Effects of hot air drying temperature and tempering time on the properties of maize starch

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Abstract: Yellow maize as raw materials, hot air drying was used to reduce moisture content, and the tempering was implemented after drying. This study aimed to investigate the effects of hot air drying temperature and tempering time on the properties of maize starch. The wet milling was used to extract maize starch. Starch yield, protein content, amylose and amylopectin content, transparency and coagulation, solubility index and swelling power, color, pasting properties, and gelatinization properties were researched. The results showed that when the hot air temperature increased, the properties such as starch yield, amylopectin content, transparency, solubility, swelling power, whiteness decreased, and properties such as protein content and amylose content, coagulation, gelatinization temperature increased. Compared to drying temperature, tempering time has a less remarkable effect on the maize starch properties. The maize starch with better whiteness, solubility, swelling power could be obtained by adjusting tempering time.

Keywords: maize starch, hot air drying temperature, tempering time
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1 Introduction

Maize is normally harvested at moisture content in the range of 23%-30% wet basis (w.b.). Research showed that microbial spoilage and deterioration reactions were greatly minimized after water was removed[1,2].

Hot-air drying is the most common method that is applied to the storage of agricultural products. The main drawbacks of the hot air drying method were undesirable physical, structural, chemical, organoleptic, and nutritional changes[3,4].

Tempering was widely used in grain drying to improve quality and decrease drying cost[5]. To reduce crack in a kernel, tempering between drying passes is recommended in order to reduce moisture-induced stress[6,7]. The tempering time on rice fissuring was investigated by Dong et al.[8] In their research, the fissure generation of three types of rough rice at different tempering time was studied. Their results indicated that tempering can prevent kernel fissuring. The tempering was adopted by Wilson et al.[9] to dry shelled maize with radiant heating. Their results indicated that the combined use of radiant heating and tempering was a rapid moisture removals method. The effect of tempering on head rice yield during drying was studied by Sadeghi et al.[10] In their research, the high drying conditions with drying temperature of 60°C and relative humidity of 17% and the low drying conditions with drying temperature of 40°C and relative humidity of 12% was investigated. Their results indicated that tempering had no significant effect on head rice yield under low drying conditions and could enhance head rice yield under high drying conditions.

In this study, the combined use of hot air drying and tempering was adopted to dry yellow maize. The content of starch in maize is about 70%-75%, it is a valuable ingredient to the food industry, being widely used as a thickener, gelling agent, bulking agent and water retention agent[11]. The drying conditions have an obvious impact on the properties of starch, such as gelatinization, coagulation, pasting, granule and functional properties.

The effect of processing parameters on the pulsed-spouted microwave vacuum drying of puffed salted duck egg white/starch products was investigated by Wang et al.[12] In their study, the moisture content of samples was dehydrated to about 12%, and the color varied under different microwave powers. The effect of drying temperature on starch digestibility of germinated brown rice was investigated by Chungcharoen et al.[13] Their research indicated that the amylose-lipid complexes occurred when the germinated samples were dried by a hot-air fluidized bed dryer at 130 or 150 degrees C.

Malumba et al.[14] indicated that high drying temperatures reduce the swelling capacities of starch granules and their solubility indexes during gelatinization. Heat-moisture treatment decreases starch solubility, swelling power, amylose leaching and peak viscosity, and increases the pasting temperature[15-18].

In this study, the combined use of hot air drying and tempering was adopted to dry yellow maize, the wet milling was used to extract maize starch, the effect of hot air drying temperature and tempering time on the properties of maize starch was investigated,

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and the experimental strategy was provided for hot air-tempering drying used in maize.

2 Materials and methods

2.1 Materials

The yellow maize was field grown in 2014 at Luoyang (Henan Province). The maize was harvested with a moisture content of 33.86% (w.b.) and immediately stored at −18°C in sealed plastic bags as maize samples. Before the drying experiment began, the maize with a sealed plastic bag was taken out and placed indoor until its temperature was not varied. The initial moisture content of the maize was 33.86% (w.b.). All chemicals and solvents used in the experiment were analytical grades.

