MEASUREMENT OF GEL STRENGTH AND VISCOSITY OF A MODIFIED MAIZE STARCH

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ABSTRACT

High amylopectin-starch samples were cooked in a direct steam injection heater for 1 minute at 90˚C, 3.3 psig and analyzed for flow rate, viscosity, and gel strength. Within 5 minutes of cooking, samples had an average viscosity of 178,666.70 cP and a flow rate (average velocity) of 0.25 cm/s. The second set of samples, which had been cooled overnight at 3.83°C, had an average viscosity of 583,333.30 cP, a flow rate of 0.17 cm/s, and an average gel strength of 5.88g. Under the conditions of this study, a stable and highly viscous starch gel was produced using a method that has advantages for use in the food processing industry. Using a relatively low pressure and rapid heating, cooking time can be significantly reduced while potentially preserving the flavor, texture, and nutritional quality of food.

INTRODUCTION

Starches have many physical and chemical characteristics that are unlike other carbohydrates. One such characteristic is that starch granules are composed of two polymers: a branched polysaccharide called amylopectin and a comparatively linear polysaccharide called amylose (Damodaran, 2017). When starch granules are cooked in water, they swell before leaching amylose and amylopectin to form a gel which can be used in many different foods, such as sauces, gravies, or gummy candies. Achieving the desired gel characteristics is important in food manufacturing as these characteristics can determine taste, texture, and shelf-life, among many other properties. In order to ensure a starch gel performs as expected, the characteristics (e.g., gel strength, viscosity, and flow rate) of the gel must be determined.

Hydro-Thermal Corporation (HTC), Pewaukee, WI, a manufacturer of direct steam injection heaters, provided samples of a modified maize starch which was cooked by a direct steam injection unit. Parameters of the cooking method were chosen to be most representative of those specified by the Gelatin Manufacturer's Institute of America (GMIA, 2013) for evaluation of gel strength.

Viscosity is a quantification of a fluid's resistance to flow due to internal molecular friction, flow rate is a measurement of the velocity that a fluid moves under its own weight. All gels and fluids have a measurable viscosity and flow rate and these values are unique to each starch or formulation. In food applications, viscosity and the development of starch pasting is an important consideration because starch is often used a thickener. Gel strength, on the other hand, is a characteristic that cannot be applied to all foods, as it is a measurement of the compressibility of a gel. All of these rheological elements depend on the chemical structure of the starch, concentration, temperature, pressure, and storage conditions.

The rheological properties of a starch are known to change during food processing and are influenced by origin of the starch source, concentration, temperature, heating and pressure. Understanding the viscosity, flow rate, and gel strength of a starch that is cooked by direct steam injection and under changing conditions of heat and pressure can indicate how it will function in

various food applications. In particular, these parameters suggest how well it will tolerate temperature, pressure, and perhaps texture, under food processing conditions.

In this study, we set out to determine three rheological characteristics of a high-amylopectin starch gel: gel strength, viscosity, and flow rate. The conditions for gel production were similar to those that were specified by an internationally accepted method for the determination of Bloom strength (GMIA, 2013), An additional parameter, pressure, was also introduced into the cooking conditions and we were also interested in establishing these same rheological characteristics. These values are intended then to be used in subsequent studies for comparison of gels produced with different pressures and temperatures, as well as with different types of starches.

METHODS & MATERIALS

SAMPLES

A modified, high-amylopectin maize starch was dissolved in distilled water at a concentration of 6.7% (w/v) and cooked for 1 minute at 90°C and 3.3 psig in a direct steam injection heater (Hydro Thermal Corporation, Waukesha, WI, U.S.A). Ten samples of 105-115 ml each were collected in 120-ml Bloom bottles (Brookfield Engineering, Middleboro, MA, U.S.A.), loosely covered with stoppers, and kept at room temperature for 15 to 20 minutes. Condensation was removed from the bottles by swirling and any surface foam was removed using a disposable plastic spoon. After the room temperature incubation period, stoppers were tightened on all the Bloom bottles and the samples were packed on ice for the 15-minute transport to Mount Mary University. Samples were then stored at approximately 10°C for 16-18 hours.

Six additional samples of approximately 450 ml each were collected in 600ml glass beakers and three were analyzed immediately (within 5 minutes of collection) for viscosity and flow rates, then discarded. The others were covered with Parafilm and packed in ice for the 15-minute transport to Mount Mary University. These were then transferred into a refrigerator and stored at 4°C for 18 hours until they were tested for viscosity and flow rate, then discarded.

