

## Effect of modified dietary fibre from wheat bran on the quality of noodle

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### RESEARCH ARTICLE

#### Abstract

Addition of dietary fibre (DF) improves the nutritional value and affects the quality of noodles. The effects of the addition of modified wheat bran DF on enriched Chinese noodles were examined. Ultrasonic-treated DF (UDF) and microwave-treated DF (MDF) were added at 0.5, 1, 1.5, and 2% to wheat flour (w/w), and the resulting noodle samples were evaluated in terms of colour, texture properties, tensile properties, water properties, cooking characteristics, and sensory evaluation. The results showed that the colour of dough sheets became darker and the texture of noodles became firmer with added DF. Overall, the water absorption and cooking losses of noodles increased compared to the non-supplemented samples. The increased breaking strength and tensile distance of the noodles improved the quality of the noodles. Noodles prepared with added MDF exhibited firmer texture and tensile properties compared to those of noodles with UDF. The total sensory score of noodles with 1% MDF was the highest of all noodles with added modified DF and was slightly below the total score of the reference product. Our results confirm that using 1.0% MDF in wheat flour is preferable for high quality of Chinese noodles.

**Keywords:** ultrasonic treatment, microwave treatment, technological properties

#### 1. Introduction

Currently, people are pursuing a high quality of life and have increased demands for the quality of their food. Dietary fibre (DF) has gained increased recognition during the last two decades due to its newly discovered role in reducing the risk of diseases such as diabetes, cardiovascular diseases, colon cancer, constipation and diverticulosis (Cao *et al.*, 2011). Many studies have reported its physiological effects and mechanism of action (Kraler *et al.*, 2015; Saura-Calixto *et al.*, 2000). DF plays an important role in the human diet and exhibits many properties that affect the physiological functions of food (Stewart and Slavin, 2009). DF can serve as a food additive and confers several advantages: it can affect product colour, flavour, and the retention of oil and water; it can affect the structure, rheological characteristics, and sensory properties; and it can modify the apparent viscosity (Seckin and Baladura, 2012; Staffolo *et al.*, 2004). Wheat bran is the main by-product of milling, serving as one of the major sources of DF (Reyes-Pérez *et al.*, 2013). The current utilisation of wheat bran is very low, and this material is mainly used for animal feed. DF has excellent water

retention, and is used as wheat bran fibre sheets, wheat bran fibre biscuits, wheat bran fibre bread, or enhanced soup (Stevenson *et al.*, 2012). Haque *et al.* (2002) found that the addition of 6% bran aqueous extract to biscuits altered the colour, texture, fragrance, and acceptability, resulting in improved biscuit quality. Uysal *et al.* (2007) found that increased wheat bran DF led to a decline in the firmness of cookies, so cookies made with wheat bran DF were softer and better. Gómez *et al.* (2011) found that the addition of extruded wheat bran to flour increased the water absorption and gas production of the dough, and improved the quality of the bread. Shao and Ming (2007) found that cooked noodles with added wheat bran DF exhibited better quality. Gurkirat *et al.* (2012) tested pasta made with wheat bran DF and found that addition of up to 15% had no effect on the physical or chemical properties or the sensory quality of pasta.

Noodles are a traditional staple food of Chinese, making up over 30% of the wheat processing industry (Fan *et al.*, 2016). The addition of DF to noodles may influence both nutritional properties and functional properties, including

colour, texture, and cooking quality. The main ingredient of wheat bran DF is insoluble DF, with relatively few soluble components that can influence the functionality of DF. Modification can be used to alter components of wheat bran DF, such as breaking hemicellulose into soluble constituents (Sanchezalonso *et al.*, 2007). Liu *et al.* (2016) showed that compared with whole wheat noodles without additional bran, the nutritional quality of whole wheat noodles supplemented with xylanase-treated bran were improved significantly. However, there is little information and few detailed studies on the effect of adding wheat bran modified DF on the production of Chinese noodles. The goal of this study was to explore the influence of wheat bran DF on the quality of Chinese noodles to further the development of wheat bran DF-supplemented foods. DF prepared with different modification methods may have different effects on the quality of the resulting noodles due to differences in the structural and physicochemical properties of the fibre. However, there is little known about these potential effects. The purpose of this study was to apply ultrasound and microwave technology to produce modified DF, and investigate the effect of this modified DF on the colour, water properties, cooking characteristics, texture characteristics, tensile properties and sensory quality of Chinese noodles.

## 2. Material and methods

### Materials

Commercial medium-strength wheat flour was obtained from a local market. Destarched wheat bran was a by-product obtained from Hainan Zhonghe Ltd (Henan, China). A commercial *Trichoderma* sp. xylanase preparation was provided by Genencor International Inc. (Palo Alto, CA, USA). Enzyme activity was 50,000 U/g.