2.2 Drying and tempering experiments

Maize samples were dried at a laboratory hot-air dryer with an air velocity of 0.43 m/s. Drying was carried out at temperatures of 60°C, 70°C, 80°C, 90°C, and 100°C, respectively. Drying was ended once the moisture content reached to 14% (w.b.). When drying was ended, tempering was begun in the dry oven at 35°C and the tempering time was 6 h, 8 h, 10 h, 12 h, and 14 h, respectively. The mass of every experiment was 100 g. In the tempering step, the sample was kept in a closed jar to avoid moisture loss[19]. After that, the sample was stored at ambient temperature.

2.3 Analysis of samples

2.3.1 Starch extraction rate

Maize starch is extracted from dried maize samples following the method of the wet-milling process of Malumba et al.[20] Starch was measured using the method of Reference [17]. The starch yield was determined by the following equation:

$$\text{Starch yield} = \frac{\text{Mass of extractive starch}}{\text{Mass of corn starch in raw material}} \times 100\% \quad (1)$$

2.3.2 Physicochemical properties of starches

1) Chemical composition of starch

The contents of starch and residual protein were measured according to the AACC method 44-15A[18], the Ewers method (ISO 10520:1997), and the macro-Kjeldahl method, respectively.

2) Amylose and amylopectin content

Single wavelength colorimetry was used to determine the amylose and amylopectin content of the maize starch. A starch sample (50 mg) was taken and mixed with 10 mL 0.5 mol/L KOH in a volumetric flask of 100 mL, then, heated and stirred in boiling water until the starch sample was completely dissolved, then, distilled water was added to the volumetric flask and maintain the total volume of solution was 100 mL. Taken duplicate 15 mL solution in a volumetric flask and then added to two breakers equally, then taken duplicate 30 mL distilled water and added to two breakers equally, and then the pH of each solution in breaker was adjusted to 3.5, with 0.1 mol/L HCL. 0.5 mL of iodine reagent was added to one of the breakers, and both volume of solution in the two breakers were added to 100 mL by distilled water. After 20 min, the solution with iodine reagent was a test sample and the solution without iodine reagent was a blank sample. The absorbance was measured at 620 nm. The amylose content and amylopectin content were determined from a standard curve developed using amylose and amylopectin blends.

3) Transparency and coagulation

With constant stirring, 1% aqueous suspension of starch was heated in a water bath at 100°C for 30 min and the volume of starch solution was maintained constant. Then, the starch paste was cooled to indoor temperature and the absorbance of it was measured at 620 nm wavelength and the distilled water as blank. The transparency of maize starch was expressed by the absorbance of starch paste. 50 mL 1% aqueous suspension of starch was put into a measuring cylinder with stopper and placed 24 h without waggle at the indoor temperature, then, recorded the volume of the supernatant liquid and sediment layer. The coagulation property can be expressed as a percentage of the sediment layer volume of total paste volume.

4) Solubility index and swelling power

Solubility index (SOL) and swelling power (SP) were evaluated by the method of Mandala and Bayas[21] with some modification. 50 mL centrifugal tubes that were filled with 2% aqueous suspension of starch were heated in a water bath at 90°C for 30 min, and periodically middle shaking was applied to prevent the sedimentation of granules during heating. After heating, samples were centrifuged at 3 000 r/min for 15 min. Precipitated paste and supernatant were obtained, the mass of precipitated paste was W_1, the dry mass of precipitated paste and supernatant were W_2 and W_3, respectively. Dry mass was obtained at 105°C for 24 h in the dryer. The SOL is the percentage of dry mass in the supernatant to the dry mass of the whole starch sample W_0. SP is the ratio of precipitated paste to the dry mass of precipitated paste. The SOL and SP were defined as follows:

$$SOL = \frac{W_3}{W_0} \times 100\% \quad (2)$$

$$SP\ (\text{g/g}) = \frac{W_2}{W_1} \quad (3)$$

5) Color analysis

An X-rite Color I5 Colorimeter (X-Rite Inc., MI, USA) was used for color evaluation of samples. The measurements were taken at three different places on each starch sample to obtain the L^*, a^*, and b^* values. L^* represents black (0) or white (100), a^* represents redness (+) or greenness (−), b^* represents yellowness (+) and blueness (−) degree, respectively. The whiteness index is defined as Equation (4)[22]:

$$\text{WI} = 100\sqrt{(100\text{-}L^*)^2 + a^{*2} + b^{*2}} \quad (4)$$

where, WI is the whiteness index of samples; L^* is brightness; a^* is redness and greenness; b^* is yellowness and blueness.

