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Comparisons of methods for measuring yield stresses in potato puree: effect of temperature and freezing

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Abstract

Seven methods for determining yield stress of concentrated suspensions were applied to fresh and frozen/thawed natural and commercial purees at different temperatures, and results were compared. Since potato puree was consistent with Herschel–Bulkley flow behaviour, yield stress was more reliably determined by extrapolation of the flow curves assuming Herschel–Bulkley model than Bingham and Casson models. Methods for determining yield stress by dynamic rheological tests were tedious and are not always applicable. Given the high correlation between Herschel–Bulkley yield stress and that as determined by Bohlin option ($R^2 = 0.8735$), Bohlin's "Yield stress option" appears to be highly useful for direct measurement of this property in potato puree. Temperature influenced yield stresses more in frozen than in fresh purees, both natural and commercial. At equal temperatures, processing reduced yield stresses in natural puree but increased them in commercial puree, showing that their structures were not affected in the same way.

Keywords: Steady shear; Dynamic rheological test; Flow curve; Yield stress; Freezing; Sample temperature

1. Introduction

Many commercially valuable foods like apple sauce and tomato paste are concentrated dispersions of insoluble matter in aqueous media. Their rheological behaviour, especially yield stress, is important for industrial handling, storage, processing and transport of concentrated suspensions (Rao, 1987). Yield stress means the stress that must be exerted simply to move one fluid layer past another (Charm, 1962), and it plays a role in the coating of solid surfaces. In terms of the strength of the coherent network structure, it is the force per unit area required to achieve breakdown of the structure followed by the cleavage of network bonds or linkages connecting the flow units (Durán & Costell, 1982; Qiu & Rao, 1988).

Several methods have been employed for the determination and comparison of the yield stress of food suspensions, but most magnitudes of yield stress are determined by extrapolation of shear rate-shear stress data according to several flow models such as those of Casson, Herschel–Bulkley and Mizrahi-Berk (Missaire, Qiu, & Rao, 1990; Qiu & Rao, 1988; Rao & Cooley, 1983). Models that account for yield stress are known as viscoplastic models (Bird, Dai, & Yarusso, 1982). The vane method, which is relatively easily to use for direct determination of yield stress, has been employed in several studies on food and non-food suspensions (Qiu & Rao, 1988; Steffe, 1992a; Yoo, Rao, & Steffe, 1995; Yoshimura, Prud'homme, Princen, & Kiss, 1987). The technique of stress relaxation, if properly utilised, can also be very useful for measurement of the yield stress of moderately concentrated solutions (Nguyen & Boger,

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1983). With the availability of automated rheometers, dynamic rheological tests can also be used to determine yield stresses of food and non-food suspensions (Hoffmann & Rauscher, 1993; Qiu & Rao, 1988; Steffe, 1992a, 1992b; Yoo et al., 1995; Yoshimura et al., 1987).

For example, Yoo and Rao (1995) determined yield stresses of tomato concentrates using the vane method, the Casson model and dynamic rheological data. Magnitudes of vane yield stress were higher than using other methods. Missaire et al. (1990) determined yield stresses of 40 model suspensions of apple pulp particles, 13 commercial food suspensions and 11 prepared apple sauce samples by the vane method, Casson model and Bingham method. The latter entails extrapolation of the straight-line portion of shear rate-shear stress data as suggested by Michaels and Bolger (1962). For unstructured apple pulp suspensions, magnitudes of vane yield stress and Casson yield stresses were nearly equal, but for structured commercial and prepared apple sauce samples, magnitudes of vane yield stress were higher than Casson yield stresses. In apple sauce, magnitudes of yield stress determined by the vane method were higher than those obtained by extrapolation of the Herschel–Bulkley or Mizrahi-Berk flow models, but they were nearly equal to the magnitudes of yield stress obtained by the Bingham method (Qiu & Rao, 1988). Durán and Costell (1982) interpreted magnitudes of yield stress by the Bingham method to indicate the extent to which pseudoplastic flow occurs and employed them to compare four apricot puree samples.

Tung, Speers, Britt, Owen, and Wilson (1990), also observed that yield stresses of salad dressings, mayonnaise, and chocolate determined by the vane method were nearly twice those determined using the Casson model. In contrast, Yoshimura et al. (1987) employed three techniques for measuring yield stresses: concentric cylinder, parallel disk and vane methods on model oil-in-water emulsions. They obtained comparable magnitudes, with no one technique consistently giving higher or lower values for the yield stress than any other, and concluded that the model oil-in-water emulsions were probably not structured emulsions.

The concept of structure relates to the organization of a number of similar or dissimilar elements, their binding into a unity and the interrelationships between the individual elements and their grouping (Raeuber & Nikolaus, 1980). Because considerable effort is expended in texturizing foods by various methods such as the application of heat (e.g., cooking of fruits and vegetables for pureed foods), yield stresses as determined by different methods can be used to study the role of structure.

The main objectives of the present study were (1) to determine, compare and correlate the yield stresses of two different potato puree types obtained by seven established methods, and (2) to study the effect of sample temperature and freezing on the magnitudes of the yield stresses. A secondary objective was to seek linear relationships between other flow model parameters.

2. Materials and methods

2.1. Preparation of samples

For preparation of the first type of potato puree, which we have called natural puree, fresh potato tubers (cv. Kennebec), from Galicia (Spain), were selected. Tubers were manually washed, peeled and diced. Natural potato purees were then prepared from 395 g of potatoes, 150 ml of milk, 100 ml of water and 5 g salt using a Thermomix TM 21. The ingredients were cooked for 20 min at 100 °C (blade speed: 100 rpm), and then the amount of liquid evaporated during boiling was determined by weighing the ingredients before and after boiling. This was then compensated by addition of boiling water and the ingredients were again cooked at 100 °C for 5 min. The mash was immediately triturated for 40 s (blade speed: 2000 rpm). The product was immediately homogenised through a stainless steel sieve (diameter 1.5 mm).

For preparation of the second type of potato puree, which we have called commercial puree, aseptically packed commercial dehydrated potato flakes (*Maggi*) were used and mashed potatoes were then prepared according to label instructions and reconstituted from potato flakes, butter, milk, water and salt ingredients. Following preparation, in both puree types, half of each sample was packed in polyethylene plastic, sealed under light vacuum (−0.05 MPa) on a Multivac packing machine and immediately frozen to −80 °C. The packs were then kept for 1 week in a freezer at −80 °C. Rheological measurements of frozen samples were made after samples had been allowed to thaw overnight in a domestic refrigerator.

2.2. Heating of samples

In both fresh and frozen/thawed natural and commercial potato purees, rheological behaviour was evaluated on the samples with temperature ranging from 25 to 65 °C. Temperatures of 25, 35, 45, 55 and 65 °C were reached in the fresh and frozen/thawed samples by placing them in a CB60VS waterbath (−30 to +110 °C) with a constant product weight:water volume ratio of 1:20. Water and product temperatures were monitored by K-type thermocouples (NiCr/NiAl; −200 to +1000 °C) using a hardware and software system developed with the LabWindows/CVI package (National Instruments Spain S.L., Madrid, Spain) for automation of the thermal process control (Rico, Alvarez, & Canet, 1995).