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Substitution of wheat flour with modified potato starch affects texture properties of dough and the quality of fresh noodles

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Abstract

This study was undertaken to investigate the potential effects of wheat flour substitution with potato starch modified by heat-moisture treatment (HMTS) and microwave treatment (MWS) on dough texture properties and on the quality of fresh noodles. The research results showed that the substitution of wheat flour with HMTS or MWS altered the texture and tensile properties of dough and cooked fresh noodles. Moreover, the dough tensile properties of resistance to extension and extensibility were extremely significant positive correlated with the cooked fresh noodles tensile properties of tensile strength and elasticity. The optimal cooking time of fresh noodles was significantly decreased ($P_{value} < 0.05$) with the increase incorporation of HMTS or MWS. The dry matter water absorption rate and loss rate of dry matter significantly increased with the increase of substitution amount of HMTS and MWS. When the incorporation amount of HMTS was less than 30% and the incorporation amount of MWS was less than 20%, the noodles could maintain good organoleptic and cooking quality attributes. More than 30% of HMTS or 20% MWS will deform the noodles and cause breakage. Therefore, the maximum incorporation of HMTS or MWS should be 30%, 20%, respectively.

Keywords: modified potato starch; fresh noodles; dough; texture properties; noodle quality.

Practical Application: Because the price of native potato starch is higher than that of wheat flour, incorporating HMTS or MWS to noodles would increase the cost. However, the incorporation of HMTS or MWS could increase the content of slowly digestible starch (SDS) and resistant starch (RS) in noodles, which is beneficial to consumer's health, such kind nutrient- enhanced noodles will definitely be more and more popular with consumers in the future. The present research results can be applied to the noodle industry, and it might also help to enlarge the application of modified potato starch in cooking noodle-like food.

1 Introduction

Noodles, as one of the three major staple food along with rice and steamed bread in China, which emerged in China four thousand years ago and consumed mainly in Asian countries (Obadi & Xu, 2021). Noodles were mainly made from wheat flour, water and salt and eventualy formed into noodles with different lengths and thickness by blending, kneading, proofing and shaping. According to various processing techniques, noodles can be categories as fresh noodles, sreamed noodles, dried noodles, boiled noodles, frozen noodles, and instant noodles (Fu, 2008). It has been widely consumed for its simplicity, convenience and easy cooking (Yousif et al., 2012). The widespread consumption of noodles enriches human dietary life, but also accelates the appearance of hypertension, hypercholesterolemia and hyperglycaemia, which is harmful to human health (Lin et al., 2019; Tangthanantorn et al., 2022). Due to the high content of rapidly digestible starch (RDS) in traditional noodles, it is easy to decompose and release glucose in human intestine after being ingested, and can be digested and absorbed by human body in short time. This rapid release is unfavorable to the balance of human blood sugar. With the increase of consumer's experctance for quality of life and the development of health eating awareness in recent years, consumers now expect to obtain viours benefits such as nutrition, health and other benefits from their daily diet (Köten & Ünsal, 2022). Therefore, a series of noodle quality improving agents must be added to change the quality of noodles or increase the slowly digestible starch (SDS) and resistant starch (RS). Modified starch can be used as a kind of noodle quality improving agent, its properties is related to noodle quality of swelling, gelatinization. Thus, it is necessary to invatigate the effects of partial substitution of whest flour with modified starch on the qulity characteristics of noodles.

The inherent deficiencies of native starch, such as poor shear resistance, heat sensitivity, easy thermal degradation and easy retrogradation, limit its application in some industrial food processing (Singh et al., 2004; Wang et al., 2023; Wang et al., 2019). To overcome these shortcomings and widen the application of starch, it is often modified by physical, chemical or enzymatic modifications (Abbas et al., 2010). Heat-moisture treatment (HMT) and microwave treatment (MW) are the most appealing physical modification method of starch due to their advantages of environmental protection, no reagent by-product, easy control process and safe for industrial production (Braşoveanu & Nemţanu, 2014; Deng et al., 2021a). HMT refers to the modification methods of moisture contents ranging from 10% to 40%, processing temperatures ranging from 80°C to 140°C and

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treatment times varying from 15 min to > 24 h (BeMiller, 2018; Pertiwi et al., 2022). Generally, HMT results in an increase of onset temperature, peak temperature and conclusion temperature of starch changed other functional properties, such as decreasing starch solubility, swelling power, amylose leaching, and peak viscosity (Wang et al., 2020). Microwave treatment (MW) refers to a modification method of starch by using electromagnetic waves with a frequency range between 300 and 300,000 MHz. Frequency, moisture content and treatment time are the main factors affecting starch modification in MW (Palav & Seetharaman, 2006). Generally, MW with higher frequency and moisture content causes greater degree of starch structure, leading to decrease of melting enthalpy, swelling power, solubility and increase of gelatinization temperatures (Oyeyinka et al., 2021).

In previous our researches (Deng et al., 2021a, 2022b), potato starch was modified by heat-moisture treatment (HMT) and microwave treatment (MW), and the results indicated that both HMT and MW could increase the SDS content and RS content of potato starch. Therefore, the addition of HMT modified potato starch(HMTS)or MW modified potato starch (MWS) is beneficial to the improvement of noodle quality. Therefore, the aim of this research was to obtain noodles with high content of SDS and RS and good quality by incorporating wheat flour with different substitution level of HMTS or MWS. The results would contribute to better comprehension of the effects of HMTS and MWS on dough and fresh noodles, providing valuable guidance for further application of HMTS and MWS in wheat-based products, and it is also of great significance for promoting potato as staple food.