6) Pasting properties

The Brabender Visco Analyzer (803302, Germany) was used for pasting the evaluation of samples. Pasting properties were evaluated by the method of Sandhu and Singh[23] with some modification. Viscosity profiles of starches samples were obtained by using an aqueous suspension of starch (6%, w/w; 460 g total weight) and a certain program. Certain heating and cooling cycle program was used, first, the aqueous suspension of starch was maintained at 30°C, then heated to 95°C at 1.5°C/min, then, maintained at 95°C for 30 min, then cooled from 95°C to 50°C at 1.5°C/min and holded at 50°C for 30 min. During measurement, the parameters such as pasting temperature, peak viscosity, trough viscosity (minimum viscosity at 95°C), final viscosity (viscosity at 50°C), breakdown viscosity (peak-trough viscosity) and setback viscosity (final-trough viscosity) were recorded.

7) Gelatinization properties

A differential scanning calorimeter (DSC, model 821e, Mettler Toledo, Switzerland) that was equipped with a thermal analysis data station was used to evaluate the gelatinization properties of starches samples by using the methods of Reference [23]. The starch (3 mg) was accurately weighed into an aluminum DSC pan, 10 μL of distilled water was added and the pan was hermetically sealed. The measurements were obtained when the pan was heated from 30°C to 110°C at a rate of 10°C/min and the other empty pan was used as a reference. The main parameters obtained were onset temperature (T_0), peak temperature (T_p), end temperature (T_c). The gelatinization properties of starch were calculated by the following equation[24]:

$$SG\ (\%) = \left(1 - \left[\frac{\Delta H}{\Delta H_c}\right]\right) \times 100 \qquad (5)$$

where, SG is the dimensionless quantity, which means the degree of gelatinization; ΔH and ΔH_c are the transition enthalpy of starches sample and the transition enthalpy of starches sample that is not subjected to the drying and tempering process.

2.4 Statistical analysis

All experiments were carried out three times. The data were subjected to statistical analysis using Orange8.5 (Minitab Inc., USA).

3 Results and discussion

3.1 Starch yield and protein content

The effect of drying temperatures, tempering time on starch yield and protein content are shown in Table 1. In Table 1, the starch yield decreases and protein content increases with the increase of drying temperature, this results are consistent with that of Mistry et al.[25] The decreases in starch yield are caused by the partial gelatinization of maize starch and the protein denaturation during the hot air drying. The increases in protein content are agreed well with the postulation of Weller et al.[26] They postulated that the high-temperature damage the endosperm protein and may prevent its solubilization during the steeping, and the starch could not set free during the wet-milling. A denatured protein may induce incomplete dissolve out of starch during the wet-milling, so starch and protein were difficult to separate.

Table 1 Starch yield and protein content under different drying temperature and tempering time

Conditions	Starch yield/%	Protein content/%
Undried	68.26±1.17	0.32±0.09
60°C	65.59±0.87	0.53±0.02
70°C	62.37±2.00	0.59±0.00
80°C	59.03±1.39	0.63±0.01
90°C	55.44±1.74	0.67±0.04
100°C	50.01±0.97	0.77±0.01
Without tempering	62.57±2.36	0.45±0.01
6 h	62.57±2.98	0.46±0.04
8 h	66.21±1.59	0.47±0.03
10 h	70.41±2.60	0.48±0.07
12 h	67.64±2.01	0.52±0.03
14 h	66.25±3.07	0.52±0.05

The starch yield increased first and then decreased with the increased of tempering time. The starch yield is the highest when tempering time was 10 h due to the internal moisture distribution of drying maize reached the best uniform state. In order to obtain a high starch yield, maintain tempering time at 10 h was a good method to increase the drying efficiency and utilization ratio of raw material. The protein content minorly increases with the increase of tempering time due to tempering enhancing the binding force between denatured protein and starch.

