Viscoelastic properties of restructured sweetpotato puree

Oladiran O. Fasina,[1]* William M. Walter Jr,[2] Henry P. Fleming[2] & Nada Simunovic[3]

1 Biosystems Engineering Department, Auburn University, Auburn, AL 36849, USA
2 U.S. Department of Agriculture, Agricultural Research Service, and North Carolina Agricultural Research Service, Department of Food Science, NC State University, Raleigh, NC 27695-7624, USA
3 Department of Food Science, NC State University, Raleigh, NC 27695-7624, USA

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Summary The viscoelastic properties of sweetpotato (SP) puree restructured with alginate were determined and compared with those of non-restructured SP puree. Results from oscillatory shear experiments showed that both purees behaved like a gel with the storage modulus (G') predominant over the loss modulus (G''). The addition of a calcium/alginate complex increased the firmness of SP puree. Gel strength of both restructured and non-restructured puree was highest at room temperature (25 °C).

Keywords Alginate, calcium, gel, loss modulus, storage modulus, viscosity.

Introduction

Sweetpotatoes (SP) are an economical and healthy food crop containing high β-carotene and substantial amounts of ascorbic acid and minerals (USDA, 1984; Woolfe, 1992). Despite this, the crop has been underutilized in the USA, perhaps because of the lack of value-added products that are derived from SP. About 60% of the commodity is therefore sold as fresh roots, which require an inconveniently long time (e.g. 80–90 min at 240 °C) for preparation of the traditional baked product (Woolfe, 1992). This might have contributed to the decline in the individual annual consumption of SP from c. 12 kg in the 1930s to only c. 2.25 kg in 1988 (Lucier, 1993). It may be possible to increase the diversity of products derived from SP by controlling the textural properties.

Calcuim salt and alginate are used in food systems to improve/modify texture, to bind food components, to influence the structure and to improve water binding of formed food products (Means & Schmidt, 1986). Alginate is added to restructured food products because of its ability to form chemically, rather than thermally, induced gels (Imeson, 1990). The gel network is formed by intermolecular association of polyvalent cations, such as calcium, with the polyguluronate sites of the alginate molecule (Sime, 1984). As gels formed by alginate are chemically induced, alginate gelation can take place at room temperature, hence the formation of mechanically and thermally stable gels. Restructuring of SP puree with alginate, tetrasodium pyrophosphate and calcium sulphate appear to be effective methods for controlling textural characteristics of SP products, and utilizing virtually all harvested roots (Truong *et al*., 1995). Model products such as simulated baked SP and a French fry-type SP product could be developed because of the increased firmness of the restructured SP puree (Truong *et al*., 1995).

Dynamic rheometric experiments are often used in food process engineering to evaluate the gel-like behaviour of food materials (Wu *et al*., 1985; Lindahl & Eliasson, 1986; Chen *et al*., 1996; Rao, 1999). A gel-like material shows distinct behaviour that is different from liquid or concentrated solutions when subject to a frequency sweep in a rheometer. With a dilute solution, the loss modulus (G'') is larger than the storage modulus (G') over the

*Correspondent: fax +1 334 844 3530;
e-mail: fasina@eng.auburn.edu

entire frequency range, but approach each other at higher frequencies. For a gel, G' is significantly larger than G'' throughout the frequency range. For a true gel, G' is almost independent of frequency, while higher dependency of both moduli on frequency exists for a weak gel (Steffe, 1996). For a concentrated solution, G'' is larger than G' at lower frequencies until a crossover (or critical) frequency is reached. At frequencies higher than the crossover frequency, G' is higher than G'' (Rao, 1999).

Rao & Cooley (1992) found from dynamic rheometric measurements that tomato pastes behaved more like true gels than weak gels. Champenois *et al.* (1998) investigated the effect of gluten on the viscoelastic properties of starch pastes and gels. These authors found that the addition of gluten to starch pastes and gels weakened the strength of both materials. Dynamic rheological data over a frequency range of 0.63–62.9 s^{-1} showed that 10% corn starch and soybean protein isolate dispersions behaved like a weak gel (Liao *et al.*, 1996). Liao *et al.* (1996) alsofound that the storage modulus of the corn starch dispersion decreased with increase in proportion of protein.

Although gels formed by alginate/calcium complex are thermally stable, Means & Schmidt (1986) showed that when alginate/calcium gel was added to structured meat, the binding force at the raw state was higher than the binding force at the cooked state. Shand *et al.* (1993) however found that the binding force for structured beef rolls was higher when the sample was cooked. It is therefore essential to investigate the effect of temperature on the viscoelastic properties of restructured SP puree as it will have to be baked or fried before consumption.

