Rheological Characterization of the Gelatinization Process on Alternative Starch Sources Used in White Sauce

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ABSTRACT

The viscosity of white sauce is one parameter used to describe its qualities. However, popular words like “good viscosity”, “mouthfeel” and other sensory ratings seem rather subjective to understand key sensory profiles of such a product.

In this introductory study, several rheological methods were used to examine gelatinization during heating of three starch containing sources. This knowledge may be of importance in many cases; for instance, when preparing white sauces using lactose reduced milk to minimize increased Maillard browning etc.

Three starch containing flours (wheat, maize and potato) were investigated in a Physica MCR301 rheometer fitted with a ST24-2D/2V/2V-30/129 spindle in a CC27 cup. The samples had the same concentration of dry material in water. All the samples were unsteady and separated in a few minutes if placed at rest.

Rotational tests investigating cold swelling at 20 °C for 30 minutes, then temperature sweeps from 20 °C to 90 °C, and down again to 20 °C were made. Amplitude sweeps were then run on the sample to determine the linear viscoelastic range.

The results show that cold swelling is detected, and, in addition, all the samples exhibit temperature dependent increases in the viscosity. Both potato flour and maize flour exhibit quite steep increases in viscosity as the temperature is increased, while wheat flour exhibits a less steep increase in viscosity with temperature.

The flours exhibit different responses to temperature, and this may be utilized in food processing using these ingredients.

INTRODUCTION

White sauce and its unlike variants are a popular and essential part of the diet in many dishes. White sauce, also known as Béchamel sauce, is one of the basic sauces in the French kitchen. The sauce is named after Louis de Béchamel. He worked as a chef steward in the French royal court of king Ludvig XIV in a period from about 1650. But the story tells us that the Béchamel sauce originally was an Italian sauce named Balsamella[1]. The sauce is usually made by whipping heated milk into a blend of starch rich flour and butter. In the Norwegian kitchen white sauce is often used together with fish balls, “lutefish”, lobster and other shellfish, as well as for cooked meat and pieces of sausages.

Starch is the most common and complex carbohydrate in the human diet. The major sources of starch intake worldwide are the cereals like rice, wheat, and maize together with some root vegetables like potatoes and cassava[2]. Examples of starch containing food may be bread, pancakes, cereals, noodles, porridge, tortilla etc. But in this context, it`s about starch from different sources used in white sauce.

Raw starch is poorly digested by humans. But when starch is cooked, like in white sauce, the digestibility is increased. This phenomenon is due to the starch gelatinization that take place during heating in water[3]. Starch gelatinization is the disruption of molecular orderliness within the starch granule. It results in granular swelling, crystallite melting, loss of birefringence, viscosity development, and solubilization.

Starch in pure, or modified form is often used in the food industry as an additive for food processing. Such additives are typically used as thickeners and stabilizers in puddings, soups, sauces, pie fillings, yoghurt, salad dressings and many modern low-fat products. But in this investigation natural or untreated starch from flour of wheat, maize and potato were used during rheological testing and measurements.

The gelatinating temperature varies between the different raw materials and between species in the same "family". Starch from rice is reported to gelatinize between 68 and 71 ºC[4] or between 58.9 and 72.4 ºC[5]. Yellow maize is reported to gelatinize between 66 and 72 ºC[4] or between 64.3 to 77.2 ºC[6]. Wheat starch is reported to gelatinize between 50 to 70 ºC[7]. In addition, there will also be effects of denaturation of proteins in wheat. Potato starch is reported to gelatinize between 52.5 to 72 ºC[8].

When being heated in abundant water, the granules of native starch swell and burst. The semi-crystalline structure is lost. The smaller amylose molecules start leaching out of the granule, forming a network that holds water and increase the mixture's viscosity[9].

In addition, some ingredients in white sauces also includes other food components than starch. Wheat flour for instance, contains proteins in addition to starch. These proteins will of course denature during heating. This process contributes in addition to gelatinating, also to increased viscosity of the sauce. The most common description of protein denaturation by heat is the process which include major changes in the secondary, tertiary, and quaternary structures without cleavage of the backbone peptide bonds. A so-called folding out of the protein molecules that contributes to different structural groups being exposed to the solvent – here water.

Most starch consumed by humans has undergone some form of processing, which usually involves heating in the presence of moisture under shear. During heat treatment, the starch granules are gelatinized, losing their crystallinity and structural organization[9]. Gelatinization occurs when native starch is heated in the presence of sufficient moisture. The granules absorb water and swell, and the crystalline organization is irreversibly disrupted. This is the same process that the starch from flour undergoes when making white sauce.

Many methods are available regarding investigation of thermal and mechanical changes of starch during gelatinization; like chemical analysis, scanning electron microscopy, polarized light microscopy, rheological methods etc.[10]. Thus, in this study, we are focusing on rheological investigations. This is because rheological analysis is one of the significant methods for understanding the structure-function relationship of polysaccharides, like starch in aqueous media.