GEL STRENGTH

Gel strength was measured following the Standard Testing Methods for Edible Gelatin (GMIA, 2013) using a Brookfield Engineering (Middleboro, MA, USA) CT3 Texture Analyzer. The analyzer was calibrated and using the 12.7mm smooth-edged probe, the penetration speed was measured at 1mm/s and a penetration distance of 4mm. The temperature of each sample was taken, centered under the analyzer probe, and the gel strength was measured.

VISCOMETRY

Viscosity of the 450 ml samples was measured using a Brookfield Engineering (Middleboro, MA, USA) dial-reading rotational viscometer, Model RV. The instrument was placed on a table free from vibration and leveled. The temperature of each sample was taken using a standard thermometer and the sample was analyzed using a #5 spindle at 0.5 rpm. Viscosity was recorded in percent torque within 5 minutes of sample collection and then again after the 18-hour storage at cool temperatures.

FLOW RATE

The flow rate of each sample was measured using a Bostwick Consistometer (CSC Scientific Company, Fairfax, VA, USA). The temperature of each sample was taken using a standard thermometer. The instrument was leveled and the gate closed. The chamber was filled with the sample and excess gel was removed with a straight edge so that the sample was level with the walls of the sample chamber. The gate was opened and the distance that the sample front traveled in 30 seconds was recorded in centimeters for each sample. The instrument was rinsed using room temperature water between samples and completely dried before the next recording. All samples were discarded after analysis.

MICROSCOPY

Starch granules were observed immediately after cooking using polarized light microscopy (Leicha Microsystems DM300). Samples were gently swabbed onto glass slides and observed at 400X without staining and under polarized light.

RESULTS & DISCUSSION

Microscopic observation of the starch immediately after cooking revealed that the starch had completely lost its granular structure. After only 1 minute of cooking by direct steam injection at 90°C and 3.3 psig, it was evident that molecular interactions between polymers had already formed and that the starch had fully gelatinized. No granules with the characteristic Maltese cross were observed or remained intact and the amorphous gel presented a uniformity in color and opaqueness. These observations confirmed that the starch had fully gelatinized in a manner that was nearly instantaneous.

Previous studies of waxy maize starches (high amylopectin content) have also shown that granular structure is completely lost under pressure (Simonin, 2009). In that study, loss of granular structure occurred at a much higher pressure of 500Mpa (72,519psi) whereas, our results confirm that a significantly lower pressure (3.3psig) and less time will produce a similar result.

Viscometry revealed that there was an inverse relationship between viscosity and temperature; as the temperature decreased, the viscosity of the cooked modified maize starch increased (Table 1). On Day 1 and at an average temperature of 79.7°C, the starch demonstrated a viscosity of 178,666.70 cP; however, on Day 2 and an average temperature of 3.8°C, the starch demonstrated an increase in viscosity at an average of 583,333.30 cP. This increase was expected as gels often thicken with cooler temperatures.

Table 1. Gel Characteristics of a Starch Cooked Under Direct Steam Injection.

		Gel strength (g)	Viscosity (Cp)	T_V (°C)	Flow Rate (cm/s)	T_F (°C)
Day 1	mean ±s.d.		178,667.7 (±2,309.40)	73.4 (±9.44)	7.5 (±0.25)	73.4 (±9.44)
Day 2	mean ±s.d.	5.88 (±0.230)	583,333.3 (±9,451.63)	3.83 (±1.44)	5.0 (±0.17)	6.0 (±0.17)

T_V is temperature at the time of measurement of viscosity; T_F is the temperature recorded at the time of the measurement of flow rate.

Measurement of flow rate revealed a similar inverse relationship; as temperature decreased, flow rate increased. On Day 1, the gel traveled a distance of 5.00cm in 30 seconds and had a flow rate 0.17cm/s. On Day 2 and at colder temperatures, the gel traveled 7.50cm in 30 seconds with a flow rate of 0.25cm/s. Again, this result was expected as viscous fluids flow more slowly under cooler conditions.

Mean gel strength was determined to be 5.88g (±0.23g), values that were consistent with those reported previously for gels with high amylopectin content (Jane and Chen, 1992). A gel solution that is heated for an extended period of time at temperatures greater than 40°C will generally exhibit weaker gel strength (GMIA, 2013) and this also was consistent with these results. Native maize starches that naturally contain amylose have been shown to form a stronger gel at similar concentrations (Wang, 1993); however, those with very little amylose compare in gel strength to those reported here. In fact, the starch gel did not show a recoverable deformation by the probe of the texture analyzer and thus did not exhibit the characteristics of a solid, but rather more like a liquid.

