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Article

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OPTIMIZATION OF HEAT-MOISTURE TREATMENT ON POTATO STARCH AND STUDY ON ITS PHYSICOCHEMICAL PROPERTIES

The object of research is the technology of modified potato starch obtained by heat-moisture treatment. Heat-moisture treatment (HMT) of starch is a hydrothermal treatment technique to modify their functional properties. Setback viscosity of potato starch gelatinization characteristic is the key factor that influences the quality of potato starch noodle. In order to obtain a green, safe and highly efficient potato starch product for vermicelli production, this study take setback viscosity as response value, a Box-Behnken model was established on the basis of single factor experiment results to optimize the modify technique. A response surface analysis was used to investigate the effects of moisture content of starch, heat-moisture treatment temperature and heat-moisture treatment time on setback viscosity of heat-moisture treatment modified potato starch. The viscosity properties, textural properties and retrogradation characteristics of HMT starch gel were estimated.

The results of response surface methodology showed the optimal parameters of HMT were that moisture content of potato starch was 23.56 %, heat-moisture treatment temperature was 90 °C, and heat-moisture treatment time was 1.5 h. Under such conditions, setback viscosity of heat-moisture treatment modified potato starch (HMTS) paste was 3677 cP, which was higher than native starch (496 cP) obviously, indicating that the gel strength and hardness of potato starch was improved significantly. Compared with native potato starch (NS), HMTS had lower peak viscosity (2966 cP), lower hold viscosity (2882 cP) and lower breakdown viscosity (84.50 cP), but higher paste temperature (71.08 °C), higher final viscosity (6559 cP) and setback viscosity (3677 cP). The results of retrogradation was consistent with the viscosity properties, all of which indicating that potato starch modified by heat-moisture treatment was more prone to retrogradation. TPA tests demonstrated that HMT can enhance the textural properties of starch gel. Compared with native starch (NS) gel, the hardness, cohesiveness, gumminess, chewiness and resilience of heat-moisture treatment starch (HMTS) gel were increased significantly, and there was no significant difference in springiness. Compared with native starch gel, heat-moisture treatment starch gel had better functional properties.

Keywords: *heat-moisture treatment (HMT), setback viscosity, textural properties, viscosity properties, retrogradation, native potato starch.*

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1. Introduction

Starch is one of the most abundant biopolymers which are typically synthesized in plant amyloplasts to reserve the energy obtained from photosynthesis. In order to achieve particular technological properties included viscosity properties in solution, digestibility, produced from native starches by partial degradation, starch-based products are nowadays used for many applications in food processing [1]. However, Starch in its natural form has some shortcomings which limit its use in some industrial food processing. Thus, it is often tailored through physical, chemical or enzymatic modifications to develop desirable functional properties [2]. Most of these modifications alter the molecular and crystal structures of starch and ultimately alter the morphological, crystalline, thermal, and rheological properties. There is great interest in the use of physical methods to improve the properties of starch with reduced wastes and increased product safety. Heat-moisture treatment (HMT) of starch is a hydrothermal treatment technique in which starches are treated at low moisture levels (<35 % moisture, w/w) for a certain period of time at a relatively high temperature (80–140 °C) that above the glass transition temperature (T_g) and below the gelatinization temperature (T_{gel}) [3]. Authors of [4] have reported that HMT affected the morphology of starch

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granule, gelatinization temperature, leaching of amylose, relative crystallinity and type of crystals. HMT also could increase the proportion of intermediate and long chains, which increase the chance of cocrystallization of tie chains [5]. HMT not only caused the disorganizations of hierarchical structures, but also promoted the molecular rearrangements and reassembly of starch chains to form new ordered molecular aggregation architecture. And the reinforced molecular interactions between starch molecules during HMT occurred to form more densely ordered structure [6].

Lots of researches had confirmed that HMT modified starch can be significantly improve the cooking texture quality of their noodle products [7–9]. However, due to the reaction conditions included the starch source, moisture content, holding temperature, holding time and other process parameters are diverse. It is difficult to define the properties of HMT starches in definitive way. And it is also difficult to define the application effects of improving the quality of final products such as vermicelli and noodles. Although authors of [10] have reported that setback viscosity had significantly correlation with the quality of noodles products, which could be used as one of the crucial methods to predict the corresponding quality of noodle products. There is still little information on the effect of moisture content, heating temperature and heating length on the starch paste properties of starch during HMT.

