UDC 664.2
DOI: 10.15587/1729-4061.2022.265234

INFLUENCE OF SUBSTITUTION OF WHEAT FLOUR WITH MODIFIED POTATO STARCH ON THE QUALITY OF CHINESE STEAMED BREAD

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The application of potato starch in flour products is very important for potato staple food. The gluten protein of wheat flour will be weakened after being mixed with potato starch, which could have inhibitory effect on quality properties of flour products. Therefore, it is, it is necessary to study the influence of substitution wheat flour with potato starch on the quality of Chinese steamed bread (CSB), which is an important staple food in North China.

This study investigated the effect of potato starch modified by heat-moisture treatment (HMTS) and microwave treatment (MWS) as wheat flour substitute in the making of CSB. The research results showed that the specific volume of CSB decreased with more incorporation of HMTS or MWS. The differences color (ΔE>3) between the control and experimental CSB were detectable by the human eye when the substitution level of HMTS or MWS was higher than 30 % or 20 %, respectively. Texture properties of CSB were affected with substitution due to the disruption of dough structure, and the incorporation of HMTS or MWS led to firmer and denser structure of CSB. The total sensory score of CSB decreased with more incorporation of HMTS or MWS. CSB can be accepted by consumers when the substitution level of wheat flour with HMTS or MWS was lower than 30 %. In general, the research results revealed that modified potato starch (HMTS and MWS) incorporation levels affected the specific volume, color, texture properties and sensory evaluation of CSB. This research can provide comprehension of the influence of modified potato starch (HMTS or MWS) on CSB and provide valuable guidance for further application of potato starch in wheat-based products

Keywords: Chinese steamed bread, potato starch, heat-moisture treatment, microwave treatment, specific volume, texture properties, sensory evaluation

Received date 01.08.2022
Accepted date 12.10.2022
Published date 30.10.2022

***How to Cite**: Deng, C., Melnyk, O., Luo, Y. (2022). Influence of substitution of wheat flour with modified potato starch on the quality of Chinese steamed bread. Eastern-European Journal of Enterprise Technologies, 5 (11 (119)), 12–27. doi: https://doi.org/10.15587/1729-4061.2022.265234*

1. Introduction

Chinese steamed bread (CSB) is one of important staple food in China for a long time, and attracts great interest in some Asia countries, including Japan and Korea, and other European and American countries [1]. The traditional CSB is made by mixing wheat flour, water and yeast, with or without the addition of sugar or salt for dough formation, followed by fermentation, kneading, molding and proofing before cooked by steaming [2]. As compared to bread manufactured by baking, the low steaming temperature during CSB production allows better retention of various endogenous and added nutrients. CSB becomes popular in the world markets and is considered as healthy food possible due to low oil and low sodium content, and also due to relatively low steaming temperature (100 °C) makes CSB not containing Maillard reaction products such as acrylamide and furan [3, 4]. There are diverse optional ingredients that are added to CSB to enhance the processing, nutritional and/or eating properties. Whole purple sweet potato flour was used in CSB up to 10 % with wheat flour to enhance the functional properties of CSB without compromising eating quality [5], so as intact chia seed addition up to 300 g/kg can enhance the nutrition of CSB without compromising eating quality [6], while inulin can ultimately affect storage characteristics of CSB by the interaction with starch and changes of water distribution between protein and starch [7].

Due to the high content of RDS in traditional CSB, 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. Therefore, a series of CSB quality improving agents must be added to change the quality of CSB or increase the content of SDS and RS. Modified starch can be used as a kind of CSB quality improving agent, its properties is related to CSB quality of specific volume and texture properties. However, there are few literatures available on the impacts of HMT and MW modified potato starch on CSB. Therefore, the research on the development of CSB with high SDS and RS content modified potato starch is of great significance for people's dietary health and the promotion of potato staple food.