### Modification of dietary fibre

The preparation of DF from wheat bran was performed as described previously (Fan *et al.*, 2016; Wang *et al.*, 2015). Briefly, destarched wheat bran was treated with 2% NaOH at 55 °C for 2 h. The resulting slurries were centrifuged and incubated with 2% neutrane (w/w) for 4 h at 40 °C. Next, the suspensions were centrifuged, mixed with three volumes of ethanol, and incubated at 4 °C overnight. The precipitate was dialysed against distilled water and then freeze-dried to obtain DF. The DF solution (5 mg/ml) was used for subsequent modification.

Ultrasonic-modified DF (UDF) was prepared as follows. The DF solution was treated with ultrasound irradiation (280 W, 30 min, 25 °C) in a Scientz-IID Ultrasonic cell crusher (SCIENTZ, Ningbo, China, 25 KHz) to obtain modified DF. Then, 1.5% (w/w) of xylanase was added to the sample solution and then heated at 55 °C in a water bath for 2 h.

Next, the slurries were boiled for 15 min to inactivate the enzymes, followed by centrifugation at 4,500×g for 15 min in a Beckman J2-MI centrifuge (Beckman Instruments Inc., Palo Alto, CA, USA). Finally, the solution was freeze-dried to obtain UDF.

The microwave-modified DF (MDF) was prepared as follows. The sample solution was treated with microwave irradiation (280 W, 90 s, 25 °C) in a P70D20TL-D4 microwave oven (Galanz Microwave Oven Electrical Appliances Co., LTD, Guangzhou, China), then enzymolysis, inactivation, centrifugation, and freezing were performed as described above for MDF preparation.

### Noodles preparation

Noodles were prepared as described previously (Fan *et al.*, 2016). Briefly, control noodle dough consisted of 100 parts of wheat flour and 35 parts of deionised water. On a flour weight basis, DF was added to 0.5, 1, 1.5, or 2%. Ingredients were mixed into dough using a pin mixer for 7 min. The dough was kneaded and passed through a laboratory noodle machine to form and compound a noodle sheet. It was then sheeted through different roll gaps (2.5, 1.5, and 1.0 mm). After that, the sheet was cut into fresh noodle strands (15.0 cm length, 2.0 cm width, 1.0 cm thickness) with cutting rollers.

### Measurement of the colour of dough sheets

The colour of the dough sheets was measured using a laboratory colorimeter (SMY-2000ST; Beijing SMY Science & Technology Co. LTD, Beijing, China) using the Hunter scale for L\*, a\* and b\*, which was calibrated with a standard white surface calibration plate (L\*=97.49, a\*=0.13, b\*=0.04). The values of L\*, a\*, and b\* refer to brightness, redness, and yellowness, respectively. The analysis was performed in triplicate.

### Water properties

Nuclear magnetic resonance (NMR variable temperature analysis system, VTMR20-010V-T; Shanghai New Mai Science and Technology Co., LTD, Shanghai, China) is a powerful method that can explicitly determine the moisture distribution and its migration in food. A smaller value of the transverse relaxation time ( $T_2$ ) indicates the closer integration of water and macromolecules. Therefore, we can understand the change of water distribution in the state by analysing the changes of  $T_2$  values in samples, reflecting structural change. So, the NMR variable temperature analysis system was used with a Carr-Purcell-Meiboom-Gill pulse to measure  $T_2$  of samples. The test conditions were as follows: number of scans = 16, echo time = 0.1 ms, and number of echo = 2,500. The NMR spectra and  $T_2$  of samples were analysed using the T<sub>2</sub>-FitFrm software

(Shanghai New Mai Science and Technology Co., LTD). This analysis allowed determination of  $T_{21}$ ,  $T_{22}$  and  $T_{23}$ . The bound water was represented by  $T_{21}$ , which is the relaxation time of the connection between protein and water molecules.  $T_{22}$  represents the water that is associated with the starch/DE, as the gelatinisation process includes water absorption. The free water is represented by  $T_{23}$ , which is the relaxation time of the distribution of water, protein, and starch (Engelsen *et al.*, 2001). The analysis was performed in triplicate.