Therefore, it is necessary to study the effect of heat-moisture conditions on starch setback viscosity optimize its process, which is relevant to the quality of HMT modified potato starch final product.

Thus, *the object of research* is the technology of modified potato starch obtained by heat-moisture treatment. *The aim of this research* was to obtain the optimal modification process of potato starch by HMT. So as to obtain HMT modified potato starch with suitable physicochemical properties, and to provide preliminary research basis for the application of modified potato starch in vermicelli, noodles and other products.

2. Research methodology

2.1. Materials. Potato starch was extracted from potato tubers by the method of with the wet extraction process.

2.2. Heat-moisture treatment of starch. Native potato starch was subjected to HMT:

1) with 25 % moisture content according to the previous research method described by [11] at 90 °C, 100 °C, 110 °C, 120 °C, 130 °C to prepared for 2 h to prepare different heating temperature groups samples (THMT). The prepared dry starch powder samples were named as THMT90, THMT100, THMT110, THMT120, THMT130, respectively;

2) with 25 % moisture content at 110 °C for 1 h, 2 h, 3 h, 4 h, 5 h and 6 h to prepare different heating time groups samples (tHMT). The prepared dry starch powder samples were named as tHMT1, tHMT2, tHMT3, tHMT4, tHMT5, tHMT6, respectively.

3) with different moisture content (15 %, 20 %, 25 %, 30 %, 35 %) at 110 °C for 2 h to prepared different moisture content groups samples (CHMT). The prepared dry starch powder samples were named as CHMT15, CHMT20, CHMT25, CHMT30, CHMT35, respectively.

2.3. Determination of pasting properties. According to the method of [12], the paste properties of starch were determined by rapid visco-analyzer (RVA Starch Master2, Perten Instruments, Sweden) with its own heating and cooling procedure.

2.4. Texture measurement. The texture characteristics of potato starch gels were measured by TA-XT plus Texture Analyzer (Exponent stable microsystem, version 6.1.2.0, Stable Microsystems Ltd., UK) using a plate probe with a diameter of 100 mm (P100) according to the previous study with slight modification [13]. The parameter of measurement mode was:

– the pre-test speed and post-test speed were 1.0 mm/s;
– the test speed was 2.00 mm/s;
– the degree of compression was 50 %;
– the trigger force was 5 g.

The hardness (g), springiness (mm), cohesiveness (–), gumminess (g), chewiness (g·mm) and resilience (–) of the sample were measured. Each sample was measured at least five times and the average value was taken.

2.5. Determination of retrogradation. Potato starch suspensions (1 %, w/w potato starch on a dry basis) were prepared by blending starch in ultrapure water and then the suspensions were gelatinized by placing in a boiling water bath for 40 min with continuously stirring. After the gelatinization was completed, took out the suspensions and cooled to room temperature, poured it into 25 mL tube and kept still in 25 °C incubator. The volumes of the starch paste supernatant were recorded every 2 h (total 16 h). The percentage of starch paste supernatant liquid volume in the total volume of starch paste changed over time to characterize its retrogradation property.

2.6. Experimental design and optimization. On the basis of single factor experiments, Box-Behnken design (BBD) with three variables (temperature, time and moisture content) at three different levels were used to find a possible correlation among these variables and obtained a response surface.

The factors and levels in the response surface analysis were shown as Table 1.

Table 1

The factors and levels in the response surface analysis

Levels	Factors		
	A: Temperature (°C)	*B*: Time (h)	*C*: Moisture content (%)
–1	90	0.5	20
0	100	1	25
1	110	1.5	30

The central point experiment was set to be repeated for five times and total of 17 experiments with three different levels (coded as –1, 0, 1) of each factor, which were shown as Table 2.

All experiments were performed in triplicate. The relationships between the responses and the independent variables were constituted by means of the quadratic polynomial equation. The optimum conditions were deduced using multiple response analysis.