2 Research methodology

2.1 Materials

The materials used in this experiment include HMT modified starch and MW modified starch (self-prepared in the laboratory), wheat flour (Chen Keming Food Co., LTD, Yiyang city, Hunan province, China), salt. Wheat flour and salt were bought in a local supermarket (Hezhou city, Guangxi province, China).

2.2 Preparation of modified potato starch

HMT modified potato starch was prepared as the method previously reported by Deng (Deng et al., 2022a). The moisture content of starch was adjusted to 23.56%, then the starch was sealed and equilibrated 24 h at room temperature for moisture balance. After equilibration, the starch samples were subjected to HMT with the processing temperatures of 90 °C and treatment time of 1.5 h. The content of RS and SDS of HMT modified starch (HMTS) was 14.03% and 57.96% respectively, while the content of RS and SDS of native potato starch was 13.69% and 55.17%. The total content of RS and SDS in HMTS was higher than that of native potato starch.

MW modified potato starch (MWS) was prepared as the method previously reported by Deng (Deng et al., 2021b). The moisture content of starch was adjusted to 25%, then the starch was sealed and equilibrated 24 h at room temperature for moisture balance. After equilibration, the starch was subjected to MW with After that, the equilibrated the starch sample was placed flat into a petri dish covered with 10 holes microwave plastic film and then subjected to MW at 400W for 5 min. The content of RS and SDS of MW modified starch (MWS) was 14.97% and 55.90%, respectively, which was higher than that of native potato starch.

2.3 Preparation of noodles

The basic formulation of noodles was consisted of wheat flour (the protein content was 10.0% ± 1.0%, 12% moisture content) 100 g, 1% salt solution 48 g. Wheat flour was substituted with HMTS or MWS at the levels of 10%, 20%, 30%, 40% and 50%, and named as HMT-10, HMT-20, HMT-30, HMT-40 and HMT-50, MW-10, MW-20, MW-30, MW-40 and MW-50, respectively. When the content of HMTS or MWS was more than 50%, the dough with strong network structure could not be formed due to too little gluten, thus the maximum substitution of HMTS and MWS was set as 50%.Wheat flour without HMTS or MWS was used as control and named as CK. Dough was formed by mixing wheat flour, HMTS or MWS, water was kneaded and shaped manually for 2 min, then the dough was divided into two parts, one for the determination of textural and tensile properties of dough, and the other one for the preparation of fresh noodles. The dough for preparation of fresh noodles was covered with plastic wrap and rested at room temperature for 15 min. After resting, was kneaded again and then passed through a small noodle machine ((Joyoung, M6-L18, Joyoung Company Limited, Jinan, Shandong, China). The dimeter of fresh noodles was 2.5 mm.

2.4 Determination of texture and tensile properties of dough

The dough was uniformly molded into cylindrical shape with diameter of 25 mm and height of 34 mm by a mold, and then was wrapped in with plastic wrap and rested at room temperature for 15 min before the determination of texture properties. The texture properties were determined by using a TA-XT plus texture analyzer (Exponent stable microsystem, version 6.1.2.0, Stable Microsystems Ltd., UK) equipped with P/50 probe, and the parameters were set as follows: the pre-test speed and post-test speed were set at 1.00 mm/s, the test speed was set at 1.00 mm/s, while the deformation level was 75% with a trigger force of 5 g. Hardness, adhesiveness, springiness, cohesiveness, chewiness and resilience were measured to evaluate dough texture properties.

The dough was covered with plastic wrap and rested at room temperature for 15 min, and then was put into the special dough strip preparation tank of the texture analyzer A/KIE probe to prepare uniformly size dough strips for tensile test. The parameters were set as follows: the pre-test speed and post-test speed were set at 2.00 mm/s, the test speed was set at 5.00 mm/s with a trigger force of 5 g. The tensile properties of the dough were evaluated by the resistance to extension and extensibility.

2.5 Cooking properties of noodles

The optimal cooking time was determined by the methods of Niu et al. (Niu et al., 2014) with some modifications. 20 sticks fresh noodles with the length of 20 cm were cooked in 500 mL of boiling water and cooked till the central opaque core in noodles disappeared, as judged by slightly squeezing the noodles between two transparent glass slides.

The dry matter water absorption rate of noodles was determined according to the methods of Mu et al. (Mu et al., 2022) with slightly modifications. The moisture content of fresh noodles was measured firstly, and the total quality (M2, g) of 20 sticks fresh noodles with the length of 20 cm was recorded and then cooked in 500 mL of boiling water until the optimal cooking time was reached. The noodles were quickly removed from the cooking water and cooled in distill water, then placed on filter papers to absorb the surface water of the noodles. The total mass of cooked noodles was recorded (M1, g). The dry matter water absorption rate was calculated as follows (Equation 1):

$$\textit{The dry matter water absorption rate}(\%) = \frac{M1 - M2 \times (1 - W)}{M2 \times (1 - W)} \times 100 \qquad (1)$$

Where M1 was the mass of cooked noodles (g); M2 was the mass of fresh noodles (g); W was the moisture content of fresh noodles (%).

