxation behavior of wheat dough, gluten, and gluten protein fractions. Cereal Chem 2003;80:333–8.
[32] Zhang PP, He ZH, Chen DS, Zhang Y, Larroque OR, Xia XC. Contribution of common wheat protein fractions to dough properties and quality of northern-style Chinese steamed bread. J Cereal Sci 2007;46:1–10.
[33] Rao VK, Mulvaney SJ, Dexter JE, Edwards NM, Peressinif D. Stress-relaxation properties of mixograph semolina-water doughs from durum wheat cultivars of variable strength in relation to mixing characteristics, bread- and pasta-making performance. J Cereal Sci 2001;34:215–32.