3.2 Amylose and amylopectin content

The effect of drying temperature and tempering time on the amylose and amylopectin content is shown in Figure 1. In Figure 1, the solid line indicated drying temperature and the dash line indicated tempering time. It was shown that amylose content increased from 24.57% to 26.69% and the amylopectin content decreased from 75.43% to 73.31% when drying temperature increases from 60°C to 70°C. The content of amylose and amylopectin has small changes during the drying temperature increases from 70°C to 100°C. It was found that the drying temperature has an obvious effect on amylose and amylopectin content when drying temperature between 60°C and 70°C. This suggested that amylopectin was more prone to degradation than amyloses during the drying temperature increases from 60°C to 70°C. It is also shown that the amylose content increases slightly and the amylopectin content decreases slightly with the increase of tempering time from 6 to 14 h.

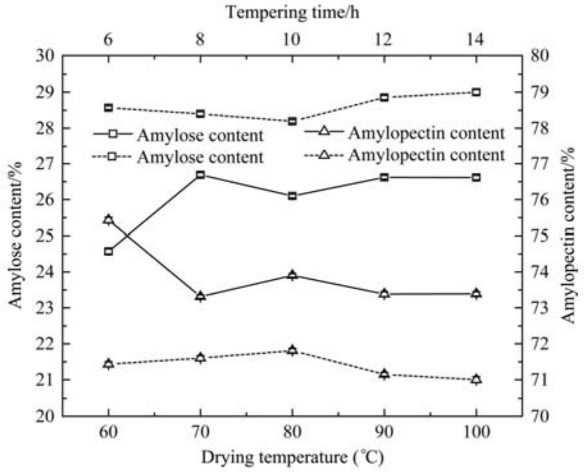

Figure 1 Effects of drying temperature and tempering time on the amylose and amylopectin content

3.3 Transparency and retrogradation

The transmittance and coagulation volume is used to reflect the transparency and retro-gradation of starch. The effect of drying temperature and tempering time on transmittance and coagulation volume is shown in Figure 2. In Figure 2, the solid line indicated drying temperature and the dash line indicated tempering time. The transmittance increases first and then decreases with the increases of tempering time. The coagulation volume decreases with the increases of tempering time. It suggested that transparency and retrogradation are closely related to the content of amylose.

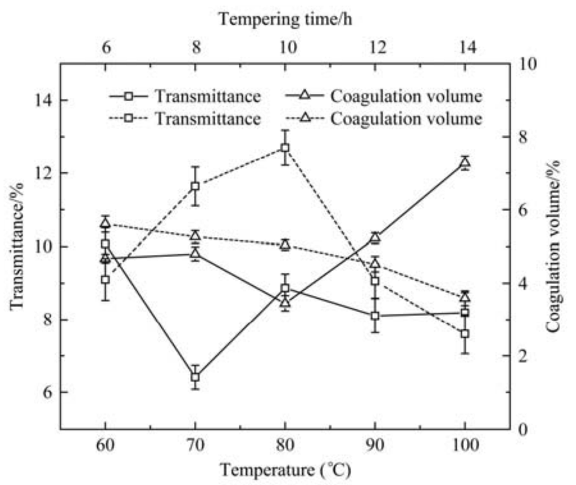

Figure 2 Effects of drying temperature and tempering time on transmittance and coagulation volume

3.4 Solubility index and swelling power

The effect of drying temperature, tempering time on solubility and swelling power are shown in Figure 3. In Figure 3, the solid line indicated drying temperature and dash line indicated tempering time. It is shown that both solubility and swelling power decreases with the increase in drying temperature or tempering time. The value change of solubility and swelling power caused by drying temperature is larger than that caused by tempering time. It is suggested that drying temperature has a more obvious effect on the solubility and swelling power than tempering time. This result was consistent with the results of Wongsagonsup et al.[27] and Kurakake et al.[28], which indicated that heat treatment can make the starch particles lightly crosslinked in the amorphous regions[27] and that the crosslinking can reduce the solubility and swelling power of starch[28].