The loss rate of dry matter was determined according to the method of Lin et al. (Lin et al., 2019) with slightly modifications. The noodles soup obtained from the determination of the dry matter water absorption rate was reserved for the determination of the loss rate of dry matter. It was transferred into weighing dish and dried in an oven at 105 °C to constant weight. The mass weight (M3) after constant weight was recorded. The loss rate of dry matter was calculated as follows (Equation 2):

$$\textit{The loss rate of dry matter} = \frac{M3}{M1(1 - W)} \times 100 \qquad (2)$$

The broken rate of noodles was determined by the method of Zhang (Zhang, 2015). 20 sticks fresh noodles with the length of 20 cm was cooked in 500 mL of boiling water until the optimal cooking time was reached. Calculated the percentage of broken noodles, which was the broken rate of noodles.

2.6 Determination of texture and tensile properties of noodles

The texture profile analysis (TPA) including the texture and tensile properties of noodles were determined as the methods reported by Zhang et al. (Zhang et al., 2017) with slightly modifications. The texture properties and tensile properties were determined within 15 min after cooking using a TA-XT plus texture analyzer (Exponent stable microsystem, version 6.1.2.0, Stable Microsystems Ltd., UK) equipped with P/36R probe, A/SPR, respectively. The noodles with same length of 20 cm and same diameter of 2.5 mm were cooked in boiling water until the optimal cooking time was reached, then quickly removed and cooled to room temperature in cold water and drained for 5 min before the measurement. the noodles were sheared same length with 4 cm. 3 sticks noodles were placed on the test bench side by side for determination for each time. The determination parameters of texture properties were set as follows: the pre-test speed and post-test speed were set at 2.00 mm/s, the test speed was set at 1.00 mm/s, while the deformation level was 75% with a trigger force of 5 g. Hardness, adhesiveness, springiness, cohesiveness, chewiness and resilience were measured to evaluate noodle texture quality.

As for the tensile test, 1 stick of cooked noodle was tied at one end of the lower arm groove of the probe and tightened. The other end of the noodle was tied to the upper arm groove with the same procedure. The determination parameters of tensile properties were set as follows: the pre-test speed and test speed were set at 2.0 mm/s, the pre-test speed was set at 10.0 mm/s, while the distance between the two arms was set at 30 mm. The tensile properties of the noodles were evaluated by the tensile strength and elasticity.

2.7 Sensory evaluations of noodles

The sensory evaluation was done according to the wheat flour for noodles industry standard SB/T 10139 of the People's Republic of China. The panelists (7 males and 8 females, ages of 20-35) were postgraduate students and the stuff of the Department of Food Science and Technology. The experimental method was based on the scoring method for sensory evaluation of Chinese white salted noodles reported by Liu et al. (Liu et al., 2019), with some modifications as indicated in Table 1. For all sensory attributes, total scores of 80 was considered as the limit of acceptability.

2.8 Statistical analysis

All the experiments were conducted in triplicate unless otherwise stated. The statistical analysis was performed on Data Processing System (version 7.05). Data were analyzed using ANOVA with Duncan's multiple range test, and the values were considered significantly different when $p \leq 0.05$.

3 Research results and discussions

3.1 Texture and tensile properties of dough

Dough texture properties reflect the combination of water and gluten, which are important indicators to measure the quality characteristics of dough within a certain range (Liu et al., 2021; Yao et al., 2019). The texture and tensile properties of dough were determined by TPA compressive test and TPA tensile test in this study, and the results were showed in Table 2 and Table 3. With the increase of HMTS substitution, the dough hardness decreased first and then increased, while the dough hardness increased with the increase incorporation of MWS. The different effects of HMTS and MWS on dough hardness were related to the different starch structure properties of HMTS and MWS. Adding proper amount of HMTS would make the dough become soft, and the hardness value would be reduced compared with the control dough. However, incorporating MWS required absorbing more water, and excessive MWS would make starch particles filled in the gluten network, which would reduce elasticity of the dough and hindered the formation of gluten network structure, thus resulting in the reduction of pores and the increase of the hardness of dough. The cohesiveness, gumminess, chewiness

Table 1. Scoring method for sensory evaluation of noodles.

Parameters	Score	Evaluation rules
Color	10	Creamy white/pale yellow (8.0-10); white (6.0-7.9); gray or dark (0-6.9)
Appearance shape	10	Smooth (8.0-10); less smooth but good shape (6.0-7.9); little distorted (4.0-5.9); very coarse or misshapen (0-3.9)
Oral chewiness	10	Good chewiness, medium hard (17.0-20); slightly hard or slightly soft (12.0-16.9); poor chewability, very hard or very soft (0-11.9)
Flavor	10	Good fragrance with fermented aroma (7.0-10); moderate aroma (4.0-6.9); unpleasant abnormal smell (0-3.9)
Stickiness	25	No stickiness (21.0-25); very slightly sticky (18.0-20.9); medium sticky (12.0-17.9); sticky (6.0-11.9); very sticky (0-5.9)
Elasticity	25	Very elastic (21.0-25); good elastic (18.0-20.9); medium elastic (12.0-17.9); low elastic (6.0-11.9); no elastic (0-5.9)
Smoothness	5	Good smooth (3.0-5.0); medium smoothness (2.0-2.9);no smoothness or coarse (0-1.9)
Flavor	5	Good flavor (4.0-5.0);medium flavor (2.0-3.9) unpleasant abnormal smell (0-1.9)

Table 2. Effect of HMT and MW modified potato starch on texture properties of dough.

