Journal of Food Engineering 102 (2011) 66–76

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Viscoelasticity and microstructure of inulin-enriched mashed potatoes: Influence of freezing and cryoprotectants

M. Dolores Alvarez [a,*], Cristina Fernández [a], M. Teresa Solas [b], Wenceslao Canet [a]

[a] Department of Plant Foods Science and Technology, Instituto del Frío (CSIC), José Antonio Novais 10, 28040 Madrid, Spain
[b] Facultad de Ciencias Biológicas, Universidad Complutense, Ciudad Universitaria s/n, 28040 Madrid, Spain

ARTICLE INFO

Article history:
Received 6 November 2009
Received in revised form 2 August 2010
Accepted 7 August 2010
Available online 12 August 2010

Keywords:
Viscoelasticity
Mashed potatoes
Cryoprotectants
Inulin
Structure
Water-holding capacity
Creaminess

ABSTRACT

The effect of the addition of inulin (0%, 1.5%, 3%, 4.5% and 6%) on viscoelastic properties and microstructure of fresh and frozen/thawed mashed potatoes (FMP and F/TMP, respectively) formulated without and with added cryoprotectants (kappa-carrageenan (κ-C) and xanthan gum (XG)) was investigated. Results showed that inulin concentration was the factor that set the minor difference among most of rheological properties, firmness and overall acceptability (OA) of the samples, whereas addition of κ-C and XG resulted in main differences between samples. Inulin effect on the thickening of the product was limited, which is mainly ascribed to a high heating temperature reached by the product during manufacture process inducing inulin hydrolysis. FMP samples presented more rigid structure than their F/TMP counterparts, although either inulin concentration or processing had much less significant effect on the viscoelasticity of the mashed potatoes containing cryoprotectants, evidencing the ability of this biopolymer blend to impart freeze/thaw stability.

1. Introduction

Mashed potatoes (MP) made from 100% fresh potato tubers may be suitable for freezing as a ready-meal component or as a product in itself such as potato gratin (Alvarez et al., 2005). However, MP based on gelatinised starch undergoes important textural changes as a result of amylose and amylopectin retrogradation in the course of freezing and thawing processes (Eliasson and Kim, 1992), and one strategy to minimize damage from freezing is to incorporate cryoprotectants. Nowadays in the market there are frozen mashed potatoes, and most likely some of these products contain cryoprotectants for optimization of their texture. For instance, addition of XG significantly reduced the appearance of syneresis in MP (Alvarez et al., 2009a) and in white sauces made with potato starches (Arocas et al., 2009).

Estimations indicate that the consumption of functional foods in Europe will tend to increase considerably and that it may reach a quota of nearly 5% of the food and drinks market in the next 10 years (Menrad, 2003). Inulin and its hydrolyzed product (oligofructose) are both recognized as functional food ingredients and are particularly attractive to people pursuing a healthy diet (Tseng and Xiong, 2009). For example, in recent years prebiotic ingredients like inulin have been added to dairy products like milk beverages or yoghurts (Brennan and Tudorica, 2008; González-Tomás et al., 2008; Paseephol et al., 2008), cheese (Hennelly et al., 2006) and dairy desserts (Tárrega and Costell, 2006), and in the food industry inulin is being used as a fat replacer or texture modifier. In particular, long-chain inulin can act as a fat mimetic thanks to its capacity to form microcrystals, which interact with each other to form small aggregates that occlude a great amount of water; this creates a fine and creamy texture that gives a mouthfeel similar to that of fat (Villegas et al., 2007).

Foods can exhibit viscous or elastic behaviour or a combination of the two, which are generally recognized as viscoelastic properties. The method most commonly used to study the viscoelastic property of foods is oscillatory viscometry, which provides more details about the rheological behaviour of foods than conventional rheometric parameters (Ahmed and Ramaswamy, 2006). Strain sweeps have been performed (0.001–500%) using oscillation experiments at a constant frequency of 10 rad s^{-1} to determine the influence of long-chain inulin addition on the linear viscoelastic (LVE) range of low-fat and whole milk set yoghurt (Guggisberg et al., 2009). Higher yield stress values were observed in yoghurt produced with higher inulin additions. Also, long-chain inulin enhances the viscoelastic properties of glucono-δ-lactone-coagulated silken tofu (Tseng and Xiong, 2009), and non-fat yoghurt supplemented with long-chain inulin exhibits rheological behaviour closer to that of control full-fat yoghurt when added at a level of 4–12% solids content (Paseephol et al., 2008). However, addition

* Corresponding author. Tel.: +34 915492300; fax: +34 915493627.
E-mail address: mayoyes@if.csic.es (M.D. Alvarez).