### Cooking characteristics of the noodles

The cooking loss rate of noodles was measured using a method modified from Zhang *et al.* (2008). The water absorption rate of noodles was determined using the Matsuo *et al.* (1986) method with slight modification. 20 g of noodles were cooked in 500 ml boiling distilled water until the white core of the noodles disappeared (4 min). Then, the noodles were transferred to a wire sieve and rinsed with distilled water for 10 sec. The liquid used for boiling noodles was allowed to evaporate and the noodles were dried to a constant weight with a laboratory drum wind drying oven (101-A-3 E; Shanghai Experimental Instrument Factory Co., LTD, Shanghai, China) at 105 °C. The moisture content was measured according to the Chinese Standard Method GB 5497-85 (SAC, 1985). The experiments were conducted in triplicate.

### Texture analysis

Cooked noodles of 15 cm length were prepared and immediately subjected to compressive (texture profile analysis, TPA) and tensile tests using a TA-XT2i Texture Analyser (Stable Micro System Ltd., Godalming, UK) equipped with a 25-mm-diameter, aluminium cylindrical probe. TPA was measured using the Awad *et al.* (2002) method with slight modification. The TPA test was performed using compression mode, trigger type, auto-20 g, pre-test speed 3 mm/sec, post-test speed 1 mm/sec, test speed 1 mm/sec, strain 70%, and the interval between compressions was 1 sec.

The breaking strength and tensile distance characteristics of the cooked noodles were measured according to a method modified from Lu *et al.* (2003). The testing parameter of the tensile test was as follows: extension mode, trigger type, auto-0.5 g, pre-test speed 2.0 mm/sec, post-test speed 10 mm/sec, test speed 2.0 mm/sec, and trigger distance 100 mm. The force–distance curves were generated and used to determine the breaking strength and tensile distance. These analyses were performed in triplicate.

### Sensory analysis

Sensory evaluation was based on the SB/T 10137-93 method (SAC, 1993) with slight modification. Noodle samples (100 g) were cooked for 4 min in 1 l unsalted water and then drained. Sensory tests were performed 10 min after draining, by an evaluation panel of 30 people (10 males, 20 females; age range of 17-40 years), who are familiar with noodles. All the noodle samples (control, with 0.5, 1, 1.5, and 2% modified DF) were evaluated in a single session. Panellists receive a sample at a time at a sample interval of 2 min. Each panellist conducted the sensory evaluation alone, sequentially, under incandescent light in a laboratory. After every evaluation, each panellist used deionised water at room temperature to cleanse the palate between samples. The panellists were asked to score the cooked noodles in terms of colour (10 points), surface appearance (10 points), hardness (20 points), stickiness (25 points), springiness (25 points), smoothness (10 points), for a total score of a potential 100 points.

### Statistical analysis

Analysis of variance (ANOVA) was performed, and the data were analysed using Duncan's test (level of significance,  $P < 0.05$ ) with SPSS software (SPSS Institute, Cary, NC, USA).

## 3. Results and discussion

### Effect of DF on the colour of dough sheet

The  $L^*$ ,  $a^*$  and  $b^*$  values for dough sheet prepared with modified DF are shown in Table 1. For colour, high brightness and low yellowness values of noodles are preferred by consumers (Lei *et al.*, 2003). The  $L^*$  values of dough supplemented with increasing amount of UDF and MDF decreased from 79.60 to 71.18 and to 67.81, respectively, indicating a significant increase in darkness. In contrast, as the addition of UDF and MDF increased, the values of  $a^*$  also increased, resulting in greater redness. The effects of the addition of UDF and MDF on dough sheet colour were not the same. The values of  $a^*$  were higher with UDF up to 1.5% addition. At that level, UDF and MDF exhibited the same effect. For  $b^*$ , the differences between UDF and MDF addition were less evident and in some cases were not significant. When the addition of MDF was 0.5%, the  $L^*$  was the highest value in samples, and the  $a^*$  value was lower than others. Therefore, addition of MDF of 0.5% yielded the best dough colour. This is possibly the effect of the Maillard reaction. During food processing or cooking at high temperature, a chemical reaction occurred between the amino acids and reducing sugars that resulted in the formation of Maillard reaction products, producing changes in fragrance and enhanced darkness. The mechanical disruption of DF partly caused this difference in colour

**Table 1. Effect of the ultrasonic-treated dietary fibre (UDF) and the microwave modified dietary fibre (MDF) content on colour of dough sheet.<sup>1,2</sup>**

