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Effect of steam jet cooking on the destruction of corn starches

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Abstract

Steam jet cooking has been used for years to prepare aqueous starch dispersions for food application. The steam jet cooking generates high shear stress to starch. The objective of this research is to study the effect of shear stress on structure of corn starch granules by steam jet cooking. A laboratory scale steam jet cooker has been established with flow rate about 1L/min. Three kinds of corn starch, waxy, regular, and high amylose were used. Starch slurries (5% w/w) were cooked by steam jet cooker at temperature 100 °C (SJ100), 120 °C (SJ120) and 135 °C (SJ135) compared with hot water boiling at 90 °C 30 min (HB). The insoluble particles of cooked starches were investigated by particle size analyzer, scanning electron microscope (SEM) and damage starch assay kit. There was a significant decrease in percent yield of insoluble particles of cooked dispersions for all starches in the order HB > SJ100 > SJ120 > SJ 135. The data also showed that SJ100 has higher destruction than HB, although the temperature of heat treatment was similar. The particle size of cooked starches was much larger than uncooked starches, and the particle size of HB was larger than SJ100 for all starches. This may be due to the time of cooking, 30 min for HB vs. a few sec for SJ100. Percentage damaged starch of cooked dispersions for all starches became higher with increasing of cooking temperature. Although, the time of heat treatment was much shorter for SJ100 than HB, the damaged starch was higher as well. Those date all revealed the effect of shear stress from steam cooking. On SEM observation, the damaged granules showed sponge like structure for the starch dispersions cooked by HB. The starches heated by steam jet cooking were fractured into small fragments.

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Keywords: Steam jet cooking; Corn starch; particle size; damaged starch.

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1. Introduction

Aqueous starch dispersions have many practical applications in food products. Steam jet cooking has been used for years to prepare aqueous starch dispersions for food and non-food application.[1][2] This technique involves pumping starch slurry through an orifice and mixing with steam at high temperature and pressure. It is known that the steam jet cooking introducing high turbulence and large pressure drop generated high shear stress to starch.[3] The steam jet cooked dispersions had been use to prepare the crystalline particles or spherulites of starch.[4] The formation of spherulite is governed by complex interactions among a number of different variables, one of variables is the heat processing condition. The conditions of heat treatment affect the destruction of starch granules which lead to vary the composition of cooked dispersions and the formation of spherulite. However, there is limited information about the destruction of starch granules by steam jet cooking. The objective of this research is to study the effect of shear stress on particle structure of corn starch granules by steam jet cooking.

2. Materials & Methods

2.1. Materials

Samples of waxy maize starch and High-amylose maize starch (Hylon VII) were obtained from National Starch and Chemical Co. (Bridgewater, NJ USA). Samples of normal unmodified cornstarch were obtained Tongaat Hulett Starch Pty. (South Africa). Starch damage assay kit was purchased from Megazme International Ireland Ltd (Ireland). All chemicals were purchased from Sigma-Aldrich Inc. (St. Louis, MO USA), and were used as received.

2.2. Processing conditions of steam jet cooking

A laboratory scale steam jet cooker has been established with flow rate about 1L/min and cooking temperature up to 145 °C. Starch slurries (5% w/w) were cooked by steam jet cooker at temperature 100°C (SJ100), 120 °C (SJ120) and 135°C (SJ135) compared with hot water boiling at 90 °C 30 min (HB). The cooked dispersions were rapidly cooled by liquid nitrogen, dried by freeze drying, ground, and sieved through 80 mesh. The cooked starches were washed three times with water and centrifuged (2000 $\times$ g, 20 min) to obtain the insoluble particles. [5]

2.3. Particle size analysis

The particle size distribution of the insoluble particles of heated starches suspended in water was determined using laser particle size analyzer (Mastersizer 2000MU, Malvern, U.K.). About 100 mg of starch was dispersed in 20mL water and separated uniformly by wet sample dispersion unit (Hydro 2000MU, Malvern, U. K.). The sample dispersion was added to circulating water until an obscuration of 10–15% was recorded. The size distribution was calculated by software provided by Malvern.

2.4. Scanning electron microscopy

For SEM, all starch samples were mounted on aluminum stubs using double-sided tape, sputter-coated with gold and investigated using a Tescan Vega Ts 5136MM SEM (Tescan, USA). An accelerating voltage of 15–20 kV was used.