Table 2

Experimental design and corresponding results for RSM

Run	*A*: Temperature (°C)	*B*: Time (h)	*C*: Moisture content (%)	Setback viscosity (cP)
1	–1	–1	0	1711.667
2	1	–1	0	2525.333
3	–1	1	0	3890.667
4	1	1	0	858.000
5	–1	0	–1	1320.000
6	1	0	–1	1740.000
7	–1	0	1	2788.667
8	1	0	1	835.333
9	0	–1	–1	966.333
10	0	1	–1	3352.667
11	0	–1	1	3072.333
12	0	1	1	1304.333
13	0	0	0	2785.333
14	0	0	0	3009.667
15	0	0	0	2901.000
16	0	0	0	2848.667
17	0	0	0	2835.333

2.7. Statistical analysis. The statistical analysis of results was conducted by analysis of variance (ANOVA) and the significant difference among samples were determined by Duncan's multiple range tests using DPSv7.05 statistical software and Design-Expert 8.0.6 software, Microsoft Office Excel and was used to graph. The P_{value}<0.05 was considered as significant.

3. Research results and discussion

3.1. Single factor experimental results and analysis

3.1.1. Effect of heat-moisture treatment on setback viscosity of potato starch under different heating temperature. The THMT starches were prepared as according to the method mentioned at section 2.2 (1), and the effect of heat-moisture treatment setback viscosity of potato starch under different holding temperature was shown as Fig. 1.

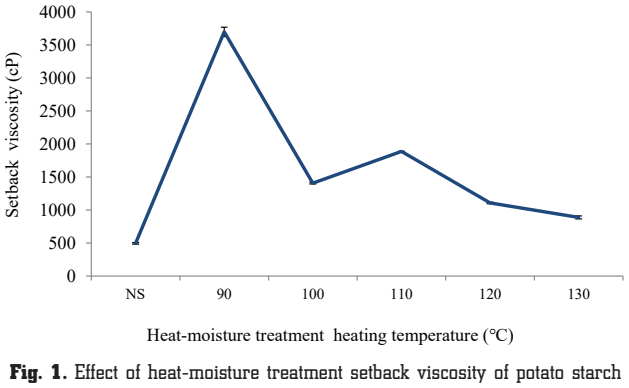

Fig. 1. Effect of heat-moisture treatment setback viscosity of potato starch under different heating temperature

During the process of HMT, the water molecules in starch crystals turned into gaseous, destroyed the –1, 6 and –1, 4 bonds under the action of heating, changed the double helix structure of amorphous and crystalline regions at the meantime [14]. All these changes led to the related properties of starch changed accordingly. As can be seen from Fig. 1, HMT holding temperature could increase the setback viscosity of starch significantly, the highest setback viscosity was 3697 cP when the heating temperature was 90 °C. Considering energy consumption and cost comprehensively, 90 °C–100 °C and 110 °C were used as the three levels (–1, 0, 1) of response surface, respectively.

3.1.2. Effect of heat-moisture treatment on setback viscosity of potato starch under different heating time. The tHMT starches were prepared were prepared as according to the method mentioned at section 2.2 (2), and the effect of heat-moisture treatment setback viscosity of potato starch under different holding time was shown as Fig. 2. Since starch molecules were in a messy state under the action of water and heat, the appropriate extension of the moisture and heat treatment time were beneficial to enhance the interaction between starch molecules, but too long time would lead to excessive degradation of starch molecules [15].

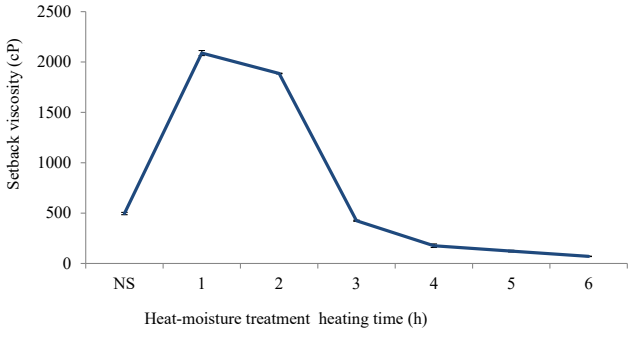

Fig. 2. Effect of heat-moisture treatment on setback viscosity of potato starch under different heating time

As can be seen from Fig. 2, HMT heating time had significant effect on the setback viscosity of starch. Setback viscosity decreased with the extension of HMT heating time, the highest setback viscosity was 2089 cP at 1 h. Therefore, 0.5 h, 1 h and 1.5 h were used as the three levels (–1, 0, 1) of response surface, respectively.