Rheological behaviour of starch during the gelatinating process or by adding different commercially available thickening powders, touches many aspects related to sensory properties of food and nutrition. As an example, starch and hydrocolloids are major ingredients in gluten-free diets. Potato starch is often used in gluten free pasta[11].

Another aspect is connected to rheology- and processing behavior of starch, used as functional additives in food for people with dysphagia. Dysphagia is the general term used for drinking- and eating disorders that can be present in a range of diseases, or in the increasing part of the elderly in our society. The complexity of how different fluid properties influence swallowing is difficult to quantify. However, it is widely accepted that some swallowing difficulties can be alleviated by using thickened fluid additives like starch[12]. This is also due when making white sauce for use in different dishes.

Starch has a wide range of applications both in the food- and feed industry, in the paper-, textile-, adhesive- and the pharmaceutical industry. Different applications require special properties from the starch. As an example, the pharmaceutical industry use starch as packaging material for various pharmaceutical preparations, e.g., in pills[13]. This industry is also concerned about rheology as one of the measures of starch that they use in various applications. They also characterize starch according to various organoleptic- and physicochemical properties like hydration capacity, swelling capacity, moisture sorption, pH, porosity, particle size and particle size distribution etc.[14]. The physicochemical properties of starch obtained from different sources vary due to differences in their amylose content, grain size, chain length and distribution of amylopectin molecules.

The primary interest in this introductory study was to investigate rheology issues regarding temperature and gelatinization of starch from different flours, Fig. 1, and Table 1. Wheat- and maize starch are grain starches, while potato starch is root starch. These starches have different characteristics, but they are used in many of the same applications. One example being white sauce.

An interesting phenomenon regarding preparing white sauce today, is the increased amount of lactose hydrolyzed milk used when preparing this product. Lactose hydrolyzed milk is more and more used by lactose intolerant people worldwide. Many challenging issues are facing using this milk in different products. Increased Maillard browning due to a double monosaccharides content may be a challenge during heating this milk in different products[15]. A gelatinizing agent that starts gelatinization at low temperature may be favorable to avoid browning when making white sauce based on lactose hydrolyzed milk.

The objective of the measurements reported in this paper was to investigate and compare rheological properties of some commercially produced starches during gelatinization at a heating rate of 4.7 °C/minute in the interval 20 °C to 90 °C.

Figure 1: The three different starch containing sources used in this rheological investigation; 1 Maize, 2 Potato, 3 Wheat.

Table 1: Approximate composition (% w/w) of the three starch containing sources investigated. Values declared by the manufacturers.

Flour	Water	Protein	Carbo-hydrate	Starch	Fiber	Fat	Sat. fat	kJ pr.100 g
Wheat	14	11.2	67.9	65.2	3.6	1.6	0.4	1433
Maize	9	<0.5	86	86	1	<0.5	<0.01	1487
Potato	20	0.1	81	81	0	0.3	0.2	1369

Figure 2: From left to right; Wheat flour, Maizena and Potato flour are all separated in cold water.

MATERIALS AND METHODS

Starch alternatives

The 3 different types of starch tested given in Table 1, were purchased from ordinary Norwegian grocery stores. The flours were all unstable in cold water and separated readily as seen in Fig. 2.

Instrumental analysis and experimental set-up

The Physica MCR301 rheometer (Paar Physica, Anton Paar, Stuttgart, Germany, 2010) fitted with a ST24-2D/2V/2V-30/129 spindle, Fig. 3, in a CC27 cup, the following tests were run:

- Rotational test at 100 1/s for 30 minutes at 20 °C.
- Rotational test at a shear rate of 100 1/s while the temperature increased from 20 °C to 90 °C and back to 20 °C in 15 minutes (4.7 °C/minute).
- Amplitude sweep tests after the temperature conditioning were run at 20 °C using an angular frequency of 10 rad/s with the strain increasing from 0.01% to 100%.
- LVR macro was then run to determine the limits of the linear viscoelastic range[16].

Figure 3: Lower end of spindle ST24-2D/2V/2V-30/129

Analysis

The Anton Paar LVR macro was run on the G’ versus strain data detecting a 3% reduction in G’ giving the limit of the linear viscoelastic region.

RESULTS

Rheometer results

The results from the viscosity measurements versus time are shown in Fig. 4. The viscosity variation as a function of temperature is shown in Fig. 5.

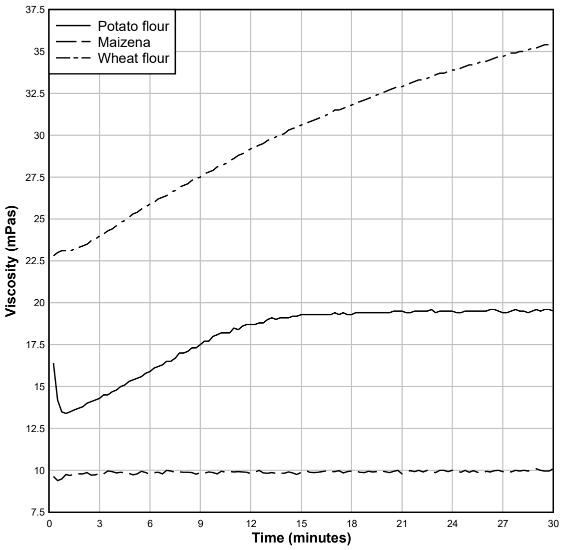

Figure 4: Viscosity in cold swelling period.