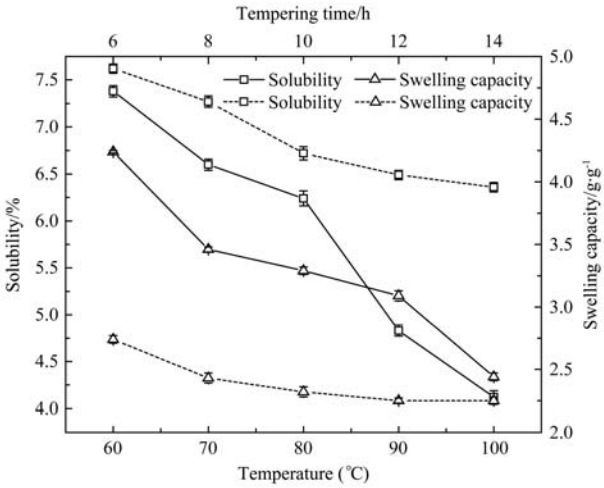

Figure 3 Effects of drying temperature and tempering time on solubility and swelling power

3.5 Colors

The WI, *L*, *a*, and *b* values of starch under different drying temperature and tempering time are listed in Table 2. The WI decreased with the increase of drying temperature and increases first and then decreases with the increase of tempering time. The high *L* value led to the high WI and the variation tendency of *L* and WI was consistent The WI at drying temperature of 100°C is 2.63% fewer than that at drying temperature of 60°C. It suggested that the change of the starch color was caused by non-enzymatic browning reactions due to high temperature. The *L* value and WI are highest when the tempering time is 10 h, and WI at tempering time of 10 h is more 2.97% than that at without tempering. The tempering time had no significant influence on color parameters. It suggested that a certain tempering time can be used to improve the WI of maize starch.

3.6 Pasting properties

The changes in the pasting properties of starch obtained from different drying temperature and tempering time are presented in Table 3. It can be observed that the pasting temperature increases with the increase in drying temperature, peak viscosity and final viscosity first increases and then decreases with the increase of drying temperature. These results were also reported in the research of Malumba et al.[29] It is also showed that the breakdown value first increases and then decreases with the increase of drying temperature. These results have been reported in the research of Mistry et al.[25] It suggested that high pre-treatments temperature prevented starch granules from breakdown. The setback value increases with the increase in drying temperature. It suggested that maize starch exhibited higher setback viscosity once the maize was subjected to higher temperatures.

Table 2 Effect of drying temperatures and tempering time on maize starch color

Condition	*L*	*a*	*b*	WI
Undried	94.53	0.77	11.25	87.47
60°C	95.52	0.96	10.01	88.99
70°C	95.91	0.96	11.08	88.15
80°C	95.07	0.88	12.08	86.92
90°C	94.82	0.81	12.15	86.77
100°C	94.77	0.78	12.19	86.71
Without tempering	95.35	1.23	12.60	86.51
6 h	95.93	0.96	11.14	88.10
8 h	96.85	0.86	11.10	88.43
10 h	96.05	0.86	10.14	89.08
12 h	96.11	0.74	10.93	88.37
14 h	96.31	0.90	11.05	88.32

Table 3 Pasting properties of maize starch at different drying temperature and tempering time

Condition	Pasting temperature /°C	Peak viscosity /BU	Final viscosity /BU	Breakdown value/BU	Setback value /BU
Undried	67.7	930	1335	405	240
60°C	69	1000	1529	602	257
70°C	69.2	1324	1725	750	322
80°C	70.7	1276	1630	677	326
90°C	70.1	1251	1500	670	357
100°C	72.1	1027	1431	534	377
Without tempering	68.8	1153	1700	810	394
6 h	68.9	1090	1679	766	336
8 h	69.1	945	1567	694	347
10 h	69	914	1538	672	351
12 h	69	740	1392	600	387
14 h	69	587	1357	592	446

Peak viscosity, final viscosity, and breakdown value decreases with the increase of tempering time. The phenomenon of peak viscosity and breakdown value decrease has been reported by Malumba[29]. They indicated that this phenomenon owed to starch granules was hard to breakdown. The decrease in the breakdown value maybe showed that the tempering steps helped to increase starch granules. It was shown that setback value increased when tempering time increased from 6 h to 14 h. According to the reported of Lan et al.[30], the amount of soluble amylose, starch particle size and unbroken starch granule swelling may affect the setback values.