3.1.3. Effect of heat-moisture treatment on setback viscosity of potato starch under different starch moisture content. The CHMT starches were prepared were prepared as according to the method mentioned at section 2.2 (3), and the effect of heat-moisture treatment setback viscosity of potato starch under starch moisture content was shown as Fig. 3.

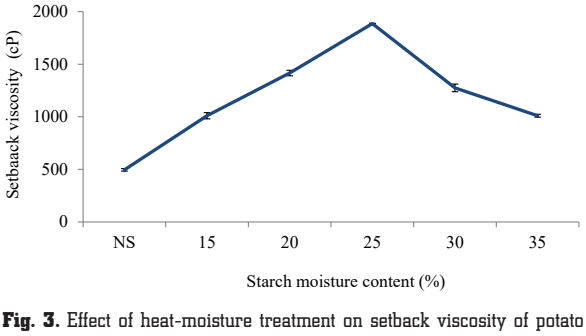

Fig. 3. Effect of heat-moisture treatment on setback viscosity of potato starch under different starch moisture content

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As can be seen from Fig. 3, HTM can increased setback viscosity significantly, with the extension of moisture content, the setback viscosity increased, the highest setback viscosity was 1886 cP when the moisture content was 25 %. As a plasticizer, water had a significant impact on the structure and properties of starch during the HMT process. The presence of water was conducive to the destruction of the starch crystal structure and promoted the movement of starch molecular chains. The rearrangements of starch molecules in amorphous regions were formed more crystals. However, too low moisture content was not conductive to the interaction between the molecular chains in the amorphous regions; starch was gelatinized easily with too high moisture content which led to excessive degradation of starch molecules [16]. Therefore, 20 %, 25 % and 30 % were used as the three levels (–1, 0, 1) of response surface, respectively.

3.2. Experimental analysis of response surface and model establishment. Response surface methodology (RSM) was used to optimize the process of HMT on the setback viscosity of potato starch under the effect of the independent variables (heating temperature, heating time and moisture content) with setback viscosity as an index. The central point experiment was set to be repeated for five times and total of 17 experiments with three different levels (–1, 0, 1) of each factor were listed in Table 2 and the analysis of variance (ANOVA) results of quadratic regression model for RSM was listed in Table 3. All experiments were performed in triplicate.

The setback viscosity of HMT starch was influenced by holding temperature, time and moisture content were fitted with the quadratic polynomial model represented by the following equations:

$$S_v = 2876 - 469.04 \cdot A + 141.25 \cdot B + 77.71 \cdot C - $$
$$- 961.58 \cdot A \cdot B - 593.33 \cdot A \cdot C - 1038.58 \cdot B \cdot C - 566.25 \cdot A^2 - $$
$$- 63.33 \cdot B^2 - 638.75 \cdot C^2,$$

where S_v is setback viscosity (cP); A, B, C were the HMT holding temperature (°C), time (h) and moisture content (%), respectively.

ANOVA was performed for the model (Table 3) and observed that the model F-value of 94.21 implied the model was significant. There was only a 0.01 % chance that a «Model *F*-Value» this large could occur due to noise. Values of «Prob>*F*» less than 0.0500 indicated model terms were significant. In this case A, B, AB, AC, BC, A^2, C^2 were significant model terms. The «Lack of Fit *F*-value» of 4.22 implied there was a 9.89 % chance that a «Lack of Fit *F*-value» this large could occur due to noise. Lack of fit was significant (P=0.0989>0.05), the model fitted well. The «Pred *R*-Squared» of 0.8973 was in reasonable agreement with the «Adj *R*-Squared» of 0.9813. «Adeq Precision» measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 31.015 indicated an adequate signal. This model can be used to navigate the design space.

The response surfaces of interaction of variables on setback viscosity were shown in Fig. 4.

The Design-Expert 8.0.6 software was used to optimize the setback viscosity equation model formula, and the optimized process parameters of setback viscosity of HMT were as follow: the temperature was 90 °C (coded –1), the time was 1.5 h (coded 1) and the moisture content was 23.56 % (coded –0.288), under such conditions the maximum theoretical setback viscosity value was 3871 cP. In order to verify the reliability of the model, triplicate experiments were carried out with the optimal process parameters (the temperature was 90 °C, the time was 1.5 h and the moisture content was 23.56 %). The mean setback viscosity was 3677 cP and there was little error between the actual setback viscosity and theoretical setback viscosity.