Dough samples	Hardness (g)	Springiness (mm)	Cohesiveness (–)	Gumminess (g)	Chewiness (g·mm)	Resilience (–)
Control	5249 ± 266^{cd}	0.903 ± 0.035^{a}	0.636 ± 0.060^{b}	3328 ± 296^{a}	3012 ± 345^{a}	0.045 ± 0.002^{a}
HMT-10	4801 ± 300^{def}	0.919 ± 0.020^{a}	0.597 ± 0.054^{bc}	2859 ± 212^{b}	2624 ± 135^{b}	0.042 ± 0.004^{b}
HMT-20	4624 ± 313^{ef}	0.923 ± 0.012^{a}	0.568 ± 0.063^{dcde}	26349 ± 401^{bc}	2429 ± 349^{bc}	0.038 ± 0.003^{cde}
HMT-30	4513 ± 257^{f}	0.914 ± 0.028^{a}	0.532 ± 0.033^{cde}	2403 ± 215^{c}	2195 ± 201^{c}	0.035 ± 0.002^{efg}
HMT-40	4723 ± 135^{ef}	0.879 ± 0.053^{ab}	0.575 ± 0.055^{bcd}	2713 ± 284^{bc}	2415 ± 316^{bc}	0.033 ± 0.001^{g}
HMT-50	4939 ± 240^{def}	0.837 ± 0.108^{b}	0.495 ± 0.090^{de}	24283 ± 366^{c}	2093 ± 477^{c}	0.032 ± 0.002^{g}
MW-10	4691 ± 284^{ef}	0.923 ± 0.012^{a}	0.760 ± 0.054^{a}	35433 ± 157^{a}	3270 ± 160^{a}	0.040 ± 0.002^{bc}
MW-20	5003 ± 256de	0.875 ± 0.055^{ab}	0.490 ± 0.050^{e}	2476 ± 304^{bc}	2175 ± 397^{c}	0.040 ± 0.001^{bc}
MW-30	5551 ± 293^{c}	0.607 ± 0.013^{c}	0.508 ± 0.037^{de}	2815 ± 197^{bc}	1710 ± 153^{d}	0.038 ± 0.002^{cd}
MW-40	6177 ± 435^{b}	0.483 ± 0.025^{d}	0.307 ± 0.034^{f}	1890 ± 164^{d}	912 ± 85^{e}	0.037 ± 0.002^{def}
MW-50	6605 ± 455^{a}	0.162 ± 0.029^{e}	0.178 ± 0.018^{g}	1171 ± 105^{e}	192 ± 53^{f}	0.034 ± 0.002^{fg}

Notes: all values are the mean of at least triplicate determinations ± SD. The means within the same column with different letters are significantly different ($P_{value} < 0.05$).

Table 3. Effect of HMT and MW modified potato starch on tensile properties of dough and fresh noodles.

Samples	Dough TPA tensile test		Fresh noodles TPA tensile test	
	Resistance to extension (g)	Extensibility (mm)	Tensile strength (g)	Elasticity(mm)
Control	60.24 ± 3.21^{a}	25.44 ± 0.77^{a}	21.63 ± 1.50a	46.34 ± 2.49^{a}
HMT-10	47.03 ± 1.44^{c}	23.06 ± 1.99^{b}	18.67 ± 2.02b	43.99 ± 2.42^{a}
HMT-20	38.28 ± 1.68^{d}	21.51 ± 0.74^{cd}	17.78 ± 0.68^{bcd}	43.36 ± 2.03^{a}
HMT-30	33.85 ± 2.18^{e}	21.34 ± 2.84^{cd}	17.43 ± 0.81^{bcd}	37.90 ± 5.53^{b}
HMT-40	29.89 ± 2.95^{f}	20.96 ± 1.80^{cd}	17.04 ± 0.86^{cd}	33.05 ± 2.61^{de}
HMT-50	29.02 ± 3.19^{f}	18.46 ± 1.41^{e}	15.45 ± 1.01^{ef}	28.72 ± 3.88^{f}
MW-10	52.38 ± 2.29^{b}	21.86 ± 1.41^{bc}	18.43 ± 1.70^{bc}	36.82 ± 2.25^{bc}
MW-20	47.55 ± 1.87^{c}	20.07 ± 0.99^{d}	18.46 ± 1.34^{bc}	34.54 ± 2.95^{cd}
MW-30	38.66 ± 2.51^{d}	18.68 ± 1.02^{e}	17.57 ± 1.80^{bcd}	32.21 ± 2.42^{de}
MW-40	34.57 ± 1.82^{e}	18.38 ± 0.96^{e}	16.67 ± 0.77^{de}	30.76 ± 1.72^{ef}
MW-50	29.94 ± 0.92^{f}	15.86 ± 0.85^{f}	14.71 ± 1.36^{f}	25.27 ± 4.88^{g}

Notes: all values are the mean of at least triplicate determinations ± SD. The means within the same column with different letters are significantly different ($P_{value} < 0.05$).

and resilience were decreased with the increasing incorporation of HMTS or MWS. The dough springiness has no significant change with the increasing incorporation of HMTS except the sample HMT-50, but the dough springiness reduced with the increasing incorporation of MWS. These results might be related to the fact that the incorporation of starch reduced the gluten content in dough, leading to the deterioration of the dough network structure.