2. Literature review and problem statement

Potato is the fourth most important crop in the world after rice, wheat, corn and plays an important role in human diets [8]. Starch is the most component of potato tubers, accounting for 75 % of dry potato tubers [9]. Due to its high water-binding capacity and swelling power and other unique characteristics, potato starch is widely used as ingredients of additives in textile, chemical, pharmaceutical, food and other industrial products [10]. Starch has inherent limitations that can be overcome by the modification methods as physical, chemical, enzymatic, and combinations of them [11]. Physical modification methods have gained wide acceptance for their no-pollution, no by-products and low cost [12]. Heat-moisture treatment (HMT) is one of the most important physical modification methods of starch, which refers to the utilization of high moisture content (10–35 %) and temperature (90–120 °C) for a period of treatment time (15 min–16 h) [13]. Many pervious researches have confirmed that HMT directly affects starch digestibility through the formation of slowly digestible starch (SDS) and resistant starch (RS) and the reduction of rapidly digestible starch (RDS), which is very important for realizing consumers' health benefits. The SDS and RS of HMT modified flour using oven method and autoclave method increased to 4–16 % and 4–15 % [14]. RS content of HMT pearl millet starches increased as compare to native starches and varied from 18.1 to 40.2 % [15]. HMT could increase the amount of RS + SDS in pea starch than that of native starch [16]. These results indicated that HMT could reduce the digestibility of starch by converting some RDS fractions into SDS or RS fractions. Microwave treatment (MW) is another appealing physical modification method of starch for its effectively heating, high yield and potentially good quality of products [17]. MW was used to improve some functionality and RS content of sago (Metroxylon sagu) starches [18]. Water absorption capacity of potato starches increased from 0.82–1.16 g/g with HMT treatment time while oil absorption capacity decreased from 0.63–0.53 g/g [19]. Millet starches with different moisture content showed different physicochemical and in vitro digestion after being modified by MW [20]. MW also enhanced canna starch etherification with citric acid and enhanced the formation of RS [21]. Many researches have studied the influence of MW on the digestibility of starch [18, 22], and the results of these researches indicating that MW could increase the content of RS and SDS.

During the past ten years, the prevalence of diabetes in Chinese adults has been maintaining at 10 % [23]. An analysis of a China nationally representative survey shows that China has more than 130 million adults with type 2 diabetes, and 350 million individuals with prediabetes (3) [24]. It is a feasible strategy to develop functional foods with improved nutritional properties to solve these health problems. Since most of the wheat products belong to high glycemic index (GI) foods, enhancing CSB with functional components has the potential to be beneficial [25]. Strategies for developing CSB with low GI remain to be developed to help people with diabetes and other diseases [26]. Partial substitution of wheat flour with whole flour or other functional ingredients can enhance the nutritional quality of CSB. However, the dough rheological properties and the product quality may be altered by substitution of wheat flour with other types of low-gluten flour [27]. Therefore, it is necessary to investigate the effects of substitution of wheat flour with other types of low-gluten flour on the quality characteristics of CSB.

In previous our researches [28, 29], potato starch was modified by HMT and 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 CSB quality or the nutrition.

3. The aim and objectives of the study

The aim of the study is to analyze the effects of different substitution levels of HMT and MW modified potato starch (HMTS and MWS) as wheat flour substitute on the quality characteristics of CSB. The CSB obtained in this study will provide a healthier choice for customers.

To achieve this aim, the following objectives are accomplished:

– to determine specific volume, surface color and interior color of CSB;

– to determine the textural properties of CSB;

– to determine the sensory acceptance of CSB.

4. Materials and methods

4. 1. Object and hypothesis of the study

The object of the research is Chinese steamed bread incorporated with HMT and MW modified potato starch. The main hypothesi of this study is that incorporating appropriate amount of HMT and MW modified potato starch will not reduce the quality of Chinese steamed bread, but also improve the nutritional value of steamed bread.

4. 2. 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), instant dry yeast (Angel Yeast Co., LTD, Yichang, Hubei province, China). wheat flour and instant dry yeast were bought in a local supermarket (Hezhou city, China).

4. 3. Methods

4. 3. 1. Prepartion of modified potato starch

HMT modified potato starch was prepared as the method previously reported by Deng [28]. Based on the results of previous experiments, the starch was sealed after adjusting the moisture content to 23.56 % and placed at room temperature for 24 h to equilibrate the moisture. The equilibrated starch was then placed in hot-air oven ((DH411C, Yamato, Tokyo, Japan) at 90 °C for 1.5 h to obtain the HMT modified potato starch (HMTS). The *in vitro* digestive properties of HMTS were determined by the Englyst method [30]. The content of RS and SDS of HMT modified potato starch 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 [29]. Briefly, adjusted the moisture content of native potato starches to 25 % and then equilibrated the starch sample at 25 C for 24 h. 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 400 W for 5 min. The treated starch sample was dried and stored in an airtight container for conducting further studies. The prepared treated starch was named as MWS, and the SDS content and RS content of MWS was 55.90 %, 14.97 %, respectively, which was higher than that of native potato starch.

4. 3. 2. Preparation of Chinese steamed bread

The procedures for CSB manufacture were mixing, resting, sheeting, dividing, moulding, proofing, and steaming. The recipe of control of CSB was 100 g wheat flour (12 % moisture content), 55 g water, 1.0 g yeast and 1.0 g salt. Wheat flour was replaced by HMTS or MWS at the levels of 10 %, 20 %, 30 %, 40 % and 50 %. 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 %. Dough was formed by mixing wheat flour, HMTS or MWS, water, salt and yeast and was kneaded and shaped manually for 2 min. Then the dough samples were fermented in a fermenting box at 35 °C and 65 % relative humidity for 60 min. After fermentation, the dough samples were kneaded one more time by adding 5 g mixed flour (different substitution of wheat flour and HMTS/ or MWS), and then divided into small pieces (50±0.5 g), rounded and shaped into buns, proofed for 10 min at 35 °C and 65 % relative humidity and then steamed at 100 °C for 20 min at atmospheric pressure. The steamed bread buns were cooled at room temperature for 1 h prior to all analyses.