Therefore, it was feasible to use RSM to optimize the process of HMT on potato starch and had practical application value.

Table 3

ANOVA for response surface quadratic model

Source	Sum of Squares	*df*	Mean Square	*F* Value	P_{value} Prob > *F*	Significance
Model	14698408	9	1633156	94.20812	<0.0001	**
A	1760001	1	1760001	101.5251	<0.0001	**
B	159612.5	1	159612.5	9.207197	0.019	*
C	48308.68	1	48308.68	2.786671	0.139	–
AB	3698570	1	3698570	213.3509	<0.0001	**
AC	1408178	1	1408178	81.2303	<0.0001	**
BC	4314621	1	4314621	248.8876	<0.0001	**
A^2	1350059	1	1350059	77.87774	<0.0001	**
B^2	16888.89	1	16888.89	0.97423	0.3565	–
C^2	1717901	1	1717901	99.0966	<0.0001	**
Residual	121349.4	7	17335.62	–	–	–
Lack of Fit	92236.25	3	30745.42	4.224271	0.0989	–
Pure Error	29113.11	4	7278.278	–	–	–
Cor Total	14819758	16	*R*-Squared	0.991812	Adj *R*-Squared	0.9813

Note: * – indicated significant (P_{value}<0.05); ** – indicated extremely significant (P_{value}<0.01); A – temperature; B – time; C – moisture content

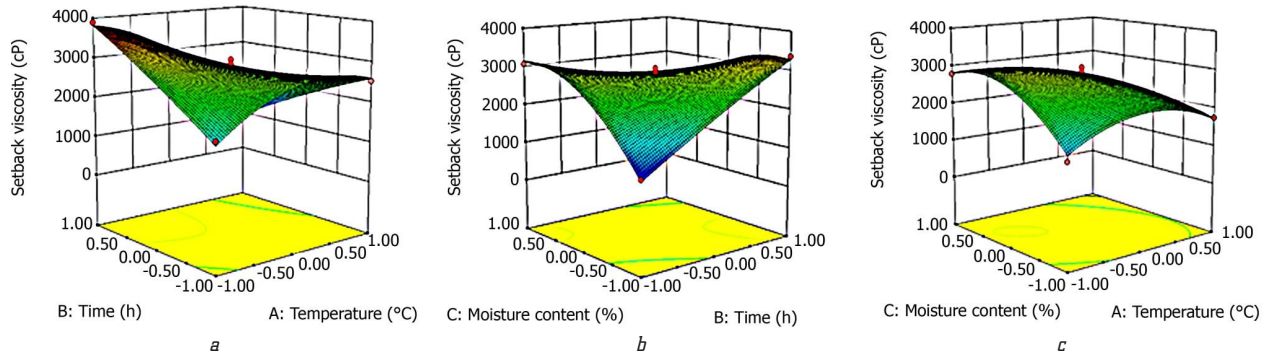

Fig. 4. The response surfaces for the interaction of various factors on setback viscosity of HMT modified starch: *a* – the interaction of HMT heating temperature and heating time; *b* – the interaction of HMT heating time and starch moisture content; *c* – the interaction of HMT heating temperature and starch moisture content

3.3. Analysis of viscosity properties. The starch viscosity properties are correlated to the gel texture properties, the stability of starch paste, and retrogradation tendency. The pasting properties of native potato starch (NS) gel and optimized heat-moisture treatment modified starch (HMTS) were listed in Table 4 and the rapid viscosity analysis (RVA) pasting profiles were illustrated in Fig. 5.

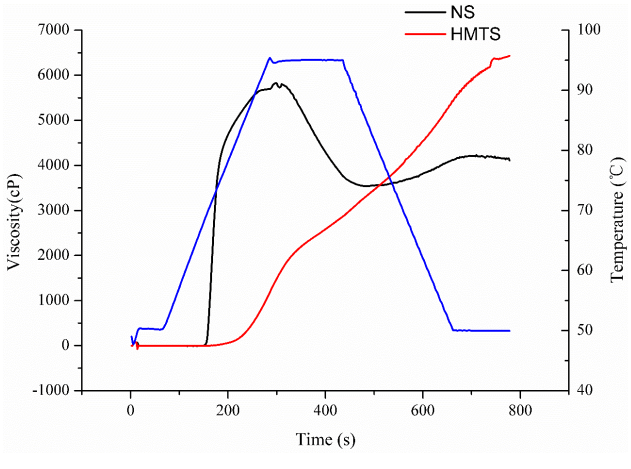

Fig. 5. Rapid viscosity analysis (RVA) pasting profiles of native and modified potato starch