2.5. Damaged starch content

Damaged starch in raw and cooked samples was determined by a spectrophotometric method (AACC Method 76-31) using damage starch assay kit (Megazyme Ltd. Ireland). Starch samples 100 ± 10 mg was weighted accurately in a thick wall glass centrifuge tube (16 × 120 mm, 12 mL capacity) and pre-equilibrated at 40 °C for approx. 5 min. A fungal α-amylase solution (50 units/mL in sodium acetate buffer (0.1 M, pH 5) with calcium chloride (5.0 mM)) was also pre-equilibrated at 40 °C for approx. 5 min in a small glass beaker. To each tube, 1.0 mL of pre-equilibrated fungal a-amylase solution was added, stirred on a vortex mixer for approx 5 sec, incubated at 40 °C for exactly 10 min (from time of addition of the enzyme), and 8.0 mL of dilute sulphuric acid solution (0.2 % v/v) was added and stired vigorously for approx. 5 sec to terminate the enzymatic reaction. Tubes were centrifuged at 3,000 rpm (1000 × g) for 5 min 0.1 mL aliquot of the supernatant solution was carefully and accurately transfer to the bottom of two test tubes. 0.1 mL of amyloglucosidase solution (2 unit/mL in 100 mM sodium acetate buffer) was added to each tube. The tube was stirred on a vortex mixer and incubated at 40°C for 10 min. Add 4.0 mL of glucose oxidase and peroxidase determination reagent (GOPOD, Megazyme Ltd. Ireland) to each tube (including glucose standards and reagent blank tubes) and incubate the tubes at 40°C for 20 min. The absorbance of all solutions was determined at 510 nm against a reagent blank using spectrophotometer (ChromTech CT-2800). Percentage of damaged starch was calculated using absorbance (reaction) read against the reagent blank multiply conversion factor of absorbance to μg.

2.6. Statistical analyses

All tests were run in triplicate. Results are expressed as means±standard deviation of triplicate determinations. Analysis of variance was used to determine the least significant at $P < 0.05$ using Microsoft Excel (2007).

3. Results & Discussion

3.1. The percentage of insoluble particles

During steam jet cooking, starch slurry was pumped through a small orifice and mixed with steam which introduced high turbulence and large pressure drop generating high shear stress to starch. To understand the effect of steam jet cooking on integrity of starch particles, the raw and cooked starches were washed three times with cold water, the insoluble particles were isolated by centrifugation in centrifuge at 2000 × g for 20 min. Percent yield was determined by freeze drying the water-washed particles. Percentage of insoluble particles was calculated by the weight of freeze dried water-washed particles divided by original starch weight × 100%. The results are shown in Table 1. The percent yields of insoluble particles of raw starches were all excess 98 %. The effect of heat treatment was revealed by decreasing in percent yield of insoluble particles with increasing temperature of treatment. There were also significant differences in percent yield of insoluble particles among different starches. As expected, high amylose corn starch sustained shear stress better with highest percentage of insoluble particle. Waxy corn starch lost 80% of insoluble particles. There was a significant decrease in percent yield of insoluble particles of cooked dispersions for all three starches in the order HB > SJ100 > SJ120 > SJ 135. That is the starch granule destruction was exacerbated by jet cooking and increasing of cooking temperature. The percent yield of insoluble particles of waxy corn decreased from 56.2 for hot water boiling to 18.8 for steam jet cooking at 120 °C, regular corn from 81.7 to 75.9, and high amylose corn from 96.9 to 93.9. By comparison the result of hot water boiling and steam jet cooking, the data also showed that steam jet cooking at 100 oC has higher destruction than hot water boiling, although the temperature of heat treatment was similar. This result could be due to the shear effect of steam jet cooking on destruction of starch granules.

Table 1. Cold water insoluble starch content of waxy, normal corn starch and Hylon VII after boiling water and steam jet-cooking.

Sample	**Cold water insoluble starch** (%w/w)		
	Hylon VII	**Normal corn**	**Waxy corn**
Untreated	99.89 ± 0.25^{a}	99.22 ± 0.86^{a}	98.04 ± 0.49^{a}
Boiling	96.93 ± 0.28^{b}	81.71 ± 0.24^{b}	56.21 ± 0.51^{b}
SJC-100	96.56 ± 0.29^{c}	79.45 ± 0.29^{c}	40.22 ± 1.14^{c}
SJC-120	95.58 ± 0.29^{d}	77.87 ± 0.69^{d}	29.55 ± 2.02^{d}
SJC-135	93.88 ± 0.07^{e}	75.94 ± 0.28^{e}	18.78 ± 0.51^{e}

Reported values are the mean ± SD (n = 3).

$^{a\text{-}e}$ Values in a column for each sample with different superscripts are significantly different ($p < 0.05$).

3.2. Particle size of insoluble fractions

To understand the effect of cooking on the size of insoluble particles, the dried sample was dispersed in cool water and the particle distribution was analyzed by particle size analyzer. The results of particle size distribution analysis revealed that the insoluble particles swelled on contact with water, the particle size of studied starches were much larger than uncooked raw starches, and the particle size of HB was larger than SJ100 for all starches. (Table 2) This may be due to the time of cooking, 30 min for hot water boiling vs. a few sec for steam jet cooking at 100 °C.