The tensile properties reflect the strength and extensibility of dough. The resistance to extension reflects the longitudinal elasticity of the dough, and the greater resistance to extension reflects the stronger longitudinal elasticity of the dough. The extensibility reflects the transverse extensibility of the dough, and the greater extensibility reflects the better ductility (Trevisan et al., 2022). Based on the tensile test results (Table 3), it was observed that resistance to extension and extensibility of dough significantly decreased with the increase incorporation amount of HMTS or MWS, which might due to incorporation of HMTS or MWS diluted the gluten protein in the mixed flour. At the same time, the filling of starch particles in dough hindered the formation of gluten network, which would weaken the combination between the components, thus reducing the energy required for tensile process. Therefore, incorporation of HMTS or MWS would significantly weaken the tensile characteristics (resistance to extension and extensibility) of the dough.

3.2 Cooking properties analysis of fresh noodles

The network structure of fresh and wet noodles and the degree of crosslinking of starch inside noodles directly affect the cooking properties of noodles. If the gluten network inside the noodles is poor and the crosslinking of starch is not tightly combined, it will cause the noodles to be lost during cooking process, or even the noodles will be broken (Tian et al., 2022). Starch gelatinization and gluten swelling have a certain effect on the dry matter water absorption of noodles, which mainly reflects the degree of hydration of protein and starch in noodles (Sajilata et al., 2006).

Table 4 showed that substitution wheat flour with HMT and MW modified potato starch (HMTS and MW) significantly decreased the optimal cooking time of fresh noodles ($P_{value} < 0.05$), moreover, the optimal cooking time of noodles with HMTS was lower than that of noodles with MWS when the substitution amount was same. HMTS and MWS weakened the binding strength between protein and starch, resulting in the formation of sparse structures in the noodles, making it easier for water to enter the interior of the molecules during cooking process, thereby reducing the optimal cooking time of noodles (Mu et al., 2022). The dry matter water absorption rate is referred to the total amount of water that noodles can be absorb and the loss rate of dry matter is related to the resistance to disintegration during cooking process (Fu, 2008). The dry matter water absorption rate and loss rate of dry matter significantly increased with the increase of substitution amount of HMTS and MWS. Moreover, both of the dry matter water absorption rate and loss rate of dry matter of noodles with HMTS were lower than that of noodles with MWS when the substitution amount was same, indicating noodles with HMTS had a better cooking quality than that of noodles with MWS in optimal cooking time condition. The increase in dry matter water absorption rate may due to the disruption of the double helical structure of amylopectin and the dissolution of amylose during starch gelatinization (Zhou et al., 2013). The added modified potato starch weakened the network structure in noodles, which might lead to the dissolution of water- soluble substances, thus increasing the loss rate of dry matter of noodles. Starch granules in noodles were over-expanded or even damaged during the cooking process, resulting in the increase of starch granules leaching, affecting the loss rate of dry matter, and even leading to the breakage of noodles. When the incorporation amount of HMTS was less than 30% and the incorporation amount of MWS was less than 20%, the noodles could remain intact without breaking.

3.3 Texture and tensile analysis of fresh noodles

Texture of food is a key quality characteristic that determines its edible quality and consumer's acceptance. Textural properties of cooked fresh noodles were determined by TPA compressive test and tensile test in this study. The results (Table 5) showed that the control noodles made by 100% wheat flour had the best texture than that of noodles made by partial substitution of wheat flour with modified potato starch, which might be because the gluten protein content of the starch- added flour was lower than that of original wheat flour. The incorporation of HMT and MW modified potato starch into noodles had some effects on the textural properties of cooked fresh noodles. The hardness and gumminess of cooked fresh noodles increased first and then decreased with the increase substitution amount of HMTS or MWS, the noodles with modified potato starch had the highest value of hardness and gumminess when the substitution amount of HMTS or MWS was 30% (HMT-30a and MW-30a, Table 5). Our previous research had confirmed that appropriate MW and HMT modification could increase gel hardness of potato starch, therefore the increased hardness of noodles with certain amount of HMTS or MWS could attributed to the improved rigidity of starch gel. However, excessive addition of modified potato starch would reduce the gluten protein content in wheat flour, and would weaken the network of flour dough, resulting in poor texture properties of the noodles.

Based on the tensile test results of fresh noodles (Table 3), it was observed that tensile strength and elasticity of cooked fresh noodles decreased with the increase substitution amount of HMTS or MWS, which might due to the decreased content of gluten protein in wheat flour after adding modified potato starch. When the gluten protein content decreased, the stability of the gluten network formed by mixing and stirring wheat flour and

Table 4. Effect of HMT and MW modified potato starch on cooking properties analysis of fresh noodles.