Type	Content (%)	L*	a*	b*
Control	0	79.60±0.36 <sup>a</sup>	-0.77±0.08 <sup>g</sup>	21.30±0.31 <sup>bc</sup>
UDF	0.5	74.92±0.39 <sup>c</sup>	1.61±0.06 <sup>e</sup>	22.28±0.16 <sup>a</sup>
	1	71.18±0.32 <sup>e</sup>	2.82±0.10 <sup>c</sup>	21.06±0.39 <sup>c</sup>
	1.5	74.81±0.07 <sup>c</sup>	2.50±0.03 <sup>d</sup>	21.13±0.12 <sup>bc</sup>
	2	72.75±0.10 <sup>d</sup>	2.91±0.06 <sup>bc</sup>	20.36±0.23 <sup>d</sup>
MDF	0.5	77.42±0.16 <sup>b</sup>	1.19±0.04 <sup>f</sup>	20.41±0.57 <sup>d</sup>
	1	71.69±0.46 <sup>e</sup>	2.53±0.16 <sup>d</sup>	21.71±0.38 <sup>b</sup>
	1.5	73.18±0.51 <sup>d</sup>	3.02±0.05 <sup>b</sup>	20.80±0.20 <sup>cd</sup>
	2	67.81±0.33 <sup>f</sup>	3.97±0.06 <sup>a</sup>	21.13±0.18 <sup>bc</sup>

<sup>1</sup> Values are means ± standard deviation of triplicate values; mean values with different letters are significantly different ( $P<0.05$ ).

<sup>2</sup> Control = noodle without dietary fibre; UDF = noodle with ultrasonic enzymatic modified dietary fibre; MDF = noodle with microwave enzymatic modified dietary fibre; L\* = brightness; a\* = yellowness; b\* = redness.

attributes. There are likely differences in the structure and properties of the modified DF produced by ultrasonic and microwave degradation, which may alter the extent of bond cleavage in DF (Hromadkova *et al.*, 2008; Zhang *et al.*, 2011). Increased bond cleavage will promote the Maillard reaction because of the greater availability of reducing sugars into protein. In sum, the colour of dough sheet became darker with the addition of modified DF. The appropriate additive amount is less than 1.5%, because their brightness and yellowness values were more close to the control compared with noodles with 2.0% DF.

### Effect of DF on the water properties of noodles

Table 2 shows the effect of modified DF on the water properties of noodles. The results indicate that along with the increased UDF and MDF, the relaxation time  $T_{21}$ ,  $T_{22}$  and  $T_{23}$  of noodles decreased. This was probably due to proton exchange of the hydroxyl group of the protein from either the DF or sulfenyl groups with water, which helped decrease the mobility of the water and shorten the relaxation time. The data also indicated that noodles with UDF and MDF hold water tightly, and this affects the taste. Wang *et al.* (2004) reported that the chemical exchange of DF, water, starch, and protein affects the distribution of moisture in noodles, decreasing the relaxation time. The relaxation time  $T_{21}$  of noodles with MDF supplementation were relatively shorter than those with UDF exception of 2% addition. The similar trend was found in  $T_{22}$  exception of 1% addition. When DF addition was lower than 1.5%, noodles with MDF were significant lower in  $T_{23}$  than those

**Table 2. Water properties of noodles containing the ultrasonic-treated dietary fibre (UDF) and the microwave modified dietary fibre (MDF) as determined by nuclear magnetic resonance.<sup>1,2</sup>**

Type	Content (%)	Relaxation time		
		$T_{21}$	$T_{22}$	$T_{23}$
Control	0	0.10±0.03 <sup>a</sup>	3.02±0.08 <sup>a</sup>	34.73±6.53 <sup>a</sup>
	0.5	0.09±0.01 <sup>ab</sup>	2.56±0.28 <sup>b</sup>	33.76±5.35 <sup>a</sup>
UDF	1	0.08±0.03 <sup>abc</sup>	1.29±0.28 <sup>cd</sup>	31.51±4.03 <sup>a</sup>
	1.5	0.05±0.01 <sup>bcd</sup>	0.97±0.13 <sup>de</sup>	18.64±0.88 <sup>b</sup>
	2	0.03±0.01 <sup>d</sup>	0.28±0.03 <sup>f</sup>	3.69±0.82 <sup>c</sup>
MDF	0.5	0.08±0.01 <sup>abc</sup>	2.29±0.16 <sup>b</sup>	23.67±0.14 <sup>b</sup>
	1	0.05±0.01 <sup>bcd</sup>	1.39±0.11 <sup>c</sup>	4.04±0.00 <sup>c</sup>
	1.5	0.04±0.01 <sup>cd</sup>	0.82±0.06 <sup>e</sup>	3.93±0.17 <sup>c</sup>
	2	0.03±0.01 <sup>d</sup>	0.27±0.04 <sup>f</sup>	4.24±0.23 <sup>c</sup>

<sup>1</sup> Values are means ± standard deviation of triplicate values; mean values with different letters are significantly different ( $P<0.05$ ).