According to the different substitution of HMTS (10 %, 20 %, 30 %, 40 % and 50 %), the experimental CSB buns (named as HMT-CSB) were named as HMT-10, HMT-20, HMT-30, HMT-40 and HMT-50. Similarly, according to the different substitution of MWS (10 %, 20 %, 30 %, 40 % and 50 %), the experimental CSB buns (named as MW-CSB) were named as MW-10, MW-20, MW-30, MW-40 and MW-50. CSB made entirely of wheat flour without HMTS and MWS were used as control, named as CK.

4. 3. 3. Specific volume of Chinese steamed bread

The specific volume of CSB was determined by millet displacement method according to Cao [8]. Cooled CSB was weighed, and the volume was determined through millet replacement method, and the specific volume (mL/g) of CSB was calculated by the ratio of volume to the weight of CSB.

4. 3. 4. Determination of color

Color parameters (L*, a*, b*) of CSB (crumb and crust) were determined at least three times by a colorimeter (CR-400, Konica Minolta Inc., Japan) after the calibration of the equipment with a standard whiteboard. The color difference (ΔE) between control CSB and experimental CSB was expressed as follows:

$$\Delta E=\sqrt{\left(L^*-L_0^*\right)^2+\left(a^*-a_0^*\right)^2+\left(b^*-b_0^*\right)^2}, \quad (1)$$

where L*, L_0^* is the lightness value of experimental CSB and control CSB; a*, a_0^* is the greenness/redness value of experimental CSB and control CSB; b*, b_0^* is the blueness/yellowness value of experimental CSB and control CSB. The smaller value of ΔE indicates the smaller color difference between experimental CSB and control CSB. A ΔE value>3 was used to indicate whether the color differences between two different samples could be visibly differentiated [31, 32].

4. 3. 5. Texture analysis of Chinese steamed bread

CSB texture properties were determined according to the methods of [4] with slight modifications. The crumb of CSB was cut into cubes with the size of 2×2×2 cm and assayed using TA-XT plus Texture Analyzer (Exponent stable microsystem, version 6.1.2.0, Stable Microsystems Ltd., UK) equipped with P/36R probe. The pre-test speed and post-test speed were set at 2.0 mm/s, the test speed was set at 1.00 mm/s, while the deformation level was 50 % with a trigger force of 5 g. Hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience were calculated by the instrument software.

4. 3. 6. Sensory characteristics of Chinese steamed bread

The sensory evaluation was done according to the wheat flour for steamed bread industry standard SB/T 10139 of the People's Republic of China. The experimental method was based on the scoring method for sensory evaluation of Chinese northern style steamed bread reported by [33], with some modifications as indicated in Table 1.

Table 1

Scoring method for sensory evaluation of CSB

Parameters	Score	Evaluation rules
Specific volume	20	The highest score is 20 points for 2.3 mL/g, the score decreased by 1 point for each decrease of 0.1 mL/g
Color	10	Creamy white/pale yellow (7.1–10); dark yellow (4.1–7.0), gray or dark (0–4.0)
Appearance shape	20	Good volume and symmetry, good upright, very smooth, bright, no specks (16.1–20.0); basic symmetry and upright, fewer rough surfaces, fewer specks or bubbles on the surface (10.1–16.0); no symmetry, low height, and bad shape, rough surface, specks or bubbles on surface (0–10)
Internal texture	10	Good crumb structure dense homogenous and spongy (no big holes) (7.1–10); acceptable crumb, homogenous with few big holes (4.1–7.0), poor, uneven large holes, and not homogenous (0–4.0)
Flavor	10	Good fragrance with fermented aroma (7.1–10); moderate aroma (4.1–7.0); unpleasant abnormal smell (0–4.0)
Oral chewiness	10	Good chewiness, soft and easy to swallow (7.1–10); moderate hardness and chewiness (4.1–7.0); poor chewability, hard and difficult to swallow (0–4.0)
Elasticity	20	Good bounce back, CSB can be pressed to 1/2 volume (16.1–20.0); bounce back slowly, CSB can be pressed to 1/4 volume (10.1–16.0); poor no bounce and crumbly (0–10)

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. According to the sensory score table, the total sensory score for all sensory attributes of experiments was 100, and the obtained total sensory score of 80 was considered as the limit of acceptability.

4. 3. 7. 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 $p \leq 0.05$.