The higher gel strength and decreased velocity after 18 hours of cooling are both indicative of the ageing of the gels to a more viscous starch. Under the conditions of this study, the very high viscosity and flow rate indicate that the cooked starch can be characterized more as a paste than a gel. As the temperature decreased, the intermolecular movements began to slow, resulting in reduced flow and increased viscosity. Entanglement of the long amylopectin chains are likely to be responsible for the high viscosity of the starch paste and this correlates with findings previously reported (Jane and Chen, 1992). The high viscosity, just like gel strength, is likely to be due to the high amylopectin and low amylose content of these samples since the presence of higher levels of amylose tends to decrease viscosity (Ai and Jane, 2015).

Interestingly, the degree of change differed between viscosity (a 3.3-fold decrease) and flow rate (only a 1.5-fold decrease) and did not show a direct correlation. Although both measurements are reflective of intermolecular (or internal) friction, flow rate is also influenced by additional forces: cohesion and adhesion to the floor and walls of the instrument. The surface area of

spindle #5 used to measure viscosity is significantly smaller than the surface area of the floor and walls of the Bostwick consistometer; therefore, flow rate was likely to be more affected by adhesive and cohesive forces, thus slowing it down further.

The samples that were provided by Hydro-Thermal Corporation were processed at a relatively low pressure of 3.3 psig. Numerous reports show that high pressure (200-1500 MPa and 29,007.5-217,556.6 psig) will decrease the temperature at which starch becomes a gel (Yamamoto, 2016). Although these studies used much higher pressure than what was used in the current study, theoretically it is feasible to assume that any amount of pressure might have an impact on the temperature of gelatinization. In fact, this was confirmed by the observations of the starch paste under the microscope: a temperature of 90˚C and a pressure of only 3.3psig is enough to cause the starch to fully form a strong gel.

Upon cooling, starch gels generally undergo retrogradation where the amylose and amylopectin molecules re-associate. In the process, water is squeezed out and forms a watery surface on the product. This syneresis, or weeping, did not occur over the 18-hour ageing process, which is most likely a reflection of the low amylose-content of the starch samples in this study.

Industrial applications of this rapid gel formation under low pressure has potential advantages in the food industry. Typically, a starch is added to a sauce and cooked at temperatures of 85˚C or higher for several minutes in order thicken the sauce. Under these conditions, flavor, nutritional value, and color can be lost. However, when starch is cooked quickly under higher pressure, these important parameters may be preserved resulting in a more desirable product.

The type of starch used as a thickening agent will affect the texture and mouthfeel of any food to which it is introduced. Thus, it is important that a food manufacturer choose a starch with characteristics such as gel strength and viscosity that are optimal for each product. A gel intended for use in a savory gravy, for example, may not work well in the production of a sweet pie filling, and vice versa. The highly viscous gel produced under the conditions of this study suggests that less starch may be necessary in creating the desired texture and mouthfeel for a food product.

Additional testing should be done to evaluate how consistently the production of the same high-amylopectin starch gelling characteristics can be reproduced when cooked at 3.3psi at 90˚C for 1 minute. Providing evidence of consistent viscosity, flow rate, and gel strength to customers will provide confidence in the culinary steam injection product manufactured by Hydro-Thermal Corporation. In addition, further understanding of the capabilities of the culinary steam injection system can be gained by comparing the data in this study to a starch that contains a higher amylose content. In the current study, the formation of the starch gel occurred so rapidly that even some preliminary changes to the cooking parameters did not produce the normally observed sequence in starch production. In other words, the initial starch grain swelling and subsequent leakage of carbohydrate polymers could not be observed microscopically. In several food applications, the timing of these steps can provide for better control of texture and mouthfeel. By repeating this study with a starch that contains a higher concentration of amylose, starch swelling and leakage may be visible in freshly collected samples since these starches tend to gelatinize more slowly, including higher temperature and pressure. Subsequent data on the viscosity, flow rate, and gel

strength will further characterize the qualities of the gel that can be produced using this alternative starch, giving customers a more complete understanding of the capabilities of the culinary steam injection system.

CONCLUSION

The modified maize starch cooked in an Hydro-Thermal direct steam injection heater produced a product that had a thicker consistency and was more viscous at a lower pressure than what is reported in much of the literature. With a viscosity of 178666.70 cP at the time of sample collection, viscosity increased over 3-fold to 583333.30 cP after 18 hours of storage at approximately 4˚C. The gel strength, which averaged 5.88g after cool storage, confirmed that the starch was characteristic of a paste rather than a gel. Under the conditions of this study, a stable and highly viscous paste was produced using a method that has advantages for use in the food processing industry. Using a relatively low pressure and a quick heating time, cooking time can be significantly reduced while potentially preserving the flavor, texture, and nutritional quality of food. Further studies should be done to determine the reproducibility of this starch cooking process as well as whether the progression of gel formation can be further controlled by the use of other forms of modified starch that contain varying levels of amylose.

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