The aim of this study was to investigate the influence of alginate on the gel-like behaviour of SP puree at different temperatures.

Materials and methods

Restructured puree preparation

Sweetpotato roots from the Beauregard cultivar were used in this study. The puree was prepared using the method described by Truong *et al.* (1995) except that the roots were hand-peeled instead of lye peeling. The peeled roots were cut into slices (0.95 cm thick) and steam-cooked for 20 min. The cooked slices were then pureed using a hammer mill (model D, Fitzpatrick Co., Chicago, IL, USA) fitted with a 0.15 cm screen.

Cooked puree was restructured using the alginate–calcium system by mixing 3 kg of the treated puree with a mixture containing 6.28 g of tetrasodium pyrophosphate and 70 g of sucrose. After thorough mixing, a mixture containing 12.2 g of alginate and 70 g of sucrose was added, and mixing was continued. Finally, 18 g of $CaCl_2 \cdot 2H_2O$ suspended in 70 mL of water was added and the mixing completed. The restructured SP puree was cured overnight at 4 °C and held at −20 °C in a freezer until needed (Truong *et al.*, 1995).

Dynamic rheometric measurements

A Bohlin VOR rheometer (Bohlin Rheologi, Lund, Sweden) was used to obtain dynamic rheometric data on restructured and non-restructured SP purees. Oscillatory shear experiments were conducted on the SP puree samples using a cone-plate system (30 mm diameter, 5.44° cone angle). The rheometer was operated in the frequency sweep mode from 0.20 to 62.75 rad s^{-1} at a strain of 0.005. The choice of frequency range and strain were based on preliminary strain sweep data to determine the limits of the linear viscoelastic range.

Testing of samples was performed at temperatures ranging from 5 to 85 °C. Sample temperature was maintained within ± 0.1 °C of the desired value by means of a circulating water-bath. The control of the equipment and circulating water-bath was achieved by the software provided by the manufacturers of the rheometer.

After applying a sample, a few drops of multipurpose Teflon-based lubricant (Radio Shack, Fort Worth, TX) were placed at the cone's edge to minimize moisture loss. During testing, storage modulus (G') and loss modulus (G'') were recorded as a function of frequency. Testing of samples was performed in duplicate.

Statistical testing

Analysis of variance (SAS, 1996) was used to statistically test the effect of process variables on experimental data. Statistical testing was performed at the 95% confidence interval.

Results and discussion

Linear viscoelastic behaviour of the restructured SP puree was measured by using an amplitude sweep, with the rheometer operating under the controlled strain mode at frequencies of 0.1 and 10 Hz. Figure 1 shows that at both frequencies the linear strain range was constant up to 0.0087. At strains greater than 0.01, the G' and G'' cease to be independent of strain. Higher values of the moduli were obtained at a frequency of 10 Hz, in comparison with 0.1 Hz. Based on the amplitude sweep results, a strain of 0.005 was used for the frequency sweep experiments to ensure the inclusion of the linear viscoelastic range in the determination of the dynamic rheological properties of restructured SP puree.

Figure 2 shows the log–log plot of storage and loss moduli vs. frequency for restructured and non-restructured SP puree samples tested at 25 °C. Similar plots were obtained at other temperatures used in this study (Fig. 3a,b). Statistical testing ($P < 0.05$) indicated that G' values were significantly higher than G''. This implied that solid-like properties (characterized by $G' > G''$) were predominant. In addition, both moduli showed only slight variation with frequency as evident from the low positive values of the slopes of the log–log plot (slope < 0.1). The typical slope value for a gel is c. 0.0371, compared with 0.840 for a concentrated solution (Steffe, 1996). Restructured and non-restructured SP puree, therefore, exhibited weak gel-like properties rather than solution-like properties (Ma & Barbosa-Canovas, 1997) over the range of frequencies studied.

At each temperature tested, the storage modulus (G') and loss modulus (G'') for restructured SP puree were significantly higher ($P < 0.05$) than

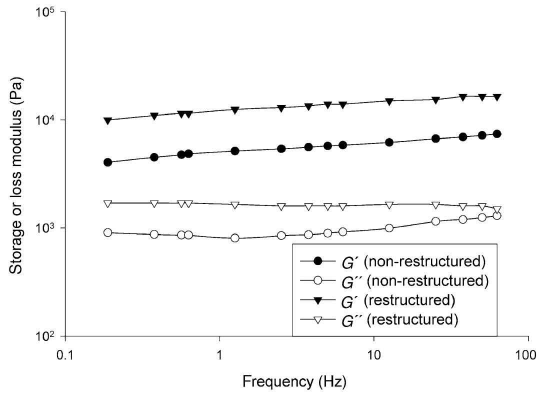

Figure 2 Comparison of storage modulus (G') and loss modulus (G'') for restructured and nonrestructured sweet-potato puree.