5. Results of the effects of wheat flour substitution with HMTS or MWS on dough texture properties and quality of Chinese steamed bread

5. 1. Research results on specific volume and color of Chinese steamed bread

The specific volume and colors of the CSB are shown in Table 2. The specific volume of CSB decreased with the increase of substitution levels of HMTS and MWS, which was significantly lower than that of the control CSB. The specific volume of control CSB (Table 2, CK) was 2.82 mL/g, while the lowest specific volume of CSB (MW-50) was 1.85 mL/g (Table 2, MW-50). Compared with HMTS, MWS had greater effect on the specific volume of CSB, and the specific volume of MW-CSB was lower than that of HMT-CSB at the same substitution level. The specific volume of CSB is positively related to the amount of gluten and gas hold capacity. Strong gluten network structure is essential for the gas cell in dough to provide expansion strength during fermentation and steaming. Substitution of wheat flour with HMTS and MWS reduced the amount of gluten in mixed flour, and the mixed dough cannot form strong network structure needed for gas retention, thereby, reduced the specific volume of CSB.

Table 2 presented the results of experiments evaluating the effect of partial substitution of wheat flour with HMTS or MWS on the crust and core colors of CSB. The results showed that for both crust and core, as the amount of added HMTS and MWS increased, the lightness value (L*) and the red-green value (a*) increased, the yellow-blue value (b*) decreased, which indicated that as the lightness of CSB increased, the red value increased, and the transparent color became lighter.

In general, MWS had greater effect on the crust and core colors of the CSB than that of HMTS. The color differences (ΔE) between each experimental CSB and the control CSB increased with the increase of substitution levels of HMTS or MWS. Moreover, when the substitution levels of HMTS were higher than 30 % or MWS was higher than 20 %, the color differences (ΔE) between each experimental CSB and the control CSB was above 3, indicating that the differences in color between the control and experimental CSB were detectable by the human eye.

5. 2. Research results on texture properties of Chinese steamed bread

The texture properties of food mainly refer to its tissue characteristics and this quality is related to the sensory and edible properties of food. The hardness, gumminess and chewiness are negatively correlated with the quality of CSB, while springiness, cohesiveness and resilience are positively correlated with the quality of CSB. The texture results of CSB are shown in Table 3.

The results showed that the hardness, gumminess and chewiness increased significantly with the increase of substitution levels of HMTS or MWS. As a major indicator of textural properties, hardness is the force required to resist deformation, a small value of hardness implies a fluffy texture of CSB.

Table 3

The textural properties of Chinese steamed bread

Sample	Hardness (g)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
CK	367 ± 19^{j}	0.97 ± 0.01^{a}	0.86 ± 0.01^{a}	314 ± 17^{j}	303 ± 15^{h}	0.48 ± 0.01^{ab}
HMT-10	416 ± 15^{i}	0.97 ± 0.01^{a}	0.84 ± 0.02^{a}	348 ± 17^{ij}	338 ± 17^{gh}	0.48 ± 0.01^{ab}
HMT-20	547 ± 28^{h}	0.96 ± 0.01^{a}	0.80 ± 0.02^{b}	437 ± 16^{h}	418 ± 15^{f}	0.46 ± 0.02^{bc}
HMT-30	688 ± 22^{f}	0.96 ± 0.01^{a}	0.79 ± 0.01^{bc}	542 ± 20^{f}	518 ± 18^{e}	0.45 ± 0.00^{c}
HMT-40	1375 ± 15^{c}	0.91 ± 0.02^{c}	0.70 ± 0.01^{d}	967 ± 14^{c}	881 ± 24^{b}	0.39 ± 0.01^{e}
HMT-50	1685 ± 29^{a}	0.88 ± 0.03^{d}	0.67 ± 0.02^{e}	1129 ± 51^{a}	999 ± 59^{a}	0.38 ± 0.01^{e}
MW-10	442 ± 21^{i}	0.96 ± 0.01^{a}	0.84 ± 0.01^{a}	372 ± 15^{i}	359 ± 15^{g}	0.48 ± 0.01^{a}
MW-20	620 ± 25^{g}	0.93 ± 0.01^{b}	0.79 ± 0.01^{bc}	487 ± 21^{g}	455 ± 17^{f}	0.42 ± 0.01^{d}
MW-30	840 ± 43^{e}	0.93 ± 0.02^{b}	0.76 ± 0.04^{c}	639 ± 22^{e}	596 ± 24^{d}	0.42 ± 0.03^{d}
MW-40	995 ± 44^{d}	0.92 ± 0.01^{bc}	0.73 ± 0.03^{d}	722 ± 21^{d}	664 ± 21^{c}	0.41 ± 0.02^{d}
MW-50	1634 ± 58^{b}	0.89 ± 0.02^{d}	0.66 ± 0.03^{e}	1085 ± 58^{b}	963 ± 554^{a}	0.37 ± 0.02^{e}

Note: all values are the mean of at least triplicate determinations ±SD. The means within the same column with different letters are significantly different (P<0.05)

Table 2

Effect of various levels of HMTS and MWS on the specific volume and colors of the Chinese steamed bread