<sup>2</sup> Control = noodle without dietary fibre; UDF = noodle with ultrasonic enzymatic modified dietary fibre; MDF = noodle with microwave enzymatic modified dietary fibre;  $T_{21}$  = tightly bound water;  $T_{22}$  = less tightly bound water;  $T_{23}$  = free water.

with UDF. It indicated that redistribution of water occurred in the noodle structure as affected by DF structure. The degradation of arabinoxylans after modified treatment may increase the amount of ferulic acid. The oxidative cross-linking centre of ferulic acid can attract water to migrate from gluten-starch network to the arabinoxylans, resulting in a reduction in the amount of bound and half-bound water in the noodle matrix.

### Effect of DF on the cooking properties of noodles

Figure 1 and Figure 2 show the effect of modified DF on the cooking characteristics of noodles. The water absorption rate of noodles prepared with added modified DF was higher than that of the control noodles. The same trend was observed in the cooking loss rate. However, the water absorption rate decreased at addition of 2.0% MDF. The present results indicate that the addition of modified DF had an important impact on the water uptake. This is consistent with a previous study of the water properties of noodles that also showed higher water absorption in samples supplemented with DF (Fan *et al.*, 2016). This effect is probably due to the competitive relationship of the modified DF and the gluten network. The addition of modified DF may promote the formation of a relatively stable matrix of DF-starch-protein that can retain more water due to the higher water absorption of DF. The water absorption rate of the noodle prepared with MDF was slightly higher than

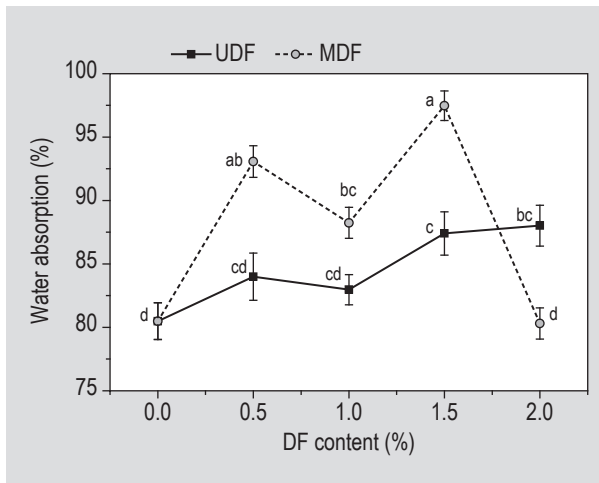


Figure 1. Effect of dietary fibre (DF) on the water absorption rate of noodles (UDF = noodle with ultrasonic enzymatic modified dietary fibre; MDF = noodle with microwave enzymatic modified dietary fibre). Bars and error bars represent mean  $\pm$  standard deviation calculated from triplicates. Different letters indicate significant differences ( $P < 0.05$ ).

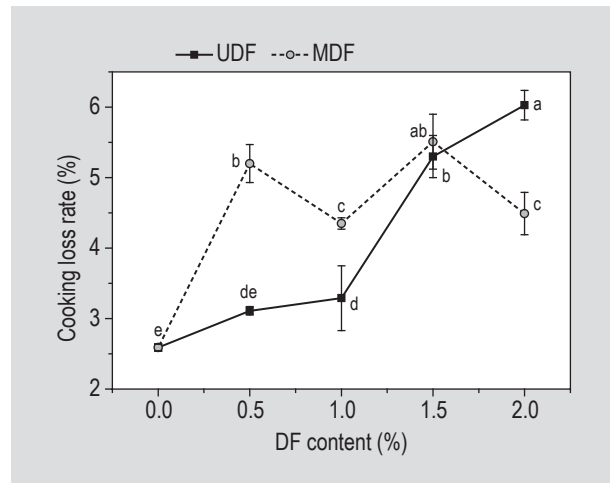


Figure 2. Effect of dietary fibre (DF) on the cooking loss rate of noodles (UDF = noodle with ultrasonic enzymatic modified dietary fibre; MDF = noodle with microwave enzymatic modified dietary fibre). Bars and error bars represent mean  $\pm$  standard deviation calculated from triplicates. Different letters indicate significant differences ( $P < 0.05$ ).

the samples with UDF. However, the cooking loss rate of noodles with MDF was higher than the control. Increasing the amount of UDF from 0% to 2% increased the cooking loss rate of noodles. The obtained results indicated that UDF or MDF had a significant impact on cooking loss. This is possibly because the gluten matrix is responsible for the integrity of noodles and the incorporation of non-gluten ingredients may have disrupted structure, causing greater solid loss during cooking.