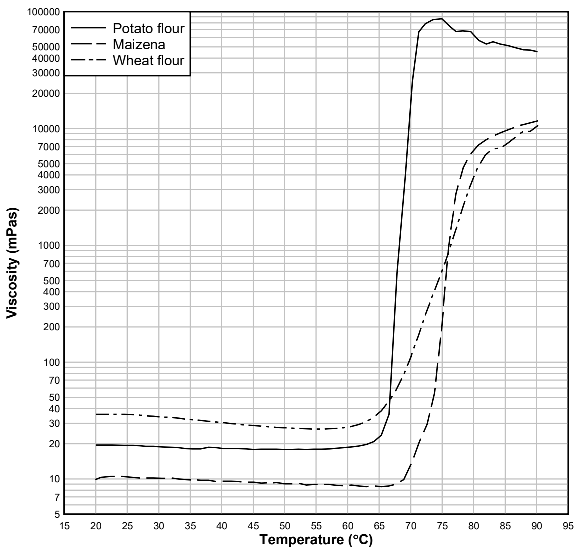

Figure 5: Viscosity with increasing temperature.

The samples gel in the rheometer as a result of the temperature treatment. The gels are seen in Fig. 6-8.

The results from the linear viscoelastic range macro are shown in Table 2.

Figure 6: Potato flour gel

Figure 7: Maizena flour gel

Figure 8: Wheat flour gel

Table 2: Results from linear viscoelastic range analysis.

Starch from	G' (Pa)	Strength (Pa)	Limiting strain (%)
Potato flour	645	297	44
Maizena	4786	1485	31
Wheat flour	3428	214	6

DISCUSSION

The results from the viscosity measurements showed that potato flour and wheat flour swelled at room temperature (20ºC). Maizena flour did not; Fig 4. This is interesting regarding starches used as cold swelling agents in food products, especially in low fat- or fat reduced products like mayonnaise and salad dressings. In such products cold-swelling starch, microcrystalline cellulose and/or guar gum are used as stabilizers. In this case regarding the white sauce that will be heated, this cold swelling property does not matter.

The starches used are divided into so-called native- and chemically modified variants. Both varieties occur, but the chemically modified ones are probably dominating in the food industry. This is because the physiochemical and functional properties of native starches are seldom uniform and stable. As a result, native starch molecular structures are often modified using physical, enzymatic, and/or chemical methods to allow them to meet industrial needs. This is in contrast to this study which is concentrated just about native starches.

Another criterion for starches in the food industry is the demand of water-soluble varieties. Normally they are available in all types of thickeners used. This is also in contrast to the starches investigated in this study; see photos in Fig. 2.

Fig. 5 illustrate the viscosity change of the different starches with increasing temperature. The gelatinating temperature varies according to the information from the literature given in the introduction. When the temperature was raised, potato flour gelatinized at the lowest temperature, maize flour at the highest. Regarding wheat flour which also includes approximately 11% protein in addition to 68% starch, these viscosity measurements were not able to distinguish between increase in viscosity caused by protein denaturation and/or from gelatinizing of the starch. This may be related to the fact that the protein denaturation and the gelatinating reaction in wheat flour take place in the same temperature area. Otherwise, two peaks would be expected regarding the viscosity increase for wheat flour in Fig. 5.

The photos in Fig. 6, 7 and 8 show the gels in the rheometer as a result of the temperature treatment. According to the results from the linear viscoelastic range analysis, maize flour gave the strongest structure; Tab. 2. Some differences are expected since native starch is biopolymers produced and packed as granules which vary in shape and size depending on the botanical source. This individual granule morphology affects and dictates functional and physiochemical behaviour of different starches used in food products during processing.

In this introductory study, the rheological methods were just used to investigate and characterize gelatinization of starch without going into detail of the gelatinization process. The heating process requires starch as a solute and water as a solvent. This phenomenon which breaks down the intermolecular bonds of the starch molecules in presence of water and heat, allow the hydrogen bonding sites to engage more water. This irreversibly dissolves the starch granules in water. Three main processes happen to the starch: granule swelling, double-helical melting, and amylose leaching. Our next rheological challenges will be to study the above-mentioned processes more in depth in different food products.

CONCLUSIONS

The conclusions of this screening study can be summarized as follows:

- Potato flour and wheat flour swelled at room temperature.
- All the flours exhibited increase in viscosity when the temperature was raised, potato flour at the lowest temperature, maize flour at the highest.
- Maize flour gave the strongest structure.
- Wheat flour had a low allowable strain. This may be seen in connection with the fact that wheat flour also contains 11% protein. This is in contrast to starches from potato and maize that do not contain protein.

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