Table 2. Particle size of cold water insoluble fractions in three corn starch after boiling water and steam jet-cooking. (μm)

Sample	**Volume mean**		
	Hylon VII	**Normal corn**	**Waxy corn**
Untreated	10.309 ± 0.057^{e}	12.788 ± 0.004^{e}	14.171 ± 0.007^{d}
Boiling	30.991 ± 1.468^{c}	148.126 ± 6.384^{b}	53.759 ± 2.949^{c}
SJC-100	22.146 ± 0.490^{d}	120.624 ± 0.860^{d}	102.534 ± 2.627^{a}
SJC-120	89.618 ± 2.858^{b}	166.666 ± 3.966^{a}	63.451 ± 1.371^{b}
SJC-135	113.245 ± 2.449^{a}	137.648 ± 6.367^{c}	56.066 ± 4.158^{c}

Reported values are the mean ± SD (n = 3).

$^{a\text{-}e}$ Values in a column for each sample with different superscripts are significantly different ($p < 0.05$).

3.3. Percentage damaged starch of cooked dispersions

To investigate the damage of cooked starch particles, damage starch assay kit was used to test the percentage of damaged starch. Percentage damaged starch of cooked dispersions for all three starches became higher with increasing of cooking temperature. (Table 3) The high amylose corn starch (Hylon VII) was more resist to steam jet cooking than the others. Although, the time of heat treatment was much shorter for steam jet cooking at 100 °C than hot water boiling, the percentage of damaged starch was higher. This also revealed the effect of shear stress from steam cooking.

Table 3. Percentage damaged starch of waxy, normal corn starch and Hylon VII after hot water boiling and steam jet-cooking.

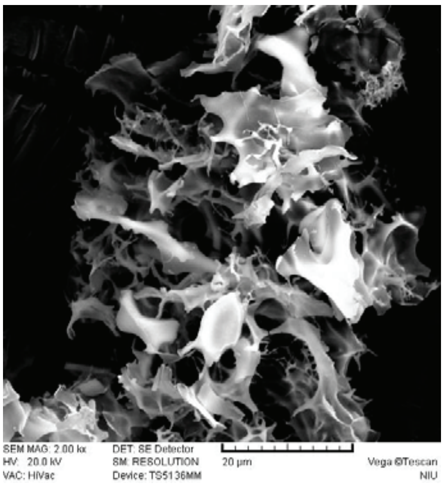
Sample	Starch damage (%)		
	Hylon VII	**Normal corn**	**Waxy corn**
Untreated	1.91 ± 0.02^{e}	1.06 ± 0.01^{c}	1.22 ± 0.02^{e}
Boiling	36.49 ± 0.27^{d}	71.90 ± 0.18^{b}	74.56 ± 0.53^{d}
SJC-100	38.99 ± 0.27^{c}	72.01 ± 0.24^{b}	77.53 ± 0.11^{c}
SJC-120	40.06 ± 0.51^{b}	77.07 ± 0.93^{b}	79.81 ± 0.86^{b}
SJC-135	41.11 ± 0.11^{a}	80.60 ± 0.06^{a}	83.19 ± 0.79^{a}

Reported values are the mean ± SD (n = 3).

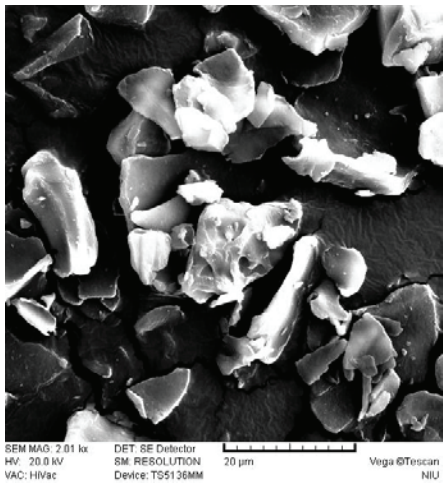
$^{a\text{-}e}$ Values in a column for each sample with different superscripts are significantly different ($p < 0.05$).

3.4. Scanning electron microscopy

On SEM observation, waxy corn starch granules appeared to be fractured by all heat treatments. The damaged granules showed sponge like structure for the starch dispersions of normal corn starch cooked by hot water boiling. The starches heated by steam jet cooking were fractured into small fragments (Figure 1). For high amylose corn starch, hot water boiling treatment only caused granule swelled. Steam jet cooking at 100 °C not only swelled the granule but also fractured some filamentous pieces from starch granule. When cooking temperature increased high than 120 °C, the starch granules were fractured and some sponge like structures were observed.



(A)



(B)

Fig. 1. Scanning electron micrographs of Corn, (A) Boiling 30 min, (B)jet-cooking 100°C

4. Conclusions

The effect of shear force by steam jet cooking on destruction of corn starches granule is significant. The comparison between hot water boiling and steam jet cooking at 100 °C revealed the destruction of shear force by steam jet cooking. The starches heated by steam jet cooking were fractured into small fragments. The degree of destruction relates to the amylose content of corn starch. Waxy corn with little amylose is easy to swell during heat treatment and to destroy by shear force of jet cooking. High amylose corn starch (Hylon VII) sustained the integrity of starch granule after heat treatment of hot water boiling and steam jet cooking at 100 °C. The study offered basic information of starch granule destruction by steam jet cooking for further application in food product development and processing design.

Acknowledgements

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