Sample	specific volume (mL/g)	Crust				Core			
		L^*	a^*	b^*	**ΔE**	L^*	a^*	b^*	**ΔE**
CK	2.82 ± 0.14^{a}	82.63 ± 0.63^{e}	2.05 ± 0.07^{d}	11.84 ± 0.45^{a}	–	79.02 ± 0.42^{g}	2.02 ± 0.07^{f}	12.81 ± 0.62^{a}	–
HMT-10	2.64 ± 0.05^{b}	83.00 ± 0.86^{e}	2.07 ± 0.04^{d}	10.62 ± 0.24^{b}	1.49 ± 0.05^{h}	79.27 ± 0.38^{fg}	2.05 ± 0.07^{ef}	12.26 ± 0.55^{b}	0.65 ± 0.62^{i}
HMT-20	2.47 ± 0.04^{c}	83.10 ± 0.59^{e}	2.10 ± 0.03^{d}	10.40 ± 0.41^{b}	1.57 ± 0.51^{gh}	79.65 ± 0.43^{f}	2.08 ± 0.04^{ef}	11.70 ± 0.24^{cd}	1.35 ± 0.11^{h}
HMT-30	2.38 ± 0.07^{cd}	84.99 ± 0.37^{cd}	2.17 ± 0.08^{cd}	10.13 ± 0.54^{bc}	2.97 ± 0.12^{d}	80.72 ± 0.48^{e}	2.13 ± 0.03^{de}	11.26 ± 0.23^{d}	2.34 ± 0.19^{f}
HMT-40	2.30 ± 0.07^{de}	84.48 ± 0.25^{d}	2.26 ± 0.06^{bc}	9.48 ± 0.18^{d}	3.01 ± 0.21^{d}	82.028 ± 0.08^{d}	2.35 ± 0.03^{c}	10.23 ± 0.33^{ef}	3.98 ± 0.18^{e}
HMT-50	1.99 ± 0.10^{f}	85.27 ± 0.26^{c}	2.44 ± 0.07^{a}	9.37 ± 0.16^{d}	3.65 ± 0.11^{c}	83.76 ± 0.28^{b}	2.46 ± 0.04^{b}	9.24 ± 0.18^{g}	5.95 ± 0.27^{b}
MW-10	2.61 ± 0.11^{b}	84.38 ± 0.22^{d}	2.08 ± 0.08^{d}	11.53 ± 0.27^{a}	1.80 ± 0.19^{fg}	80.68 ± 0.28^{e}	2.07 ± 0.03^{ef}	12.29 ± 0.36^{b}	1.79 ± 0.14^{g}
MW-20	2.46 ± 0.10^{c}	84.51 ± 0.08^{d}	2.12 ± 0.03^{d}	11.30 ± 0.44^{a}	1.99 ± 0.14^{f}	81.16 ± 0.27^{e}	2.16 ± 0.09^{d}	11.81 ± 0.45^{bc}	2.40 ± 0.19^{f}
MW-30	2.27 ± 0.03^{de}	84.36 ± 1.09^{d}	2.16 ± 0.08^{cd}	10.31 ± 0.66^{b}	2.58 ± 0.11^{e}	83.22 ± 0.16^{c}	2.32 ± 0.04^{c}	10.43 ± 0.38^{e}	4.85 ± 0.19^{d}
MW-40	2.22 ± 0.07^{e}	86.54 ± 0.21^{b}	2.35 ± 0.07^{ab}	9.68 ± 0.55^{cd}	4.50 ± 0.10^{b}	83.47 ± 0.25^{bc}	2.32 ± 0.09^{c}	9.89 ± 0.37^{f}	5.34 ± 0.11^{c}
MW-50	1.85 ± 0.04^{g}	87.35 ± 0.27^{a}	2.41 ± 0.25^{a}	9.26 ± 0.45^{d}	5.41 ± 0.26^{a}	86.07 ± 0.48^{a}	2.54 ± 0.05^{a}	8.92 ± 0.34^{g}	8.08 ± 0.31^{a}

Note: all values are the mean of at least triplicate determinations ±SD. The means within the same column with different letters are significantly different (P<0.05)

The incorporation of HMTS from 10 % to 50 % led to the increase of hardness from 416 to 1685 g, and the incorporation of MWS from 10 % to 50 % led to the increase of hardness from 442 to 1634 g, whereas the hardness of control CSB (CK) was 367 g (Table 3). Thus, higher replacement levels of HMTS or MWS firmed the structure of CSB. When the addition amount was less than 30 %, MWS had greater effects on the increase of CSB hardness than that of HMTS under the same substitution level. The chewiness and gumminess had similar results of hardness due to positive correlation between them. The springiness, cohesiveness and resilience were reduced with the increase of substitution levels of HMTS or MWS. These results of texture properties of CSB indicated that the incorporation of HMT or MWS led to firmer and denser structure of CSB.

