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Assessing the microstructural and rheological changes induced by food additives on potato puree

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ABSTRACT

The effects of agar, alginate, lecithin and glycerol on the rheological properties of commercial potato puree were investigated and interpreted in terms of starch microstructural changes, and the applicability of the Cox-Merz rule was evaluated. Each additive was applied separately at two concentrations (0.5 and 1%). Microscopic observations revealed more swollen starch aggregations in lecithin and glycerol compared with those of potato puree and agar, consequently affecting the rheological properties of potato puree. All samples exhibited shear thinning non-Newtonian behaviour. Rheological measurements were strongly concentration dependent. At 0.5% concentration, additives exerted decreases in all the rheological properties of potato puree in the order of glycerol > alginate > lecithin > agar, while at 1% concentration, the order changed to glycerol > lecithin > alginate, whereas 1% agar behaved differently, increasing all rheological values. This study also showed that agar and alginate in addition to potato puree could be valuable and advantageous for further technological processes, such as 3D printing.

1. Introduction

There is a movement towards potato vegetable purees as high-quality products and part of the rapidly growing ready-to-eat (convenience) food market. Recently, potato purees have been used as a potential substrate for the innovative technique of 3D food printing due to the malleable textural properties of starch, its capability of water retention and its capacity as an excellent colloidal stabilizer and bulking agent (Eliasson, 2004). Potato starch is a natural-versatile biopolymer composed of linear amylose chains and highly branched amylopectin. It can be easily obtained and modified using different chemical, enzymatic and physical methods to improve its functional characteristics, making potato starch one of the preferred polymers used in many technological manipulations in the food industry, such as in thickening, coating, and gelling and as an encapsulating agent (Singh, Kaur, & McCarthy, 2007).

In addition to the technological complexity of producing, processing and handling potato starches and potato purees, accepting these perishable food materials requires a wide knowledge of their physical properties, emphasizing the importance of studying their rheological properties. Monitoring the rheological behaviour of a product can aid in the development of a new successful product with the specific desired textural characteristics and quality attributes, enhancing the acceptability of the food. Additionally, this knowledge is important in food processing and handling for predicting the analysis of process design and flow conditions, such as in 3D printing (pump sizing, syringe size and length, total time of printing, extrusion, layer and conformation stabilization, etc.). Above all, investigating the rheological properties of a food, specifically potato puree, can serve as vital basic research into the different ingredient interactions (Maceiras, Álvarez, & Cancela, 2007; Tabilo-Munizaga & Barbosa-Cánovas, 2005) .

Structurally, potato puree prepared from commercial potato flakes consists of single starch cells and cell aggregates embedded inside a matrix of starch gel released from damaged cells during the cooking, mashing and drying processes of preparation (Alvarez & Canet, 1999). Thus, the rheological behaviour of commercial potato is governed by the starch structure, amylose content, granule size distribution, granule shape, granule volume fraction and interactions among different starch granules (Kaur, Singh, & Singh, 2004), in which the maximum viscosity at a given concentration depends on the capacity of granules to swell freely prior to their physical breakdown (Adebowale & Lawal, 2003). This swelling is attended by consequent leaching of granules constituents and the formation of a three-dimensional network responsible for rheological modifications upon heating and shearing starch (Li & Yeh, 2001).

Potato starch and its derivatives, such as potato puree, are generally

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used in food industrial applications after being mixed with different hydrocolloids and food additives since native starches generally do not possess ideal properties for the preparation of food products. This mixing improves the functionality, stability, and texture of the product and facilitates its performance during processing and at the same time adjusts its rheological properties to compatible values (Chaisawang & Suphantharika, 2005). However, it is very difficult to identify optimal combinations and rheological characterizations in a complex food system such as potato puree with different additives. BeMiller expressed the difficulty of finding a unique mechanism to explain the effects that several hydrocolloids have on starch structure. Because of the complexity and variety of those systems, their properties depend on both the starch-hydrocolloid ratio and the particular starch-hydrocolloid combination (BeMiller, 2011). In the same sense, it was found that the addition of sodium alginate and carrageenan to starch could preserve the granular structure of amylose-rich, swollen rigid granules, consequently attributing to an increase in the rate of viscosity (Hongsprabhas, Israkarn, & Rattanawattanaprakit, 2007). The addition of other types of hydrocolloids revealed different methods of interaction, such as xanthan and guar gum, which inhibit the swelling of granules by preventing water penetration; they promote granular association by bridging and stabilizing the granular shape, forming a stronger three-dimensional network due to an amylose and amylose-gum system and allowing the starch paste to exhibit a more solid-like behaviour (Chaisawang & Suphantharika, 2005).

