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Rheological study of different mashed potato preparations using large amplitude oscillatory shear and confocal microscopy

Helen S. Joyner (Melito)*, Alexander Meldrum

University of Idaho, 875 Perimeter Dr., MS 2312, Moscow, ID 83843, USA

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ABSTRACT

Texture is a major driver for mashed potato products. Measuring food texture via descriptive sensory analysis can be expensive and timeconsuming, so rheometry is often used as a method of estimating food texture. The objective of this study was to determine small- and largestrain rheological behavior of different mashed potato formulations. Rheological data, including large amplitude oscillatory shear data, and confocal microscopy images were collected. Comparison of rheological data and confocal images showed relationships between sample rheological behavior and sample structural damage were found. With the exception of freeze-dried samples, samples exhibiting greater starch damage exhibited more linear, fluid-like rheological behavior. Freeze-dried samples showed microfractures on the surface of the starch granules. It was hypothesized that these microfractures allowed amylose strands to leach from the granules without destroying structural integrity. Based on these results, mashed potato rheological behavior, and therefore texture, can be controlled by controlling extent of starch damage.

1. Introduction

Texture plays an important role in consumer acceptance of mashed potatoes and other potato products (Faulks, 2014). In cooked potatoes, most consumers prefer a soft, mealy potato compared to a non-mealy, sticky or waxy potato (van Marle et al., 1997). A high solids content can result in increased product firmness due to the increase in structural stability. Free amylose can form gels, also resulting in increased product firmness. Amylose can be released from the starch granule if the granule's surface has been damaged (Linehan and Hughes, 1969).

The current gold standard for evaluating textural attributes is descriptive sensory analysis, which uses a trained panel to evaluate food products. However, developing and maintaining a trained panel can be time-consuming and expensive. An alternative way to obtain information about food texture is to relate texture to structure through mechanical behavior. Mechanical properties of food can be acquired through rheological techniques.

Traditional rheology focuses on small-strain mechanical properties. Small-strain tests are useful for describing initial responses to stress and strain in a sample. However, small-strain tests are limited to the linear viscoelastic region, or the region in which the sample displays ideal behavior. Strains placed on foods during processing or chewing are generally much larger. It has been found that large-strain mechanical behavior relates more closely to oral processing and sensory behavior than small strain behavior (Çakir et al., 2012). Unfortunately, it can be difficult to measure fundamental mechanical behavior of foods under large strains due to violations of the assumptions of linearity made in the calculation of fundamental parameters or difficulties in preparing or maintaining samples in the required shape for testing.

Over the last several decades, there has been increased effort to develop novel techniques to measure nonlinear viscoelastic behavior of foods. One such technique is large amplitude oscillatory shear (LAOS). Similar to traditional small amplitude oscillatory testing, samples are placed under an oscillating torque or deformation. In small-strain testing, the strain placed on the samples usually does not exceed 1%. In LAOS, the strain amplitude is much larger, ranging from 25% to >100%. These large strains can result in significant nonlinear behaviors, which can be viewed in a plot of stress versus strain, or a Lissajous plot, as deviations from an elliptical shape. Ewoldt et al. (2008) developed a technique to quantify the extent and type of nonlinear behavior shown in these Lissajous plot. Briefly, a mathematical technique is used to deconvolve the output stress waveform into various harmonics. Further mathematical manipulation allows the third-order harmonic data

* Corresponding author.
E-mail address: hjoyner@uidaho.edu (H.S. Joyner).

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to be used to determine both extent and type of nonlinear behavior. The extent of nonlinear behavior can be measured using the third harmonic viscoelastic moduli, G'_3 and G''_3. The type of nonlinear behavior can be identified by using two new viscoelastic moduli and two new instantaneous viscosities defined by Ewoldt et al. (2008). These new parameters can be seen in the Lissajous plots in Fig. 1. The ratio between the large-strain elastic modulus (G'_L) and the minimum-strain elastic modulus (G'_M) can be compared to find the extent of strain-softening ($G'_L/G'_M < 1$) or strain-hardening ($G'_L/G'_M > 1$) behaviors. The ratio of the instantaneous viscosities at maximum shear rate (η'_L) and at minimum shear rate (η'_M) can be used in a similar manner to determine the extent of shear-thinning ($\eta'_L/\eta'_M < 1$) and shear thickening behaviors ($\eta'_L/\eta'_M > 1$) (Melito et al., 2012b).

Various LAOS techniques have been used to characterize nonlinear viscoelastic behavior of polymers for several decades. These techniques can also be used to measure nonlinear viscoelastic behavior of food products, such as whey protein gels (Melito et al., 2012a), gluten gels (Ng et al., 2011), hydrocolloid solutions (Melito et al., 2013a), and cheese (Melito et al., 2013a). Understanding how and to what extent food structures deform under strain can yield valuable insight on how food structure and structural changes impact food texture. Therefore, the objective of this study was to evaluate small- and large-strain rheological behaviors of different mashed potato preparations, and determine the relationships between starch structure and rheological behavior by comparing rheological data with confocal microscopy.

