The Effect of Oat Bran on the Dough Rheology and Quality of Chinese Steamed Bread

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Abstract: The present study investigates the effects of incorporating oat bran (OB) into Chinese steamed bread (CSB). Different levels (5%, 10% and 15%) of OB were used to replace wheat flour in the manufacture of CSB. The rheological properties of the dough were measured (water absorption (WA), development time, mixing tolerance, extensibility and stickiness). The addition of OB significantly increased WA, development time and stickiness, whereas decreased extensibility of dough. The physical properties of CSB were determined using specific volume, loaf height, moisture, and texture analysis. The nutritional quality of the bread was also analysed using an *in vitro* digestion method mimicking intestinal digestion. The results illustrated that the incorporation of OB into wheat flour decreases specific volume and softness of CSB. The addition of OB decreased the glycaemic response of steamed bread. This study illustrates the potential addition of OB to improve the nutritional quality of CSB.

Keywords: Oat bran; Dough rheology; Glycaemic response

1 Introduction

Oat bran (OB) is a low-cost by-product produced during oat milling, and is a good source of dietary fibre (DF)^[1]. The main DF component of OB is β -glucan, which is a natural polymer composed of glucose molecules joined by β -(1-3) and β -(1-4) glycoside bonds^[2-3]. β -glucan can easily form the viscous solutions and has been shown to slow the intestinal transit rate, delay gastric emptying and slow glucose and sterol absorption in the intestine^[4]. Previous studies have illustrated that OB β -glucan has other beneficial effects, such as attenuation of postprandial blood glucose, reduction in insulin responses and a decrease in serum LDL cholesterol levels^[5-6]. Additionally, OB has a potential role for disease prevention and control such as coronary heart disease, diabetes and obesity^[7-8].

Currently, consumers have a growing awareness of the link between diet and nutrition, thus there has been an increased demand for healthier products with a consequent rise in interest in functional and nutritional items by the food industry^[9-12]. As a functional ingredient, DF has been proven to have many health beneficial effects and a potential role for disease prevention^[13-16]. Therefore, at present the major goal of scientists is to incorporate the cereal brans into cereal-based and other food products in order to increase the intake of DF. OB is an important source of DF and common ingredient added to food products, especially bread. Most of studies in this area focus on Western bread, due to the addition of bran is detrimental to the baking performance^[17]. Previous researches reported that the addition of OB led to higher water absorption (WA), stickier dough and lower loaf volume^[17-18]. However, there is a paucity of information regarding the effect of

OB on the quality of Chinese steamed bread (CSB).

CSB, also known as mantou, is a traditional fermented food and widely consumed as a staple food in China. Currently, steamed bread has widely spread to other Asian countries, North America and some European countries, and is estimated to account for around 15% of the wheat consumption in these regions^[19]. Due to the differences in processing, the properties of CSB and Western style baked bread are significantly different. For instance, the flavours of CSB are formed during the fermentation, while the flavours of western style breads are derived during baking by Maillard reaction^[20]. In addition, the lower processing temperature (100 °C) may result in the greater retention of nutrients in CSB^[21].

Hence, the present study investigated the effects of incorporating OB into CSB. Different levels (0, 5%, 10% and 15%) of OB were added into wheat flour. The quality of CSB was analysed from two perspectives: physical properties and nutritional quality. For physical properties, specific volume, loaf height, moisture, and texture were measured by AACC methods. The nutritional quality of the bread was analysed using the glycaemic response determined by an *in vitro* digestion method. The research aimed to determine whether the use of OB in CSB could provide CSB with similar physical properties to a control CSB, and also if the addition of OB could reduce the glycaemic response of the CSB hence improving its nutritional quality in terms of postprandial glycaemia.

2 Materials and Methods

2.1 Materials and Reagents

Wheat flour (Champion Flour Milling Ltd., Christchurch, New Zealand), Oat bran (Sun Valley Foods Ltd., Auckland, New Zealand), yeast powder and salt were purchased at the local supermarket (Table 1). Megazyme analysis kit (Megazyme International Ireland Ltd., Wicklow, Ireland) were used to determine starch content of the breads.