Therefore, four food additives, agar-agar gum, alginate, lecithin and glycerol, with different known modes of behaviour, were used in this study at two different concentrations. Gum (Agar-Agar) was used based on its known capacity to interact with other polysaccharides, leading to a synergistic increase in viscosity, as in whipped cream and starch-based mixtures (Zhao, Zhao, Yang, & Cui, 2009). Alginate is a polysaccharide made up of 2 polymers, β-d-mannuronic acid (M) and α-l-guluronic acid (G), which provide thickening, stabilizing, film-forming and gel-producing properties to the food agent (Koushki & Azizi, 2015). Lecithin has been used to modify the properties of waxy maize starch because of its emulsifying property, colour and taste; it has been used also as a lubricant in food industrial applications, such as extrusion, resulting in less nozzle wear and tear. Lecithin is also used as an emulsifying agent in many confectionary and chocolate products (Lončarević et al., 2013), while glycerol is used more as a plasticizing agent with edible starch films to reduce their tensile strength, thus reducing their viscosity (Bonilla, Vicentini, Dos, Bittante, & Sobral, 2015). Although glycerol is not widely used for food processing, we included it in the study because of its chemical and physical characteristics in comparison with the other additives used. Therefore, the present work aims to contribute to the knowledge of the effects that these additives can exert on commercial potato starch microstructure and rheology and to provide proper explanations for such effects and mechanisms to improve the usage of potato puree in advanced food technologies. To this end, two types of rheological tests were conducted: dynamic oscillatory and steady rotational tests. Additionally, the Cox Merz rule, which is used to characterize material properties by examining the relationship between dynamic viscosity and steady shear viscosity, was applied and evaluated.

2. Materials and methods

2.1. Sample preparation

Dehydrated potato puree (Maggi, origin) and whole milk were purchased from the local supermarket. Agar-agar, soybean lecithin, sodium alginate and glycerol (food grade) were procured from Sigma–Aldrich Co. Potato puree samples were prepared according to the following ratio (90 mL milk and 10 mL water heated previously to 40 °C, to which 23 g of potato powder was added). The mixture was then homogenized for 3 min using an electrical hand blender (Braun, Germany). The same procedure was followed for preparing the puree samples with the four different additives at two different concentrations (0.5 and 1%). Additives at their corresponding percentages were added and dissolved in the warmed solution (milk and water) prior to the incorporation of the potato powder. However, for agar, the solution was boiled to 100 °C, after which the dehydrated potato powder was added. Subsequently, all samples were placed in an incubator, and the temperature was maintained at 20 °C prior to the microscopic observations and rheological measurements.

2.2. Microscopic observations

To compare the structure and the alignment of the starch particles between the different preparations, a thin film from each of the potato puree samples was spread on a glass slide and stained with diluted Lugo's Solution; the stained films were then examined under a compound light microscope (better images were taken at 10x magnification).

2.3. Rheological measurements

The rheological measurements were performed in a rheometer (Rheostress RS1, version 127, Barcelona, Spain) controlled with commercial computer software (HAAKE RheoWin 3 Job and Data Manager Software). Samples were analysed for their flow properties using 35-mm plate-plate geometry (PP60 sensor) with a 2.5-mm gap between the plates. The upper plate was lowered, and the excess sample was trimmed off. After loading, samples were rested for 3 min prior to testing. Two types of rheological tests were conducted: a dynamic oscillatory test and a steady rotational test. The temperature of the rheological tests was kept constant at 20.0 ± 0.1 °C. The results were reported as the average of three replicates (a new sample was loaded for each repetition).

2.3.1. Dynamic rheological measurement, frequency sweep test

The strain sweep test was performed to identify the linear viscoelastic region. Thereafter, a shear rate of 0.0025 s^{-1} was selected and deformation within the elastic property was detected. Moreover, oscillatory tests were performed from 0.1 to 10 Hz to determine the strength and stability of the material and to clarify the behaviour of the sample, whether viscous or elastically dominated. Storage modulus G′ (indicator of the elastic behaviour), loss modulus G″ (indicator of the viscosity behaviour) and complex viscosity n^* (related to the global viscoelastic response) were recorded.

Results were reported as the average of three replicates (a new sample was loaded for each repetition).

2.3.2. Steady rotational rheological measurements, thixotropy and yield stress

A hysteresis loop test was performed to provide an indication of whether the sample was thixotropic and to determine the degree of thixotropy. The shear rate was increased logarithmically from 0.1 to 10 s^{-1} during the first 30 s, was then maintained at 10 s^{-1} for 30 s, and finally was decreased logarithmically again to 0.1 s^{-1} over 30 s. Consequently, the viscosity (η) and the shear stress (τ) were recorded, along with the yield stress for each sample. Accordingly, a rapid drop in viscosity as a response to increased shear stress and shear rate was registered. Two methods were used to quantify the yield stress. The first one involved attempting to fit the experimental data to the best mathematical equation or model (Hershel Bulkey, Casson Model, Power Law, Bingham). Bingham was determined to be the best model to fit the flow characteristics of the samples, with a high coefficient of determination ($R > 0.957$). The Bingham equation is ($\tau = \tau_0 + \eta_p \gamma$), where τ (Pa) is the shear stress, τ_0 (Pa) is the yield stress, η_p (Pa s) is the viscosity and γ (s^{-1}) is the shear rate. Nevertheless, this model was not suitable for 1% agar (w/v). Therefore, an alternative method was used