5. 3. Research results on sensory evaluation of Chinese steamed bread

Sensory evaluation directly reflects the acceptability of food. HMTS or MWS replacement affected different sensory quality attributes of CSB to different degrees (Table 4).

As can be seen form Table 4, increasing HMTS incorporation level decreased the total scores of CSB from 89.9 to 52.7, increasing MWS incorporation level decreased the total scores of CSB from 88.8 to 49.8, whereas the control CSB had total score of 90.0. For all sensory attributes, total scores of 80 was considered as the limit of acceptability. Thus, the maximum incorporation of HMTS or MWS should not be exceeded 30 %. When the replacement levels of HMTS or MWS exceed 40 %, the oral sensation of CSB deteriorated sharply, and the internal structure of CSB become too hard and too firm, making it difficult to swallow.

The photoes of CSB made by different incorporation of HMTS or MWS were showed in Fig. 1.

As can be seen form Fig. 1, incorporation of HMTS or MWS made the surfaces of CSB become rougher, and even appeared a few specks or bubbles on the surface. Moverover, The appearance scores of the sensory evaluation were consistent with the results shown in the photos (Fig. 1).

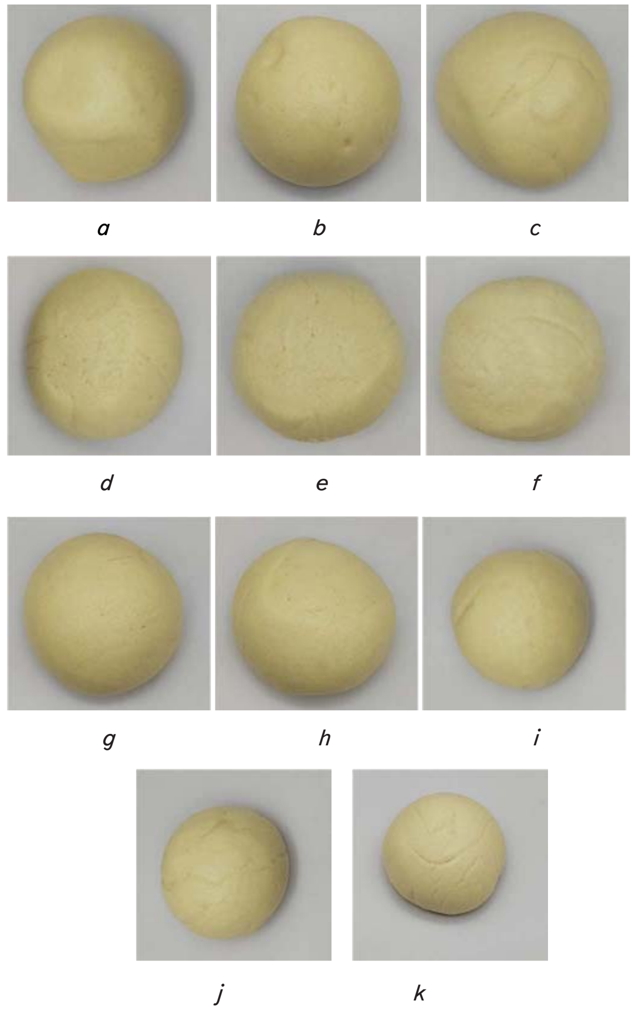

Fig. 1. Photos of Chinese steamed bread with different incorporation of heat-moisture treatment or microwave treatment modified potato starch: *a* – CK; *b* – HMT10; *c* – HMT20; *d* – HMT30; e – HMT40; *f* – HMT50; *g* – MW10; *h* – MW20; *i* – MW30; *j* – MW40; *k* – MW50

Table 4

Sensory evaluation scores of Chinese steamed bread (CSB)