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Table 1 Nutrition information

Per 100 g	Wheat flour (g)	Oat bran (g)
Protein	11.0	10.5
Fat, total	1.4	9.9
- saturated	<1	2.0
Carbohydrate	77.3	44.3
- sugars	<1	2.9
Dietary fibre	3.1	10.0
Sodium	0.005	0.003

Note: Supplied by Sun Valley Foods Ltd. and Champion Flour Milling Ltd.

2.2 Dough Rheological Analysis

The dough rheological properties were measured using a Dough LAB (Perten Instruments Australia, Macquarie Park, Australia) following AACC standard method. A 300 g mixing bowl was used for all measurements and tests were performed at $(30 \pm 1)^\circ\text{C}$. The weight of the dough ingredients was adjusted according to the moisture content of the samples to obtain consistency in moisture contents and WA (as is) was corrected to 500 FU. Dough development time, stability, softening, mixing tolerance index (MTI), and departure time were all measured using Dough LAB software (ver. 1.3.0.185). Analysis was performed three times.

2.3 Preparation of CSB with OB

CSB loaves were produced using the formulation of Lin et al.^[20] with some modifications. The recipe consisted of wheat flour (200 g), yeast powder (4 g), salt (1 g), and water (to give a maximum consistency of 500 FU). The dough and steamed bread were prepared by replacing wheat flour with different levels of OB (5, 10 and 15 g/100 g W/W based on wheat flour dry weight). The dough was formed by using stand mixer (BBEK1092, Briscoes New Zealand Ltd.) for 5 min and kneading by hand for 5 min, then it was rested at 28°C for 5 min. After that, the dough pieces were divided into two portions, one was used for analysis of dough extension and stickiness, the other was kneaded for a further 8 min before fermentation in an incubator at 30°C for 30 min. After fermentation, the dough was rolled out, and allowed to rise at 30°C for 25 min. Finally, the dough pieces were placed in a Convotherm mini easy Touch oven (CONVOTHERM Elektrogeräte GmbH, Germany) and steamed for 20 min. Steamed bread loaves were cooled to room temperature and then analysed.

2.4 Moisture Content Analysis

Moisture content of the dough and bread was determined by an oven drying method ($(105 \pm 2)^\circ\text{C}$ overnight) described by AACC International Approved Method 44-16.01. The analysis was performed in triplicate and the results were expressed as g water/100 g sample.

2.5 Physical Properties of CSB Incorporated with OB

Volume of steamed bread loaves were measured using the rapeseed displacement method, following the AACC International Approved Method 10-05.01. The measurements were carried out in triplicate.

The specific volume of steamed bread was calculated by dividing loaf volume by loaf weight, according to the AACCI Approved Method 10-05.01. The measurements were performed in triplicate.

The texture properties of steamed bread were determined using TA-XT2 Texture Analyser (Stable Micro Systems, Surrey, England) equipped with a 25 mm diameter cylinder probe.

2.6 Total Starch Analysis

The total starch determination of the steamed bread was carried out with the Megazyme Total Starch analysis kit (Megazyme International Ireland Ltd., Wicklow, Ireland) following AACCI Approved Method 76-13.01 as described by Brennan et al.^[22].

2.7 Glycaemic Response Analysis

In vitro Method Analysis: An *in vitro* glycaemic measurement as described by Brennan et al.^[23]. Milled samples of bread were treated to *in vitro* using 10% pepsin dissolved in 0.05 mol/L HCl for 30 min at 37°C under constant stirring to accomplish gastric digestion. Starch digestion was continued using 0.1 mL amyloglucosidase and 5 mL of 2.5% pancreatin in 0.1 mol/L Na maleate buffer pH 6 at 37°C for 120 min with constant mixing. Triplicate 1 mL aliquots were placed in 4 mL ethanol at 20, 60 and 120 min and reducing sugar values were measured by the DNS method, using glucose references^[24]. Each sample was measured in triplicate.