#### Effect of DF on breaking strength and tensile distance of cooked noodles

The breaking strength and tensile distance of the cooked noodles with modified DF are presented in Figure 3 and Figure 4. As can be seen from Figure 3, UDF content from 0.5% to 1.5% led to an increment in strength value from 0.09 to 0.11, then, the strength value decreased to 0.10, which was higher than the control. There was no significant

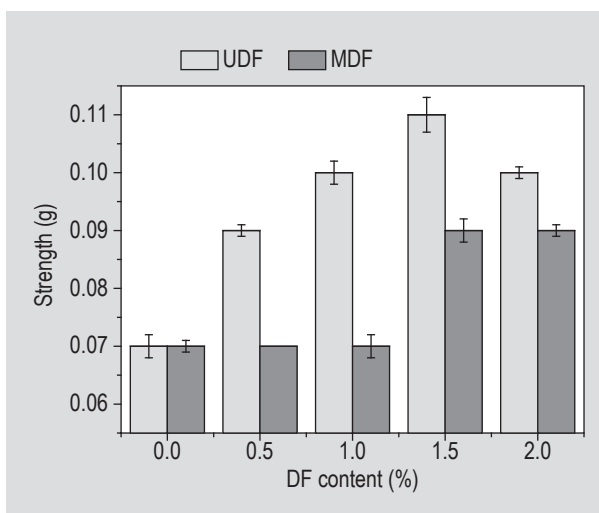


Figure 3. Effect of dietary fibre (DF) on the breaking strength of noodles (UDF = noodle with ultrasonic enzymatic modified dietary fibre; MDF = noodle with microwave enzymatic modified dietary fibre). Bars and error bars represent mean  $\pm$  standard deviation calculated from triplicates. Different letters indicate significant differences ( $P < 0.05$ ).

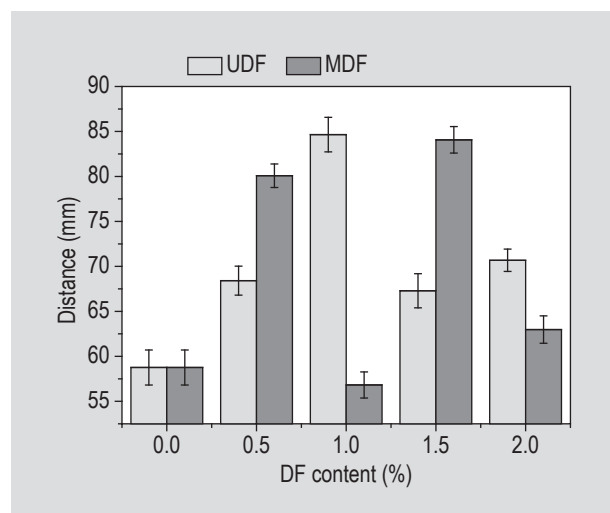


Figure 4. Effect of dietary fibre (DF) on the tensile distance of noodles (UDF = noodle with ultrasonic enzymatic modified dietary fibre; MDF = noodle with microwave enzymatic modified dietary fibre). Bars and error bars represent mean  $\pm$  standard deviation calculated from triplicates. Different letters indicate significant differences ( $P < 0.05$ ).

difference in strength value when MDF addition was lower than 1.0%. Noodle with 1.5% and 2.0% had similar strength value, higher than the control. According to the Figure 4, all tensile distance values of noodles were higher than those of the control except for 1.0% MDF addition. Tensile distances were around 80 and 85 mm for 0.5% and 1.5% MDF addition, respectively, significant higher than the same UDF addition. These effects are probably because the addition of modified DF promoted the tensile strength of noodles and enhanced the toughness of noodles by increased cross-linking of ferulic acid, protein, and starch (Migliori and Gabriele, 2010). In addition, the viscosity of the DF was greater, and caused an increase in the tensile distance of noodles. Therefore, an appropriate level of addition of modified DF improved the tensile properties of the noodles. According to this experiment, the suitable amount of modified DF addition was 1% of UDF and 1.5% of MDF.

### Effect of DF on the texture of cooked noodles

The hardness increased significantly with the addition of MDF compared with the control sample (Table 3). The addition of 1.5–2% UDF caused an increase in hardness. There was no significant decrease in adhesiveness except for 1–2% MDF addition, and the adhesiveness of the modified noodles was lower than that of the control. The resilience and cohesiveness slightly fluctuated with the DF addition, and there is no difference between springiness of DF. The highest resilience and cohesion were observed in the 1.5% MDF sample. Meanwhile, the hardness, gumminess and chewiness of the noodles prepared with MDF addition were higher than those values for the noodles prepared with added UDF. This result was probably due to changes in the oxidation, crosslinking, and ability of DF to hold water that

altered the network structure and water retention of the noodles, resulting in increased plastic viscosity, hardness, and chewiness of the noodles.