Sample	Specific volume score	Color	Appearance	Internal texture	Flavor	Oral chewiness	Elasticity	Total score
CK	20.0 ± 0.0^{a}	8.0 ± 0.0^{a}	18.0 ± 0.0^{a}	8.2 ± 0.3^{ab}	8.0 ± 0.0^{a}	9.0 ± 0.0^{a}	18.8 ± 0.4^{a}	90.0 ± 0.6^{a}
HMT-10	20.0 ± 0.0^{a}	8.0 ± 0.0^{a}	18.0 ± 0.0^{a}	8.5 ± 0.5^{a}	8.0 ± 0.0^{a}	8.8 ± 0.4^{a}	18.6 ± 0.5^{a}	89.9 ± 0.5^{a}
HMT-20	20.0 ± 0.0^{a}	8.0 ± 0.0^{a}	17.8 ± 0.4^{ab}	8.0 ± 0.0^{abc}	7.8 ± 0.4^{a}	8.7 ± 0.4^{a}	18.5 ± 0.5^{a}	88.8 ± 0.8^{a}
HMT-30	20.0 ± 0.0^{a}	7.8 ± 0.4^{a}	17.0 ± 0.0^{bcd}	7.6 ± 0.5^{bcd}	6.4 ± 0.4^{b}	6.6 ± 0.2^{c}	17.6 ± 0.5^{b}	83.0 ± 1.3^{c}
HMT-40	19.8 ± 0.4^{ab}	7.7 ± 0.4^{a}	16.0 ± 0.1^{e}	7.4 ± 0.5^{cde}	5.2 ± 0.4^{c}	4.0 ± 0.0^{f}	14.6 ± 0.5^{c}	74.6 ± 0.8^{e}
HMT-50	16.9 ± 0.6^{c}	7.1 ± 0.2^{b}	11.2 ± 0.8^{g}	6.0 ± 0.0^{f}	4.1 ± 0.2^{d}	1.3 ± 0.4^{g}	10.6 ± 0.9^{d}	57.2 ± 1.7^{f}
MW-10	20.0 ± 0.0^{a}	8.0 ± 0.0^{a}	17.8 ± 0.4^{ab}	8.2 ± 0.8^{ab}	8.0±0.0a	8.0 ± 0.0^{b}	18.8 ± 0.4^{a}	88.8 ± 1.6^{a}
MW-20	20.0 ± 0.0^{a}	8.0 ± 0.0^{a}	17.4 ± 0.9^{abc}	7.4 ± 0.5^{cde}	8.0±0.0a	7.8 ± 0.4^{b}	18.0 ± 0.0^{ab}	86.8 ± 1.5^{b}
MW-30	19.7 ± 0.3^{ab}	7.8 ± 0.4^{a}	16.4 ± 0.5^{de}	7.2 ± 0.8^{de}	6.0 ± 0.0^{b}	6.0 ± 0.0^{d}	17.4 ± 0.9^{b}	80.5 ± 1.6^{d}
MW-40	19.4 ± 0.4^{b}	7.7 ± 0.4^{a}	14.8 ± 0.8^{f}	6.8 ± 0.4^{e}	5.2 ± 0.4^{c}	5.1 ± 0.2^{e}	15.0 ± 0.7^{c}	74.0 ± 2.0^{e}
MW-50	15.5 ± 0.4^{d}	6.8 ± 0.4^{b}	9.5 ± 1.0^{h}	5.1 ± 0.5^{g}	2.6 ± 0.5^{e}	1.3 ± 0.4^{g}	9.0 ± 1^{e}	49.8 ± 2.8^{g}

Note: all values are the mean of at least triplicate determinations ± SD. The means within the same column with different letters are significantly different (P<0.05)

6. Discussion of the results of studying incorporation of modified potato starch on quality of Chinese steamed bread

The research evaluated the effects of different substitution levels of wheat flour with HMTS or MWS on the quality of CSB, including specific volume, texture properties of hardness, gumminess, chewiness, springiness, cohesiveness and resilience and sensory evluation. Based on the current research results, it is conclude that different incorporation of HMTS or MWS has a profound impact on the quality attributes of CSB.

Although the research results showed that the specific volume score of sensory evaluation of CSB was not significantly different from the control CSB when the substitution level of HMTS or MWS was less than 30 %, all the CSB containing modified potato starch (HMTS or MWS) demonstrated an observably lower specific volume compared with the wheat flour CSB. A high steamed bread specific volume represents a better product appearance [34]. The reason for the decrease of specific volume likely due to the reduced gluten content and diluted gluten network of the dough. The dilution also affected the formation of an elastic network during steaming, resulting in easy weaken of the gluten network and lower specific volume of steamed bread.

As an intuitive indicator of food, color is one of the most important quality indicators CSB and plays a decisive role in consumption and popularity [35]. A higher L* value is generally as an indicator of better acceptance and quality [36]. In this study, although the L* value of both crust and core of CSB increased with more incorporation of HMTS or MWS, and there was no significantly difference color score of sensory evaluation between wheat flour CSB and all CSB containing modified potato starch (HMTS or MWS) except with 50 % substitution (HMT-50 and MW-50), which indicated that consumers pay more attention to their health than food color preference.