2.8 Statistical Analysis

All data were treated using analysis of variance (ANOVA) by using Minitab 17 statistical software, version 17.2.1 (Minitab Pty Ltd., Sydney) at Tukey's significant differences level $P < 0.05$ ^[25].

3 Results and Discussion

3.1 Rheological Properties of Dough Incorporated with OB

The effects of OB on the rheological properties of CSB dough are presented in Table 2. In terms of WA, there was a significant ($P < 0.05$) increase from 63.67% to 67.77% as the addition of OB levels increased from 0 to 15%. Similar results were observed by Rieder et al.^[26] who observed that the substitution of wheat flour with OB significantly increased the WA due to the high fibre content. Dhinda et al.^[27] illustrated the addition of OB significantly increased the WA of wheat flour dough because of the high hydration property of DF. These observations can be attributed to the large number of hydroxyl groups in the structure of DF, which can interact with the hydrogen bonds of water^[28-29]. The development time is the time taken for mixing the dough to reach the peak consistency (500 FU). The addition of OB increased the development time from 2.73 to 9.5 min, whereas there was no significant difference between 10% and 15% OB. This observation is consistent with Rieder et al.^[26], who pointed out the inclusion of OB led to an increase in development time due to high water binding capacity of DF and disturbance of gluten network of DF. Krishnan et al.^[18] have illustrated that the addition of 10% and 15% OB to wheat flour can increase the dough development time. With regards to MTI and departure time, dough incorporated with OB has high values than wheat flour dough. This effect could be related to the high content of soluble fibre in OB. Similar effects on MTI

and departure time were observed by Sudha et al.^[30] who reported that the addition of OB significantly increased the MTI. The dough stability results are presented in Table 2. The highest stability value (14.7 min) was observed with the substitution level of 5% OB. However, there was a significant decrease in the dough stability after the addition of 5% OB. This observation is consistent with the research of Liu et al.^[31] where the stability increased as the addition levels of bran increased from 0 to 5%, and stability values decreased with levels of inclusion higher than 10%.

3.2 Extensibility and Stickiness of Dough

The effect of OB on the dough extensibility and stickiness are presented in Table 3. The extensibility decreased significantly ($P < 0.05$) from 37.06 to 11.27 mm when the substitution of OB increased from 0 to 15%. This effect could be related to the disruption of the starch-gluten network by OB. Similar results were observed by Rieder et al.^[26] who illustrated the addition of OB significantly decreased the extensibility and resistance to extension due to dilution of wheat gluten. In addition, Liu et al.^[31] pointed out the addition of bran reduced the dough extensibility owing to the interactions between fibre and wheat gluten. For the extension, a decrease was observed as the substitution of 15% OB, although there was no significant difference between 5% and 10%. Sudha et al.^[32] and Skendi et al.^[33] both illustrated that the addition of bran negatively affects the gluten network due to the disruption of starch-gluten matrix by bran. The effect could also be related to the percentage of bran added, the bran source, and particle size^[34-36].

Dough stickiness increased significantly ($P < 0.05$) from 46.22 to 54.87 g when the OB substitution increased from 0 to 15%. Campbell et al.^[17] reported that the addition of OB increased the dough stickiness due to the higher content of soluble fibre (β -glucan). This effect could be attributed to the unbound water in β -glucan and starch-gluten system. The excess water in the β -glucan and wheat gluten dough that is not bound by proteins

and this seems to be responsible for the increased stickiness^[37].

3.3 The Physical and Textural Properties of CSB

Table 4 shows that the addition of OB to CSB influenced the physical properties of CSB from the specific volume, loaf height and moisture. In terms of specific volume and loaf height, a significant ($P < 0.05$) decrease was observed as the substitution of OB increased from 0 to 15%. These observations are consistent with Rieder et al.^[26] who reported that the addition of wheat and OB led to a significant decrease in bread volume compared to bread made with wheat flour. Additionally, Liu et al.^[31] illustrated that the addition of wheat bran resulted in poor quality of CSB, such as a reduction of specific volume and loaf height. These observations can be attributed to the dilution of gluten in wheat flour-based dough and disrupting the hydration of gluten^[20, 27, 31]. The moisture of CSB significantly increased when the substitution of OB increased due to the water holding capacity of DF^[38-39].