Noodles Samples	Optimal cooking time (s)	Dry matter water absorption rate (%)	Loss rate of dry matter (%)	Cooking breakage rate (%)
Control	133.3 ± 1.2^{a}	120.6 ± 1.3^{g}	1.94 ± 0.05^{j}	0.00 ± 0.00^{b}
HMT-10	121.5 ± 2.5^{b}	122.5 ± 0.3^{f}	2.98 ± 0.06^{i}	0.00 ± 0.00^{b}
HMT-20	106.3 ± 2.1^{d}	124.1 ± 0.2^{e}	3.38 ± 0.02^{h}	0.00 ± 0.00^{b}
HMT-30	87.3 ± 0.6^{f}	125.3 ± 0.3^{e}	4.39 ± 0.04^{g}	0.00 ± 0.00
HMT-40	77.0 ± 2.0^{g}	127.5 ± 0.0^{d}	5.43 ± 0.03^{d}	1.67 ± 1.44^{b}
HMT-50	75.0 ± 1.0^{g}	135.5 ± 1.9^{b}	6.00 ± 0.05^{c}	1.67 ± 1.44^{b}
MW-10	124.3 ± 2.1^{b}	122.7 ± 1.2^{f}	3.40 ± 0.10^{h}	0.00 ± 0.00^{b}
MW-20	118.3 ± 0.6^{c}	127.2 ± 0.6^{d}	4.51 ± 0.06^{f}	0.00 ± 0.00^{b}
MW-30	103.7 ± 1.5^{d}	128.4 ± 0.9^{d}	5.00 ± 0.10^{e}	1.67 ± 1.44^{b}
MW-40	97.3 ± 2.5^{e}	130.6 ± 0.4^{c}	7.13 ± 0.05^{b}	1.67 ± 1.44^{b}
MW-50	97.7 ± 2.5^{e}	147.4 ± 0.7^{a}	8.18 ± 0.04^{a}	5.00 ± 0.00^{a}

Notes: all values are the mean of at least triplicate determinations ± SD. The means within the same column with different letters are significantly different ($P_{value} < 0.05$).

water would be weakened, resulting in lower tensile strength and shorter stretching distance (lower elasticity value) (Lin et al., 2019).

3.4 Sensory evaluation of fresh noodles

The sensory evaluation of fresh noodles consisted seven components- color, appearance shape, oral chewiness, elasticity, stickiness, smoothness and flavor, and the individual scores were added together to obtain the total score (Table 6). The incorporation of HMTS or MWS had different effects on the sensory evaluation indicators of noodles. Incorporation of HMTS or MWS significantly increased the color score of noodles, but significantly decreased appearance shape score of noodles. However, according to the scoring method for sensory evaluation of fresh noodles (Table 1) and the results of sensory evaluation (Table 6), the appearance shape scores of all the noodles with modified potato starch were higher than 8.0 except the sample of MW-50, indicating that the appearance shape of noodles after incorporating of HMTS or MWS was still acceptable for consumers. Incorporation of small amount of HMTS (≤20%) or MWS (≤10%) would not significantly change the score of oral chewiness, elasticity, smoothness and total score of noodles. The other sensory evaluation indicators, including oral chewiness, elasticity, stickiness, smoothness and flavor, decreased with the increase substitution amount of HMTS (>30%) or MWS (>20%), and similarly, the total score of sensory evaluation also decreased. Increasing HMTS incorporation level decreased the total score of fresh noodles from 88.06 to 76.68, increasing MWS incorporation level decreased the total scores of fresh noodles from 87.46 to 75.78, whereas the control fresh noodles had total score of 88.38. In terms of general acceptability, there was no significant difference between the samples of HMTS-10, HMT-20, MWS-10 and the control fresh noodle, the sample MW-50 was the least acceptable. For all sensory attributes, total score of 80 was considered as the limit of acceptability. Thus, the maximum incorporation of HMTS should not be exceeded 40%, and incorporation of MWS should not be exceeded 20%. According to the results of sensory evaluation and cooking properties analysis (Table 4, cooking breakage rate) of fresh noodles, the optimal incorporation of HMTS and MWS was 30% and 20%, respectively. The noodles made with 30% HMTS or 20% MWS could remain intact without breaking and had good acceptability.

3.5 Correlation analysis between dough texture properties and noodles texture properties

The correlation analysis between the TPA compressive texture properties of dough and noodles was investigated, and the results were showed in Table 7. It can be seen from

Table 5. Effect of HMT and MW modified potato starch on texture properties of noodles.