As shown in Fig. 5, the RVA profiles of HMTS had great difference with that of NS. Compared with native potato starch (NS), HMTS had lower peak viscosity (2966 cP), lower hold viscosity (2882 cP) and lower breakdown viscosity(84.50 cP), but higher paste temperature (71.08 °C), higher final viscosity (6559 cP) and setback viscosity(3677 cP). HMTS had lower viscosity but higher gelatinization temperature, indicating that the starch modified by heat moisture treatment requires more energy to decompose its structure and form paste, thus improving the gelatinization of the sample. Heat moisture treatment could enhance the interior interactions of starch, preventing the penetration of water into starch granules, thus resulting in decrease of peak viscosity. As shown in Table 4, the peak viscosity of HMTS was lower than final viscosity, while the peak viscosity of NS was higher than final viscosity, indicating that HMTS was more prone to retrogradation than NS [17].

The breakdown viscosity is related to the thermal stability of the swollen starch granules in the starch paste during heating and shearing, lower breakdown indicates more resistance to shear force [18, 19]. The setback viscosity has great relativity to the retrogradation properties of starch and has a great influence on the tensile strength of vermicelli food or noodles, higher setback viscosity indicates higher tensile strength [20].

3.4. Analysis of textural properties. Textural properties of the native potato starch (NS) gel and optimized HMT starch (HMTS) gels, including hardness, springiness, cohesiveness, gumminess, chewiness and resilience, were determined by TPA test (Table 5). The textural properties of starch gels depend on the constituents of starch and amylose, the volume and deformation of the granules and the interaction between the continuous and dispersed phases [21].

Table 4

Pasting properties of native and modified potato starch

Samples	Paste temperature (°C)	Peak viscosity (cP)	Hold viscosity (cP)	Final viscosity (cP)	Breakdown viscosity (cP)	Setback viscosity (cP)
NS	68.53±0.23^b	6598±73^a	4072±25^a	4567±37^b	2526.33±47.34^a	496±12^b
HMTS	71.08±0.84^a	2966±46^b	2882±44^b	6559±61^a	84.50±2.38^b	3677±21^a

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

Table 5

Textural parameters of native and modified potato starch gel (10 %, w/w) determined by TPA test

Starch gel	Hardness (g)	Springiness (mm)	Cohesiveness (–)	Gumminess (g)	Chewiness (g·mm)	Resilience (–)
NS	2705.55±3.11^a	0.8255±0.012^a	0.6285±0.0049^b	1700.43±11.44^b	1403.77±29.88^b	0.3995±0.0346^a
HMTS	6082.15±8.32^b	0.809±0.0014^a	0.7255±0.0021^a	4920.46±1.87^a	3569.79±11.80^a	0.422±0.0311^a

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

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Gel hardness generally rerated to the retrogradation of starch. Previous study reported a positive correlation between gel hardness and the amylose content of the starch and high-amylose starches produced a harder gel [22]. Linear amylose molecules re-associate more easily than high-branched amylopectin molecules. As can be seen, the HMTS gel showed significantly higher hardness than NS gel, the difference between the hardness of NS gel and HMTS gel can be attributed to higher amylose content of HMTS.

Springiness reflects the ability of starch gel to recover from its deformation with a period of time after being squeezed. The springiness of starch gel is affected by the number of crosslinking points and the density of crosslinking points of the network structure formed by starch molecules. The more effective crosslinking points, the greater springiness of the gel. There was no significant difference of springiness between NS gel and HMTS gel, although NS gel showed greater springiness than HMTS gel.

Cohesiveness is a measure of how well a starch gel resists the second deformation according to its behavior in the first deformation, which means cohesiveness is a criterion of how well a starch gel can keep its structure after the first bite [23]. Starch gels with good gel setting and high acceptability in starchy food are identified by high cohesiveness. HMTS gel represented the higher amount of cohesiveness (0.7255) than NS gel (0.6285), which indicated that the HMTS has a better ability to withstand deformations.