The influence of OB on the textural properties of CSB from hardness, springiness, cohesiveness, gumminess, chewiness and resilience are presented in Table 5. There was a significant ($P < 0.05$) increase in hardness, gumminess and chewiness as the substitution of OB increased from 0 to 15%. Compared to control CSB, a slight increase was observed among 5%, 10% and 15%, whereas there was no significant difference. In terms of cohesiveness and resilience, only CSB incorporated with 15% OB had lower values than control CSB, while no significant differences were observed among 0, 5% and 10%. Similar trend was observed by Liu et al.^[31], who illustrated that the addition of bran increased the hardness, gumminess and chewiness of CSB, whereas reduced the springiness and cohesiveness. In addition, Rieder et al.^[26] reported that bread incorporated with OB had a higher crumb firmness than wheat bread owing to the β -glucan content and molecular weight. Previous research has illustrated that OB has a higher molecular weight of β -glucan than oat flour, this β -glucan may disrupt the reaction between starch and protein in wheat flour, resulting in the CSB being hard and less springy^[20,31,40-42].

Table 2 The rheology of dough incorporated with OB

Sample	WA (%)	Stability (min)	Development time (min)	Softening (FU)	Departure time (min)	MTI (FU)
Wheat flour	63.67±0.11 ^D	11.17±0.47 ^C	2.73±0.06 ^C	41.46±4.11 ^A	12.72±0.85 ^B	10.51±1.10 ^B
Wheat flour + 5% OB	64.73±0.11 ^C	14.70±0.60 ^A	7.73±0.21 ^B	37.83±1.34 ^A	16.60±0.53 ^A	21.83±1.27 ^A
Wheat flour + 10% OB	66.30±0.17 ^B	12.73±0.11 ^B	9.26±0.31 ^A	37.90±1.04 ^A	16.93±0.11 ^A	20.06±0.25 ^A
Wheat flour + 15% OB	67.77±0.45 ^A	10.50±0.36 ^C	9.50±0.20 ^A	38.63±0.38 ^A	16.13±0.06 ^A	22.20±0.91 ^A

Note: Values are means±standard deviations ($n = 3$). Values in the same column with different letters differ significantly ($P < 0.05$). WA: water absorption, MTI: mixing tolerance index, OB: oat bran.

Table 3 Extensibility and stickiness of dough incorporated with OB

Dough samples	Stickiness (g)	Cohesiveness (mm)	Extension(g)	Extensibility (mm)
Control	46.22±1.94 ^C	4.46±0.72 ^A	38.99±4.78 ^A	37.06±0.51 ^A
Dough + 5% OB	48.63±0.78 ^{BC}	2.73±0.14 ^B	37.80±0.28 ^A	17.35±0.28 ^B
Dough + 10% OB	51.26±0.31 ^B	2.63±0.03 ^B	37.51±1.17 ^A	14.36±0.23 ^C
Dough + 15% OB	54.87±0.53 ^A	3.12±0.21 ^B	21.55±0.24 ^B	11.27±0.16 ^D

Note: Values are means±standard deviations ($n = 3$). Values in the same column with different letters differ significantly ($P < 0.05$). OB: oat bran.

Table 4 The physical properties of CSB incorporated with OB

CSB samples	Loaf height (mm)	Specific volume (mL/g)	Moisture (g water/100 g sample)
Control	62.14±0.38 ^A	2.47±0.03 ^A	40.10±0.01 ^D
CSB + 5% OB	54.03±0.52 ^B	2.17±0.01 ^B	44.88±0.07 ^C
CSB + 10% OB	50.29±0.16 ^C	2.05±0.01 ^C	45.14±0.09 ^B
CSB + 15% OB	41.08±0.56 ^D	1.80±0.01 ^D	45.55±0.16 ^A

Note: Values are means±standard deviations ($n = 3$). Values in the same column with different letters differ significantly ($P < 0.05$). OB: oat bran.