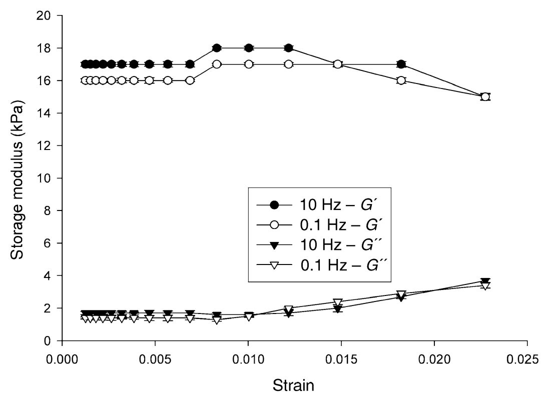

Figure 1 Strain sweep profile of non-restructured sweet-potato puree at frequencies of 0.01 and 10 Hz and temperature of 25 °C.

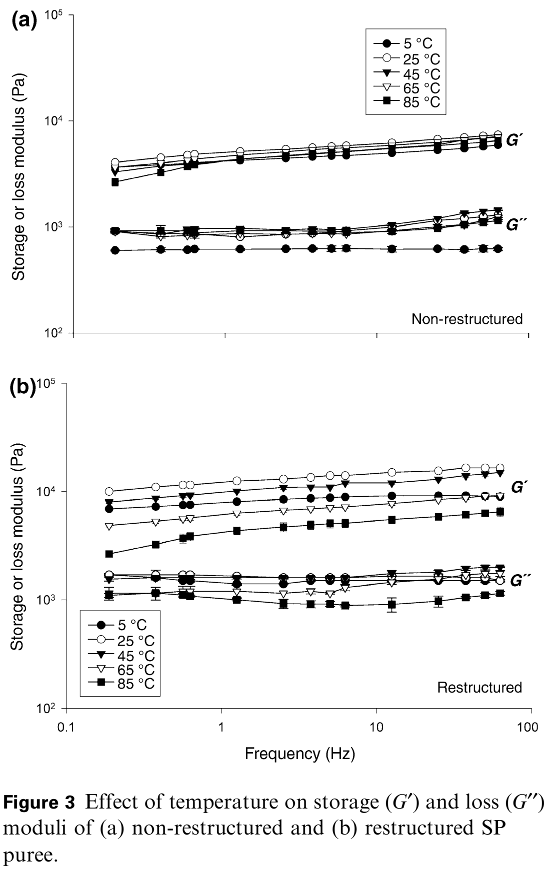

Figure 3 Effect of temperature on storage (G') and loss (G'') moduli of (a) non-restructured and (b) restructured SP puree.

the corresponding values for non-restructured SP puree. This implies that the addition of the calcium–alginate complex enhanced the gel strength and viscoelastic properties of SP puree. Similar finding was obtained by Rodriguez-Hernandez & Tecante (1999) when carrageenan was mixed with gellan. Ma & Barbosa-Canovas (1997) also found that the addition of sodium, calcium or ferric ions to xanthan enhanced gel strength and rigidity.

Although temperature significantly affected ($P < 0.05$) the viscoelastic properties of SP puree, the values of the properties did not show a definite increase or decrease with increase in temperature. Figure 3 shows that for both purees, the maximum storage modulus at any particular frequency was obtained from samples tested at 25 °C. Beyond 25 °C, storage modulus decreased with increase in testing temperature. Similar responses with temperature was obtained by Oakenfull & Scott (1984) for the gelation of high methoxyl pectins (HMP) and Lopes da Silva *et al.* (1995) for HMP/sucrose gelation. The authors attributed the temperature response of the gels to the opposing effects of increasing temperature on hydrogen bonding and hydrophobic interaction (both are responsible for the stability of HMP gels). Hydrogen bonds are weakened by temperature (Joesten & Schaad, 1974), whereas hydrophobic interaction becomes stronger with increasing temperature (Oakenfull & Fenwick, 1977). We believe that this kind of response is possible in gelation systems where more than one type of bonding is involved in the formation of the gels. In alginate gelation, the calcium ion interacts with the carboxyl group and with the electronegative oxygen atoms of the hydroxyl groups of poly-α-L guluronate segments of the alginate molecule.

Conclusions

It can be concluded from this study that SP puree has a gel-like behaviour. The addition of a calcium/alginate complex changed the viscoelastic properties and increased the firmness of SP puree, as evidenced from the higher values of the G′ for restructured SP puree in comparison with non-restructured SP puree. Temperature had significant effects on the dynamic rheological properties of both restructured and non-restructured SP puree.

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