2. Material and methods

2.1. Materials

Burbank potatoes were purchased from a local retailer and kept in a controlled atmosphere for up to 48 h before use. Instant potato flakes (Idahoan, Lewisville, Idaho, USA) were also purchased from a local retailer and kept in a desiccator to prevent moisture uptake. Potato starch was donated by AVEBE (Food Grade Potato Starch, AVEBE; Veendam, Netherlands). Samples were stained for confocal imaging with EMD Millipore HARLECO® Safranin Solution for Gram Staining (65092B-95, Merck KGaA, Darmstadt, Germany).

Potato samples evaluated were termed “whole potato”, “freeze-dried potato”, “instant potato” and “potato starch”. Whole potato refers to mashed potatoes made with a raw potato; freeze-dried potato refers to mashed potatoes prepared from whole potato samples that were freeze-dried and rehydrated; instant potato refers to mashed potatoes prepared from commercial instant potato

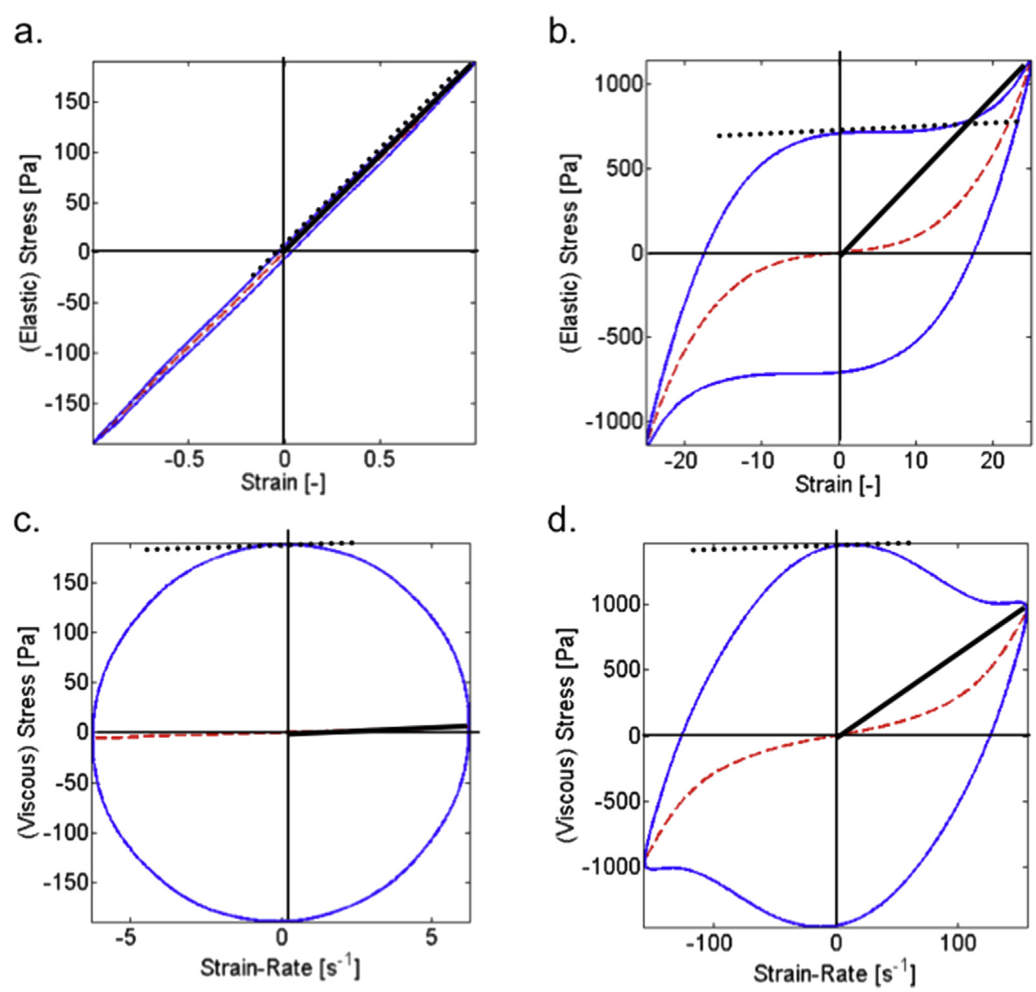

Fig. 1. Lissajous plots showing a. linear, elastic behavior; b. nonlinear, elastic behavior; c. linear viscous behavior; d. nonlinear viscous behavior. The red dashed line indecates Chebyshev polynomials of the first kind, a secondary tool to evaluate nonlinear behavior and the small dotted lines are the slope. In a. and b., G’L = slopes of the solid lines and G’M = slopes of the red dotted lines. In c. and d., h’L = slopes of the solid lines and h’M = slopes of the dotted lines (Melito et al., 2012b). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)