### Sensory analysis

Table 4 shows the sensory evaluation scores of noodle samples supplemented with UDF and MDF. Noodles supplemented with modified DF had significantly lower total scores than the control sample. Modified DF adversely affected the colour values of noodles due to the dark colour. These results are similar to those of Fan *et al.* (2016). They also reported that all the noodles prepared from wheat flour mixed with arabinoxylans from wheat bran had lower  $L^*$  values than the control due to the darker colour of the wheat bran. In this work, as the amount of modified DF increased in formulations, all the sensory indicators of the noodles first increased and then decreased. The noodles supplemented with 1% UDF or 1% MDF got the highest positive scores on the sensory indicators at each formulation. In addition, the total score of noodles with 1% MDF was the highest of all noodles with added modified DF.

### 4. Conclusions

The results illustrate the functionality of addition of modified DF for the production of Chinese noodles with high DF for nutritional benefits. This study indicated that the addition of modified DF decreased the colour of dough sheets and reduced the relaxation time of  $T_2$ . The addition of modified DF increased the cooking characteristics, breaking strength, and tensile distance of the cooked noodles, with significant effects on the water absorption rate. Noodles with MDF had better effect on the texture of noodles than noodles with UDF, by increasing hardness,

**Table 3. Texture analysis of cooked noodles containing the ultrasonic-treated dietary fibre (UDF) and the microwave modified dietary fibre (MDF).<sup>1,2</sup>**

Type	Content (%)	Hardness (g)	Adhesiveness (g sec)	Resilience	Cohesiveness	Springiness	Gumminess	Chewiness(g)
Control	0	832.50±19.39 <sup>e</sup>	-3.85±1.70 <sup>a</sup>	45.27±0.54 <sup>b</sup>	0.75±0.00 <sup>bc</sup>	91.71±7.72 <sup>a</sup>	625.14±10.43 <sup>d</sup>	573.71±57.84 <sup>de</sup>
UDF	0.5	781.76±104.40 <sup>e</sup>	-6.81±0.57 <sup>a</sup>	45.92±4.14 <sup>b</sup>	0.76±0.04 <sup>ab</sup>	90.18±0.81 <sup>a</sup>	592.47±51.20 <sup>d</sup>	534.52±50.97 <sup>e</sup>
	1	911.70±46.22 <sup>de</sup>	-5.51±1.08 <sup>a</sup>	44.82±1.27 <sup>b</sup>	0.74±0.01 <sup>bc</sup>	86.82±4.56 <sup>a</sup>	676.20±23.26 <sup>cd</sup>	587.59±51.05 <sup>de</sup>
	1.5	1,236.94±140.74 <sup>bc</sup>	-7.31±2.83 <sup>a</sup>	48.66±0.91 <sup>b</sup>	0.76±0.01 <sup>ab</sup>	88.70±0.23 <sup>a</sup>	944.37±116.22 <sup>b</sup>	837.55±100.93 <sup>c</sup>
MDF	2	1,084.35±0.11 <sup>cd</sup>	-11.20±0.90 <sup>ab</sup>	44.40±5.07 <sup>b</sup>	0.75±0.04 <sup>bc</sup>	91.60±2.55 <sup>a</sup>	809.67±45.47 <sup>bc</sup>	741.07±21.00 <sup>c</sup>
	0.5	1,140.61±55.24 <sup>c</sup>	-10.81±0.73 <sup>ab</sup>	43.76±1.74 <sup>b</sup>	0.71±0.01 <sup>c</sup>	88.27±2.08 <sup>a</sup>	809.05±47.60 <sup>bc</sup>	713.65±25.22 <sup>a</sup>
	1	1,594.18±111.46 <sup>a</sup>	-18.77±6.66 <sup>bc</sup>	44.89±1.52 <sup>b</sup>	0.78±0.01 <sup>ab</sup>	93.00±5.28 <sup>a</sup>	1,239.37±97.76 <sup>a</sup>	1,150.07±25.51 <sup>b</sup>
	1.5	1,383.43±85.67 <sup>b</sup>	-39.57±7.56 <sup>d</sup>	69.47±3.05 <sup>a</sup>	0.80±0.01 <sup>a</sup>	88.74±0.04 <sup>a</sup>	1,107.67±59.72 <sup>a</sup>	982.90±53.39 <sup>a</sup>
	2	1,597.49±128.36 <sup>a</sup>	-22.48±1.39 <sup>c</sup>	42.57±1.41 <sup>b</sup>	0.77±0.01 <sup>ab</sup>	95.47±2.60 <sup>a</sup>	1,222.52±88.70 <sup>a</sup>	1,168.30±116.49 <sup>a</sup>

<sup>1</sup> Values are means ± standard deviation of triplicate values; mean values with different letters are significantly different ( $P<0.05$ ).