It is also observed that both the increases in drying temperature and tempering time could enhance pasting temperatures. This result agreed well with the reports that the starch gelatinization and the formation of amylose-lipid complexes lead the higher pasting temperatures[31] during subjected to drying and tempering steps.

3.7 Thermal analysis

The thermal properties of maize starch after drying and tempering are listed in Table 4. It includes the gelatinization temperatures (onset temperature T_0, peak temperature T_p, and end temperature T_e), enthalpy of gelatinization (ΔH) and the degree of gelatinization (SG). The gelatinization temperatures were controlled by the amorphous region around the starch granule.

Table 4 DSC data of maize starches

Condition	T_0/°C	T_p/°C	T_e/°C	T_e−T_0/°C	ΔH/J·g^{-1}	SG/%
Undried	62.8	64.6	69.1	6.3	13.76	0
60°C	63.7	68.9	71.1	7.4	13.40	2.73
70°C	65.1	73.5	72.5	7.4	13.00	5.57
80°C	70.3	74.5	77.8	7.5	12.90	7.31
90°C	70.9	74.9	78.7	7.8	11.52	16.30
100°C	71.4	75.8	80.0	8.6	11.60	15.72
Without tempering	67.8	72.1	76.3	8.5	11.70	15.07
6 h	68.6	72.4	75.9	7.3	11.80	15.43
8 h	69.1	72.7	76.3	7.2	11.68	15.13
10 h	69.3	72.9	78.4	9.1	12.01	12.81
12 h	69.6	73.2	77.6	8.0	12.14	11.87
14 h	68.8	72.7	76.7	7.9	12.07	12.32

From Table 4, the onset temperature T_0 increases with the increase in drying temperature. The onset temperature T_0 increased first and then decreases with the increase of tempering time. The effect of drying temperature on onset temperature T_0 is more remarkable than that of tempering time. Peak temperature T_p and end temperature T_e increases significantly with the increase of drying temperature. Peak temperature T_p and end temperature T_e first increases and then decreases with the increase of tempering time, and the amplitude of augmenting and reduction is small. T_e−T_0 reflects the degree of diversification between starch granules, and the larger of T_e−T_0, the greater degree of diversification between starch granules. The impact degree of drying temperature and tempering time on T_e−T_0 was similar. The enthalpy required for melting starch ΔH decreased with the increase in drying temperature and tempering time has little effect on ΔH. The degree of starch gelatinization SG increases remarkably when the drying temperature increases from 60°C to 100°C. The SG first decreases and then increases with the increase of tempering time and there is only little variation when tempering time is between 6 h and 8 h.

4 Conclusions

The hot air drying and tempering was used to reduce moisture content in yellow maize. The effect of drying temperature and tempering time on the properties of maize starch was researched in this paper. The wet milling was used to obtain maize starch from maize samples. The maize starch properties, such as starch yield, protein content, amylose and amylopectin content, transparency and coagulation, solubility index and swelling power, color, pasting properties, and gelatinization properties were investigated in detail. The results showed that the hot air temperature had a more obvious effect on maize properties than tempering time. The increase in dry temperature lead to the increase of protein content, amylose content, coagulation, gelatinization temperature, and lead to the decrease of starch yield, amylopectin content, transparency, solubility, swelling power, whiteness. Maintain the tempering time at 10 h can obtain maize starch with the largest starch yield and transparency. The increase in the tempering time leads to slight increase in amylose content and a decrease of amylopectin, solubility, swelling power, coagulation volume.

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