Noodles Samples	Hardness (g)	Springiness (mm)	Cohesiveness (–)	Gumminess (g)	Chewiness (g·mm)	Resilience (–)
Control	4092 ± 280^{ab}	0.900 ± 0.030^{ab}	0.55 ± 0.03^{a}	2267 ± 218^{a}	2038 ± 186^{a}	0.20 ± 0.02^{ab}
HMT-10	3157 ± 297^{d}	0.918 ± 0.027^{a}	0.55 ± 0.04^{a}	1731 ± 195^{c}	1591 ± 191^{e}	0.20 ± 0.02^{ab}
HMT-20	3721 ± 2511^{c}	0.923 ± 0.033^{a}	0.54 ± 0.05^{ab}	2017 ± 255b	1869 ± 288^{bc}	0.21 ± 0.02^{a}
HMT-30	4272 ± 565^{a}	0.891 ± 0.032^{abc}	0.51 ± 0.05^{bcde}	2175 ± 158^{a}	1941 ± 170^{ab}	0.19 ± 0.02^{abc}
HMT-40	4092 ± 177^{b}	0.842 ± 0.045^{cd}	0.50 ± 0.03^{def}	2018 ± 158^{b}	1735 ± 163^{d}	0.18 ± 0.03^{abc}
HMT-50	4001 ± 149^{b}	0.860 ± 0.027^{de}	0.49 ± 0.03^{def}	1997 ± 100^{b}	1687 ± 130de	0.17 ± 0.04^{c}
MW-10	3667 ± 225^{c}	0.883 ± 0.023^{bc}	0.54 ± 0.03^{abc}	1958 ± 97^{b}	1729 ± 101^{d}	0.20 ± 0.03^{ab}
MW-20	3988 ± 187^{b}	0.880 ± 0.040^{bc}	0.51 ± 0.03^{cdef}	2020 ± 100^{b}	1778 ± 122^{cd}	0.19 ± 0.02^{abc}
MW-30	4294 ± 312^{a}	0.820 ± 0.043^{e}	0.48 ± 0.04^{f}	2038 ± 87^{b}	1672 ± 126de	0.18 ± 0.02^{bc}
MW-40	3737 ± 235^{c}	0.904 ± 0.016^{ab}	0.52 ± 0.03^{bcd}	1934 ± 128^{b}	1749 ± 120^{cd}	0.20 ± 0.04^{ab}
MW-50	3346 ± 191^{d}	0.881 ± 0.057^{bc}	0.49 ± 0.02^{df}	1630 ± 104^{c}	1436 ± 127^{f}	0.17 ± 0.03^{c}

Notes: all values are the mean of at least triplicate determinations ± SD. The means within the same column with different letters are significantly different ($P_{value} < 0.05$).

Table 6. Effect of HMT and MW modified potato starch on sensory scores of fresh noodles.

Noodles Samples	Color	Appearance shape	Oral chewiness	Elasticity	Stickiness	Smoothness	Flavor	Total score
Control	7.96 ± 0.11^{e}	8.68 ± 0.13^{a}	17.80 ± 0.45^{a}	22.80 ± 0.84^{ab}	22.20 ± 0.84^{a}	4.32 ± 0.18^{ab}	4.62 ± 0.13^{a}	88.38 ± 2.02^{a}
HMT-10	8.78 ± 0.08^{ab}	8.50 ± 0.16^{b}	17.00 ± 0.71^{ab}	23.60 ± 0.89^{a}	21.20 ± 0.84^{ab}	4.34 ± 0.11^{a}	4.64 ± 0.11^{a}	88.06 ± 1.90^{a}
HMT-20	8.68 ± 0.13^{b}	8.36 ± 0.11^{bc}	17.20 ± 0.84^{ab}	23.60 ± 1.14^{a}	20.60 ± 1.14^{b}	4.20 ± 0.16^{abc}	4.34 ± 0.11^{b}	86.98 ± 1.12^{ab}
HMT-30	8.78 ± 0.08^{ab}	8.30 ± 0.10^{c}	16.40 ± 0.89^{bc}	21.80 ± 0.84b^{c}	19.80 ± 0.84^{b}	4.12 ± 0.13^{c}	4.12 ± 0.08^{c}	83.32 ± 1.63^{c}
HMT-40	8.88 ± 0.08^{a}	8.14 ± 0.11^{d}	16.40 ± 0.89^{bc}	20.20 ± 0.84d^{e}	18.40 ± 1.14^{c}	4.14 ± 0.11^{c}	4.04 ± 0.05^{cd}	80.20 ± 0.84^{d}
HMT-50	8.82 ± 0.08^{ab}	8.02 ± 0.08^{de}	15.60 ± 1.14^{cd}	19.60 ± 1.14^{e}	16.60 ± 1.14^{d}	4.08 ± 0.08^{cd}	3.96 ± 0.11^{de}	76.68 ± 2.12^{e}
MW-10	8.80 ± 0.07^{ab}	8.46 ± 0.11^{b}	17.80 ± 0.84^{a}	22.20 ± 0.84^{bc}	21.20 ± 0.84^{ab}	4.34 ± 0.11^{a}	4.66 ± 0.11^{a}	87.46 ± 1.28^{ab}
MW-20	8.76 ± 0.11^{ab}	8.44 ± 0.11^{bc}	17.60 ± 1.14^{ab}	21.00 ± 1.00^{cd}	20.60 ± 1.14^{b}	4.16 ± 0.11^{bc}	4.40 ± 0.16^{b}	84.96 ± 3.04^{bc}
MW-30	8.54 ± 0.11^{c}	8.14 ± 0.11^{d}	16.40 ± 0.89^{bc}	17.40 ± 0.89^{f}	16.00 ± 1.00^{d}	3.94 ± 0.11^{de}	3.84 ± 0.11^{e}	74.26 ± 1.78^{f}
MW-40	8.48 ± 0.08^{c}	8.08 ± 0.08^{de}	14.80 ± 0.84^{d}	16.60 ± 1.14^{fg}	14.40 ± 1.14^{e}	3.88 ± 0.13^{e}	3.52 ± 0.15^{f}	69.76 ± 1.12^{g}
MW-50	8.22 ± 0.15^{d}	7.94 ± 0.11^{e}	13.60 ± 1.14^{e}	16.00 ± 1.00^{g}	13.40 ± 1.14^{e}	3.46 ± 0.11^{f}	3.16 ± 0.11^{g}	65.78 ± 2.65^{h}

Notes: all values are the mean of at least triplicate determinations ± SD. The means within the same column with different letters are significantly different ($P_{value} < 0.05$).