<sup>2</sup> Control = noodle without dietary fibre; UDF = noodle with ultrasonic enzymatic modified dietary fibre; MDF = noodle with microwave enzymatic modified dietary fibre.

**Table 4. Effect of the ultrasonic-treated dietary fibre (UDF) and the microwave modified dietary fibre (MDF) content on sensory evaluation of noodle.<sup>1,2</sup>**

Type	Content (%)	Colour	Surface appearance	Hardness	Stickiness	Springiness	Smoothness	Total score
Control	0	9.45±0.07 <sup>a</sup>	9.25±0.35 <sup>a</sup>	19.00±0.00 <sup>a</sup>	24.00±0.00 <sup>a</sup>	23.50±0.71 <sup>a</sup>	8.90±0.14 <sup>a</sup>	94.10±0.28 <sup>a</sup>
UDF	0.5	8.50±0.14 <sup>bcd</sup>	8.60±0.28 <sup>bcd</sup>	18.00±0.00 <sup>bcd</sup>	20.00±1.41 <sup>bcd</sup>	20.50±0.71 <sup>bc</sup>	8.30±0.14 <sup>bcd</sup>	83.90±0.71 <sup>d</sup>
	1	8.75±0.35 <sup>bc</sup>	8.75±0.35 <sup>abc</sup>	18.25±0.35 <sup>abc</sup>	20.50±0.71 <sup>bc</sup>	22.50±0.71 <sup>ab</sup>	8.55±0.07 <sup>abc</sup>	87.30±1.13 <sup>c</sup>
	1.5	8.35±0.21 <sup>cd</sup>	8.30±0.14 <sup>cd</sup>	17.50±0.71 <sup>cd</sup>	19.00±1.41 <sup>cd</sup>	19.50±0.71 <sup>c</sup>	8.20±0.28 <sup>cd</sup>	80.85±1.20 <sup>ef</sup>
MDF	2	8.25±0.07 <sup>d</sup>	8.10±0.00 <sup>d</sup>	16.50±0.71 <sup>d</sup>	18.25±0.35 <sup>cd</sup>	19.00±1.41 <sup>c</sup>	8.10±0.14 <sup>d</sup>	78.20±0.85 <sup>g</sup>
	0.5	8.70±0.14 <sup>bcd</sup>	8.40±0.14 <sup>bcd</sup>	17.50±0.71 <sup>bcd</sup>	19.00±1.41 <sup>cd</sup>	19.50±0.71 <sup>c</sup>	8.20±0.14 <sup>cd</sup>	81.30±0.42 <sup>e</sup>
	1	8.90±0.14 <sup>b</sup>	8.90±0.14 <sup>ab</sup>	19.50±0.71 <sup>ab</sup>	21.50±0.71 <sup>b</sup>	23.00±1.41 <sup>a</sup>	8.70±0.14 <sup>ab</sup>	90.50±1.27 <sup>b</sup>
	1.5	8.45±0.07 <sup>bcd</sup>	8.70±0.14 <sup>bc</sup>	18.50±0.71 <sup>bc</sup>	18.50±0.71 <sup>cd</sup>	20.50±0.71 <sup>bc</sup>	8.40±0.28 <sup>bcd</sup>	83.05±1.06 <sup>de</sup>
	2	8.30±0.28 <sup>cd</sup>	8.50±0.14 <sup>bcd</sup>	17.50±0.71 <sup>bcd</sup>	17.75±0.35 <sup>d</sup>	18.50±0.71 <sup>c</sup>	8.30±0.14 <sup>bcd</sup>	78.85±1.06 <sup>g</sup>

<sup>1</sup> Values are means ± standard deviation of triplicate values; mean values with different letters are significantly different ( $P < 0.05$ ).

<sup>2</sup> Control = noodle without dietary fibre; UDF = noodle with ultrasonic enzymatic modified dietary fibre; MDF = noodle with microwave enzymatic modified dietary fibre.

gumminess and chewiness. The total sensory evaluation score of noodles with added 1% MDF was the highest of all noodles supplemented with modified DF. Overall, using modified DF in wheat flour resulted in an improved noodle product, use of MDF in wheat flour is better than use of UDF, and 1% MDF in wheat flour allowed production of high-quality Chinese noodles. Production of these types of noodles with added modified DF can help provide desired additional nutritional value to consumers and allow the profitable utilisation of by-products of the milling industry.

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