The texture properties of food such as hardness, gumminess, chewiness, springiness, cohesiveness and resilience mainly reflect the quality of food. Hardness is the force required to resist deformation. In this study, the incorporation of HMTS led to the increase of hardness of HMT-CSB from 416 to 1685 g, while incorporation of MWS led to the increase of hardness of MW-CSB from 442 to 1634 g, whereas the hardness of control CSB (CK) was 367 g (Table 3). The increased hardness implied a firm texture of CSB, which could be largely attributed to the gluten dilution effect from the incorporation of HMTS or MWS. Chewiness refers to the energy required to break down food into small pieces by mastication. In this study, the chewiness of CSB with HMTS incorporation increased from 338 to 999 and the chewiness of CSB with MWS incorporation increased from 359 to 963, whereas the chewiness of control CSB was 303. The increased chewiness reflected the denser structure of CSB with HMTS or MWS incorporation that required more energy and longer time for oral processing before swallowing. The reduced cohesiveness of HMT-CSB (from 0.84 to 0.67) or MW-CSB (from 0.84 to 0.66) indicated the disruption of CSB microstructure due to the diluted gluten matrix by the HMTS or MWS incorporation. The reduction in springiness of HMT-CSB (from 0.97 to 0.88) or MW-CSB (0.96 to 0.89) characterized the loss of elasticity, which could due to the reduction amounts of gluten effect form the HMTS or MWS incorporation and low leavening property, leading to the structure breaking of dough.

It is worth noting that there is a great diversity in CSB texture by Chinese consumers preference [3, 6]. The altered texture of CSB due to HMTS or MWS incorporation (e. g. increased hardness, or decreased springiness) may be a textural advantage to some consumers as indicated by sensory evaluation (Table 3). The decreased appearance scores of HMT-CSB and MW-CSB could be attributed to the increased occurrence of cracks and surface roughness (Fig. 1). Moreover, the incorporation of HMTS or MWS reduced gluten content and diluted gluten network of the dough, which affected the formation of elastic network during steaming and reduced oral chewiness and elasticity of CSB during mastication, eventually resulting in low oral chewiness and elasticity scores. This agreed with the results of textural profile analysis as described in section 5.3 above.

The total sensory score of CSB with 10 % (HMT-10) and 20 % (HMT-20) HMTS was 89.9 and 88.8 respectively, which was similar to that of the control sample (90.0), whereas CSB with 10 % MWS (MW-10) was 88.8. The CSB with 50 % MWS had the lowest total sensory score of 49.8, while the total sensory score of CSB with 50 % HMTS was 57.2 (Table 4). For all sensory attributes, total sensory score of 80 was considered as the limit of acceptability. From Table 4, it is possible to conclude that CSB can be accepted by consumers when the substitution level of wheat flour with HMTS or MWS was no more than 30 %.

The disadvantages of this study are that this research only focuses on the effects of incorporation of HMTS or MWS on the quality changes of CSB, rather than exploring the internal mechanism leading to these changes. Therefore, In the following starch, it is necessary to study the mechanism of quality changes of CSB in the following study.

The limitations of this study are that this research is only at the stage of small-scale laboratory experiment, therefore, if the CSB products of this study are applied to commercial applications, further verification experiments are need. In addition, the overall acceptability of products is a subjective testing, and sensory panel members of this study were only the postgraduate students and the stuff (ages of 20–35) of the Department of Food Science and Technology. Thus, a large number of sensory evaluations should be carried out before commercial applications to reduce the influence of individual preferences on sensory evaluation results and sensory evaluation members should cover adults of all ages.

7. Conclusions

1. The research results showed that the specific volume of CSB decreased with more incorporation of HMTS or MWS. The specific volume of CSB buns made by incorporating MWS was lower than that of CSB made by incorporating HMTS, which indicated that MWS had greater impact on the specific volume of CSB than HMTS. The experimental CSB showed higher L* and a*, but lower b* values than those of the control CSB, and the color changes was more obvious with the increase of substitution level of HMTS or MWS, indicating that CSB with more incorporation of HMTS or MWS displays lighter transparent color. Moreover, when the substitution level of HMTS or MWS was higher than 30 %, 20 %, respectively, the differences in color (ΔE>3) between the control and experimental CSB can be detectable by the human eye.

2. In terms of texture properties, the results of this study showed that hardness, gumminess and chewiness of all the experimental CSB were significantly higher than those of the control CSB, while springiness, cohesiveness and resilience of experimental CSB were lower than those of the control CSB. These results indicated that the incorporation of HMTS or MWS led to firmer and denser structure of CSB.

3. The experimental results of the sensory total score were similar to those of the specific volume, both of which decreased with more incorporation of HMTS or MWS. The total sensory score of was higher than 80 when the substitution level of wheat flour with HMTS or MWS was less than 30 %, indicating the produced CSB can be accepted by consumers. The appropriated amount of substitution of wheat flour with HMTS or MWS can not only maintain

the quality of CSB, but also increase the nutrition of CSB. Based on the above research results of CSB quality, the optimal substitution of wheat flour with HMTS or MWS was 30 %. This research can provide valuable guidance for further application of HMT and MW modified potato starch in wheat-based products, and it is also of great significance for promoting potato as staple food.

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.

Acknowledgements

The authors gratefully acknowledge the financial support received from the Middle aged and Young Teachers' Basic Ability Promotion Project of Guangxi (Grant No. 2021KY0710). The authors are grateful to Guangxi Key Laboratory of Health Care Food Science and Technology for providing laboratory facilities and technical support during this research work.

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