0260-8774/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2010.08.006

Nomenclature

σ_{max}	limit shear stress value defining the linear viscoelastic region (Pa)
α	fluid-like relative angle characterizing the non-linear viscoelastic region
G^*	complex modulus (Pa)
G'	storage or elastic modulus (Pa)
G''	loss or viscous modulus (Pa)
n'	slope of ln–ln plot of G' versus oscillation frequency (ω)
n''	slope of ln–ln plot of G'' versus oscillation frequency (ω)
tan δ	loss tangent angle
ω	oscillation frequency
κ-C	kappa-carrageenan
BE	back extrusion test
XG	xanthan gum
MP	mashed potatoes, in general terms
FMP	fresh mashed potatoes
F/TMP	frozen/thawed mashed potatoes
MPA	mashed potatoes without added cryoprotectants
MPB	mashed potatoes with added cryoprotectants
FMPA	fresh mashed potatoes without added cryoprotectants
F/TMPA	frozen/thawed mashed potatoes without added cryoprotectants
FMPB	fresh mashed potatoes with added cryoprotectants
F/TMPB	frozen/thawed mashed potatoes with added cryoprotectants
LVE	linear viscoelastic
n-LVE	non-linear viscoelastic
E_w	expressible water
TSS	total soluble solids content
OA	overall acceptability
WHC	water-holding capacity

of inulin produces a shift in the viscoelastic behaviour of low-fat yoghurts towards more viscous-like materials (Brennan and Tudorica, 2008).

A previous study showed that the addition of *k*-C and XG to F/TMP at a low concentration is recommended on the basis of OA (Alvarez et al., 2009a). κ-C provided the appropriate texture, while XG imparted creaminess to the product, which is associated with an increase in the amount of XG–water interactions and reduced starch retrogradation. Presently there is a lack of knowledge about the role of fructan-type prebiotics in the texture development of MP-based products. The challenge is to develop F/TMP using inulin for adding functionality to the product at the same time providing better nutrition. With regard to the rheological properties of food products with added inulin, there is little information about the effect of both inulin addition and the possible interactions with other ingredients, like hydrocolloids or starch (Zimeri and Kokini, 2003).

To expand the use of these health-promoting carbohydrates in food application, the aim of this work was to examine the effect of the inulin concentration on viscoelastic properties and microstructure of FMP and F/TMP products formulated without and with added κ-C and XG (MPA and MPB, respectively). The influence of the effects studied on other physical and sensory characteristics of the MP samples was also investigated.

2. Materials and methods

2.1. Materials

The potatoes used were fresh tubers (cv Kennebec) from Aguilar de Campoo (Burgos, Spain). κ-C (GENULACTA carrageenan type LP-60) and XG (Keltrol F [E]) were donated by Premium Ingredients, S.L. (Girona, Spain). Inulin (Orafti®HP, BENEO-Orafti, Tienen, Belgium) was a "long-chain" inulin with a degree of polymerization, DP > 23 and purity of 99.5% (producer's data). From range-finding experiments, the lower and upper levels of inulin to be used were set at 1.5% and 6%, respectively. A sample without inulin was also prepared for each type of MP and processing conditions.

2.2. Preparation of MP samples

Tubers were manually washed, peeled and diced. MP were prepared in ~2000-g batches from 1185 g of potatoes, 450 mL of semi-skimmed in-bottle sterilized milk, 300 mL of water and 15 g of salt (NaCl) using a TM 31 thermal mixer (Vorwerk España, M.S.L., S.C., Madrid, Spain). Inulin (0–6%) was previously dissolved in the 750 mL of water and milk at 35–45 °C for 15 min, agitating with a magnetic stirrer at 600 rpm. MP were prepared without and with added κ-C and XG (MPA and MPB, respectively). In the latter case, hydrocolloids (each at 0.15%) were added to the rest of ingredients in form of a dry powder. The ingredients were cooked for 35 min at 90 °C (blade speed: 40 rpm) (Alvarez et al., 2009a). The mash was ground for 40 s (blade speed: 1200 rpm) and for 20 s (blade speed: 2600 rpm), and then the product was immediately homogenized through a stainless steel sieve (diameter: 1.5 mm). Half of each fresh blend (FMP samples) was analysed immediately, and the other half was frozen and thawed (F/TMP samples). Two repetitions of each composition were prepared in different weeks. Sample composition is shown in Table 1.

2.3. Freezing, thawing and heating procedures

Following preparation, MP samples were placed on flat freezing and microwave thawing trays and then frozen by forced convection with liquid nitrogen vapour in an Instron programmable chamber (model 3119-05, −70/+250 °C) at −60 °C until their thermal centres reached −24 °C. After freezing, the samples were packed in polyethylene plastic bags, sealed under light vacuum (−0.05 MPa) on a Multivac packing machine (Sepp Haggenmüller KG, Wolfertschwenden, Germany), and placed in a domestic freezer for storage at −24 °C. Packed frozen samples were thawed in a Samsung M1712N microwave oven (Samsung Electronics S.A., Madrid, Spain). Samples were heated for 20 min at an output power rating of 600 W. After thawing, the temperature reached at the product thermal centre was measured (+80 ± 5 °C). Samples were brought up to 55 °C by placing them in a Hetofrig CB60VS water-bath (Heto Lab Equipment A/S, Birkerd, Denmark). Sample testing temperature was 55 °C as this is the preferred temperature for consumption of MP (Alvarez et al., 2005).

2.4. Oscillatory rheological measurements

A Bohlin CVR 50 controlled stress rheometer (Bohlin Instruments Ltd., Cirencester, UK) was used to conduct small amplitude oscillatory shear experiments using a plate–plate sensor system with a 2 mm gap (PP40, 40 mm) and a solvent trap to minimize moisture loss during tests. After loading the sample, a waiting period of 5 min was used to allow the sample to recover and reach 55 °C. Temperature control at 55 °C was achieved with a Peltier Plate system (−40 to +180 °C; Bohlin Instruments). In order to determine the LVE region, first stress sweeps were run at constant