Table 7. Correlation analysis between dough tensile properties and noodles tensile properties.

Correlation coefficients		TPA compressive test of dough						TPA compressive test of noodles					
		Hardness (g)	Springiness (mm)	Cohesiveness (–)	Gumminess (g)	Chewiness (g·mm)	Resilience (–)	Hardness (g)	Springiness (mm)	Cohesiveness (–)	Gumminess (g)	Chewiness (g·mm)	Resilience (–)
TPA compressive test of dough	Hardness (g)	1											
	Springiness (mm)	-0.95**	1										
	Cohesiveness (–)	-0.84**	0.89**	1									
	Gumminess (g)	-0.70*	0.80**	0.97**	1								
	Chewiness (g·mm)	-0.86**	0.93**	0.98**	0.94**	1							
	Resilience (–)	-0.11	0.32	0.46	0.59*	0.5	1						
TPA compressive test of noodles	Hardness (g)	-0.27	0.28	0.21	0.25	0.19	-0.17	1					
	Springiness (mm)	-0.10	0.18	0.04	-0.02	0.14	0.42	-0.56	1				
	Cohesiveness (–)	-0.40	0.55	0.55	0.54	0.63*	0.70*	-0.35	0.81**	1			
	Gumminess (g)	-0.48	0.58*	0.50	0.54	0.53	0.22	0.85**	-0.12	0.2	1		
	Chewiness (g·mm)	-0.50	0.63*	0.50	0.51	0.57	0.36	0.61*	0.27	0.5	0.92**	1	
	Resilience (–)	-0.27	0.42	0.40	0.43	0.44	0.67*	-0.22	0.74**	0.87**	0.25	0.52	1

* indicates $P_{value} < 0.05$, there is significant correlation between indicators. ** indicates $P_{value} < 0.01$, there is extremely significant correlation between indicators.

Table 8. Correlation analysis between dough tensile properties and noodles tensile properties.

Correlation coefficients	Resistance to extension	Extensibility	Tensile strength	Elasticity
Resistance to Extension	1			
Extensibility	0.75**	1		
Tensile strength	0.91**	0.90**	1	
Elasticity	0.71**	0.93**	0.85**	1

** indicates $P_{\text{value}} < 0.01$, there is extremely significant correlation between indicators.

Table 7 that there was strong correlation between the texture property indexes of dough. The dough hardness index had a significant or extremely significant negative correlation with the springiness, cohesiveness, gumminess and chewiness of the dough. The springiness, cohesiveness, gumminess and chewiness of dough were extremely significant positive correlated with each other. The gumminess and chewiness of cooked fresh noodles were extremely significant or significant positive correlated with the hardness of cooked fresh noodles, while the chewiness was extremely significant positive correlated with the gumminess. The resilience of cooked fresh noodles was significant positive correlated with the springiness and cohesiveness. However, except for the weak significant positive correlation between the springiness of dough and the gumminess and chewiness of cooked fresh noodles, the weak significant positive correlation between the chewiness of dough and the cohesiveness of cooked fresh noodles, the weak significant positive correlation between the resilience of dough and cohesiveness and resilience of cooked fresh noodles, there were no significant correlation between the dough and the cooked fresh noodles of the other texture properties indicators. These results might be related to the incorporation of HMTS or MWS. The incorporation of HMTS or MWS diluted the gluten protein in flour, making the dough unable to form good gluten network structure. Moreover, the noodles made with HMTS or MWS absorbed more water than the control noodles (Table 4, dry matter water absorption rate) in the cooking process, and the starch granules were easy to dissolve (Table 4, loss rate of dry matter), which might cause the texture properties of cooked fresh noodles to be different from that of the control noodles (Table 5), which might also be the reason that there was no obvious correlation between the texture property indicators of cooked fresh noodles and that of the dough.

3.6 Correlation analysis between dough tensile properties and noodles tensile properties

Although there was no obvious correlation between the texture property indicators of cooked fresh noodles and that of the dough, the dough tensile properties of resistance to extension and extensibility were extremely significant positive correlated with the cooked fresh noodles tensile properties of tensile strength and elasticity (Table 8). The results of correlation analysis between the TPA tensile properties of dough and noodles indicated that the tensile properties of dough could be used to evaluate the tensile properties of cooked fresh noodles and could also reflect the quality of the cooked fresh noodles.

4 Conclusions

According to the present study, the substitution of with heat-moisture treatment modified potato starch (HMTS) or with microwave treatment modified potato starch (MWS) altered the texture and tensile properties of dough. Through correlation analysis, it has been concluded that the dough tensile properties of resistance to extension and extensibility were extremely significant positive correlated with the cooked fresh noodles tensile properties of tensile strength and elasticity.

The fresh noodles manufactured with HMTS or MWS substituted for 10% to 50% of wheat flour had significantly altered the cooking properties, texture properties and tensile properties. When the incorporation amount of HMTS was less than 30% and the incorporation amount of MWS was less than 20%, the noodles could maintain good organoleptic and cooking quality attributes. More than 30% of HMTS or 20% MWS will deform the noodles and cause breakage. Therefore, the maximum incorporation of HMTS or MWS should be 30%, 20%, respectively.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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