Table 5 The textural properties of CSB with OB

Samples	Hardness (g)	Springiness (ratio)	Cohesiveness (ratio)	Gumminess (g)	Chewiness (g)	Resilience (ratio)
Control	228.24±25.92 ^D	0.94±0.01 ^B	0.88±0.01 ^A	191.75±19.15 ^D	179.83±19.34 ^D	0.57±0.01 ^A
CSB + 5% OB	326.19±6.26 ^C	0.98±0.01 ^A	0.88±0.01 ^A	288.15±2.22 ^C	279.91±8.98 ^C	0.59±0.01 ^A
CSB + 10% OB	425.81±13.19 ^B	0.98±0.01 ^A	0.88±0.01 ^A	370.83±5.98 ^B	365.85±10.70 ^B	0.59±0.01 ^A
CSB + 15% OB	521.12±10.79 ^A	0.98±0.01 ^A	0.85±0.01 ^B	469.59±15.80 ^A	446.98±19.76 ^A	0.56±0.01 ^B

Note: Values are means±standard deviations ($n = 3$). Values in the same column with different letters differ significantly ($P < 0.05$); OB: oat bran.

3.4 Predicted Glycemic Impact of CSB Incorporated with OB

The total starch content of CSB with OB is presented in Table 6. There was a decrease in total starch content when the substitution of OB increased from 0 to 15%. Compared to the control, CSB incorporated with 15% OB had a lower starch content (37.52%). The values of reducing sugars released during the *in vitro* digestion of all CSB samples over 120 min is shown in Fig. 1. The results give a good indication of the rate of starch degradation and allow the calculation of a predictive glycaemic index of samples. From the results, there was a trend to reduce the starch degradation as the substitution level of OB increased. Similar results were observed by Foschia et al.^[43] and Lindström et al.^[44] who pointed out food products containing OB can reduce the postprandial blood glucose response. The area under the glucose release curve is a calculation of predicted glycaemic response for 2 h after food consumption^[24, 45-46]. Table 6 shows that the addition of OB decreased the AUC values and CSB substituted with 15% OB had the lowest value (344.61). This effect can be related to β -glucan, as a water-soluble fibre, which can easily form the viscous solutions, thus slows the intestinal transit, delays gastric emptying and slows glucose and sterol absorption in the intestine^[47-48].

Fig. 1 Reducing sugar released during *in vitro* digestion of CSB
OB: oat bran.

Table 6 Total starch and AUC value of CSB with OB

Samples	Total starch (%)	AUC values
Control	43.82±1.30 ^A	431.51±31.80 ^A
CSB + 5% OB	40.65±0.05 ^B	399.13±3.31 ^{AB}
CSB + 10% OB	39.06±0.38 ^{BC}	383.29±17.40 ^{BC}
CSB + 15% OB	37.52±0.26 ^C	344.61±2.81 ^C

Note: Values are means±standard deviations ($n = 3$). Values in the same column with different letters differ significantly ($P < 0.05$). AUC-predicted glycaemic response; OB: oat bran.

In addition, Foschia et al.^[43] has found that DF can combine with proteins and form a matrix barrier surrounding the starch granules to reduce the enzymes activity.

4 Conclusions

This study illustrates that addition of OB into wheat flour can influence the dough rheology and final quality of CSB due to the high hydration properties of DF and the disruption of the starch-gluten network by DF. This then affects the quality of CSB such as density, volume and texture. Additionally, the results also show that addition of OB led to a reduction of predicted glycaemic response. As such, findings of the present research are of great importance to the food industry as it is possible to use OB as a functional ingredient in food industry with many health benefits for consumer.

Conflict of Interest

The authors declare that there is no conflict of interest.

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