Gumminess (hardness×springiness) is the energy required to break up a semi-solid food to ready it for swallowing [20]. HMTS gel showed higher gumminess than NS gel about 189.41 %, which indicating that HMTS gel needs more energy to be ready for swallowing about 2.89-fold than NS gel. Chewiness (hardness×springiness×cohesiveness) is the energy required for disintegration and mastication of semi-solid foods. HMTS gel showed higher than NS gel about 154.27 %, which indicating that HMTS gel needs more energy to be ready for swallowing about 2.54-fold than NS gel. The variations in gumminess and chewiness values showed a similar trend as hardness, due to the high relative weight of hardness in calculating these textural parameters [24]. Resilience is other criterion of TPA test, measure how well the starch gel fights to regain its original position. HMTS gel showed higher resilience than NS gel, but there was no significant difference between them.

The changes in the textural characteristic of HMTS gel were mainly due to the rearrangement of starch molecules, and starch chains was cross-linked with non-starch molecules such as protein and fat, making the starch structure denser after the gel treatment, thus enhanced the textual properties of starch.

3.5. Analysis of retrogradation. The retrogradation of starch is the process of gelatinized starch molecules from disordered state to orderly rearrangement, finally coagulation and sedimentation. In the gelatinization process of starch by heating, the ordered starch molecules become disordered under the action of water and heat [25]. In the process of cooling and storage, due to the effect of molecular potential energy, the disorder of high energy states gradually tends to the order of low energy states.

As can be seen from Table 6, retrogradation of NS and HMTS increased with the extension of storage time, and the HMTS had higher retrogradation than that of NS, indicating that potato starch modified by heat-moisture treatment was more prone to retrogradation. This result was consistent with viscosity properties of NS and HMTS. Heat-moisture treatment destroyed the starch granules structure and reduced the hydrogen bonds between starch molecules and water molecules, which was prone to retrogradation, resulting in poor the retrogradation stability of potato starch.

The results of this research indicate that it is feasible to use RSM to optimize the process of HMT on potato starch and has practical application value. And the HMT starch prepared under the optimized conditions is suitable for the production of vermicelli, noodles and other products that require good retrogradation characteristics, which is of great significance in promoting potato as staple food. However, the modified potato starch is not suitable for products that do not need good retrogradation properties for the HMT modified gel is easy prone to retrogradation.

4. Conclusions

The effects of three process variables for HMT on potato starch were investigated using RSM. The Design-Expert 8.0.6 software was used to optimize the setback viscosity equation model formula, and the optimized process parameters of setback viscosity of HMT were as follow: the temperature was 90 °C (coded –1), the time was 1.5 h (coded 1) and the moisture content was 23.56 % (coded –0.288). Under such conditions the maximum theoretical setback viscosity value was 3871 cP. The verification experiment showed the actual mean setback viscosity was 3677 cP and there was little error between the actual setback viscosity and theoretical setback viscosity. Therefore, it was feasible to use RSM to optimize the process of HMT on potato starch and had practical application value.

The RVA profiles of HMTS had great difference with that of NS. Compared with native potato starch (NS), HMTS had lower peak viscosity (2966 cP), lower hold viscosity (2882 cP) and lower breakdown viscosity (84.50 cP), but higher paste temperature (71.08 °C), higher final viscosity (6559 cP) and setback viscosity (3677 cP).

Table 6

Retrogradation of native and modified potato starch

Samples	Retrogradation (%)							
	2 h	4 h	6 h	8 h	10 h	12 h	14 h	16 h
NS	0.00±0.00^{b}	8.00±0.00^{b}	8.00±0.00^{b}	8.00±0.00^{b}	8.00±0.00^{b}	8.00±0.00^{b}	8.00±0.00^{b}	8.00±0.00^{b}
HMTS	12.80±1.06^{a}	22.53±1.29^{a}	28.00±1.83^{a}	30.80±1.74^{a}	32.00±0.80^{a}	34.00±1.20^{a}	34.53±1.29^{a}	35.33±1.67^{a}

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

TPA tests demonstrated that HMT can enhance the textural properties of starch gel. Compared with the NS gel, the hardness, cohesiveness, gumminess, chewiness and resilience of HMTS gel were increased significantly, and there was no significant difference in springiness. The retrogradation of NS and HMTS increased with the extension of storage time, and the HMTS had higher retrogradation than that of NS, indicating that potato starch modified by heat-moisture treatment was more prone to retrogradation.

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