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Effect of particle size and temperature on rheological, thermal, and structural properties of pumpkin flour dispersion

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ABSTRACT

Controlling the rheological properties of dispersion has been of great interest in the food processing industry. Effects of particle size and temperature on oscillatory rheology of pumpkin flour dispersion were studied. Fresh pumpkin was freeze-dried, grinded and sieved through selected screens to obtain desired particle size fractions (74–841 μm). Most of the particles are spherical in shape. The glass transition temperature (T_g) and the melting temperature (T_m) of starch–lipid complex varied with particle size which is believed to be due to compositional variations. Rheological measurement of reconstituted particles as a function of temperature (10–90 °C) and concentration (4–10% w/w) indicated a solid-like behavior ($G' > G''$). Sediment volume fraction (ϕ) of isolated particle dispersions indicated a gradual decrease with decrease in particle size, which directly influences the mechanical strength and visco-elasticity of the dispersion. Particle size influenced the mechanical rigidity of pumpkin dispersion markedly whereas the temperature had the least effect. An unexpected increase in G' of finest particle containing dispersion with temperature could be associated with gelatinization of starch and flocculation of particles with broken cell walls. Microscopic observation revealed the presence of a continuous network for the finest particle dispersion, as opposed to discontinuous one for other particle sizes.

1. Introduction

Pumpkins belong to the family Cucurbitaceae and the genus Cucurbita. Pumpkins and squash are available in different shapes and sizes with attractive orange colors around the world. It is a good source of carotenoids with the presence of relatively high contents of provitamin A carotenoids (principally β-carotene, α-carotene, and sometimes β-cryptoxanthin) (Speek et al., 1988; González et al., 2001). Furthermore, pumpkins contain several biologically active components including polysaccharides, proteins and peptides, para-aminobenzoic acid, phenolic compounds and terpenoids and sterols (Kuhlmann et al., 1999). It is mostly considered to have active hypoglycaemic properties and it is reported that fruit pulp has anti-diabetic effects (Adams et al., 2011). Pumpkin flour powder (PFP) with or without sugar showed a significant increase in plasma insulin and reduction in blood glucose (Ju and Chang, 2001). Pumpkin mesocarp tissue has been used as a food matrix for iron supplement, and it is considered as a promising raw material for functional food product development (de Escalada Pla et al., 2009).

Pumpkin is used in various forms (e.g. puree, dry slice, powder) which are commonly used as an ingredient in pies, soups, sauces, stews, breads, instant noodle, and many other preparations as well as a natural coloring agent in pasta and flour mixes. Pumpkin shows a great diversity of texture in the cooked form, ranging from the smooth, pasty, dry, high-starch buttercup types to the stringy, watery, wet, low-starch types (Corrigan et al., 2001). It is difficult to understand whether texture attributes are inherited or attributed to constituents.

Size reduction is an important unit operation where the ratio of surface area to volume of a food material is increased. Size reduction results in a mixture of particles, ranging a broad distribution starting from a larger size to a fine particle whereas sieving separates milled flours on the basis of particle size. The fullest description of a powder is given by its particle-size distribution (Snow et al., 1999). Because of the wide variation in the size and shapes of the particles and related properties in suspensions, it is really difficult to understand the contributing factors that affect the rheology. It is now accepted that the food powder properties are strongly dependent on the chemical composition and the surface properties of the particles (Cuq and Rondet, 2011). Separation of particles in uniform size range could provide uniform functional properties. Furthermore, the interaction of those known particle sizes with other ingredients could provide better understanding

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Nomenclature

List of abbreviations

ASTM	American Society for Testing and Materials
ANOVA	Analysis of variance
DSC	Differential scanning calorimetry
LVR	Linear visco-elastic range
AOAC	Official Methods of Analysis
PF	Pumpkin flour
PFD	Pumpkin flour dispersion
PFP	Pumpkin flour powder
RSM	Response surface methodology
SEM	Scanning electron microscope

List of symbols

ω	angular frequency, Hz
P	bulk density, kg/m^3
η^*	complex viscosity, Pa s
A	constant
G'	elastic modulus, Pa
n	frequency exponent
T_g	glass transition temperature, °C
H_S	height of the sediment, m
S	particle size, μm
η''	imaginary part of complex viscosity
X_i and X_j	independent variables
β_0, β_1; β_{ii}; β_{ij}	response surface coefficients
Y	measured response in RSM
ε	random experimental error
η'	real part of complex viscosity
ϕ	sediment volume fraction
T_m	starch–lipid melting temperature, °C
H_T	total height of the dispersed sample, m
L	tristimulus color value, lightness
a	tristimulus color value, redness
b	tristimulus color value, yellowness
G''	viscous modulus, Pa

of food structure and stability during food formulation, quality control and product development.

Limited reports are available on the particle size dependency on rheological properties of food materials. Kerr et al. (2001) reported significant effects of particle size on the functionality of cowpea flour and reported textural problem with finer particles. Hayashi et al. (1976) obtained a good bread volume using fine fractions of hard red spring wheat flour, whereas coarse fractions were recommended for the cake applications. The viscoelastic behavior of suspensions has also been assessed by particle size distribution and shape as well as the volume fraction of particles (Nakajima and Harrell, 2001; Servais et al., 2002) and the particle–particle interactions (Shah et al., 2003). However, no attempt has been made to study the effect of specified particle range on the food rheology although it has tremendous effect on the food dispersion and even quality control of food suspensions especially soups and beverages.

The specific particle size range and the volume fraction of swollen particles significantly influence the rheology of pumpkin flour dispersion (PFD). The objectives of this research work were to determine the effects of particle size, temperature, concentration, and their interactions (temperature–particle size) on rheological behavior of pumpkin flour (PF) particles dispersion.

2. Materials and methods

2.1. Sample preparation

A single batch of mature fresh pumpkin (*Cucurbita moschata*) samples was purchased from the local market in the state of Kuwait during the winter season of 2012–2013. Samples were washed thoroughly, peeled and cut into small pieces with a sharp knife followed by manual separation of seeds from the pulp; finally pulps were macerated into puree and freeze dried. One set of fresh pureed sample was collected before freeze drying for rheological measurement. For the freeze drying operation, the samples were frozen in a freezer, and later transferred to the freeze-drier (GAMMA 2-16 LSC; Martin Christ GmbH, Osterode am Harz, Germany) for 38 h at a temperature between −47 °C and −50 °C, and a pressure of 0.7 Pa. Dried PF samples were grinded in a laboratory size grinder (Robot Coupe R5, France), and passed through a series of U.S. Standard sieve numbers 20, 30, 50, 100 200 and 230 mesh (Endecotts, London, UK), manually. The fractions obtained from those sieve analysis retained by the sieve were designated as 841 (−20; +30), 595 (−30; +50), 297 (−50; +100), 149 (−100; +200), and 74 (−200; +230) μm. The −ve sign represents pumpkin flour particles passed through the sieve and the retained particles are expressed through +ve sign. Fractionated samples were packed in amber glass bottles and stored at 5 °C till further use.

2.2. Physico-chemical properties

The proximate compositions of the ground PF samples were analyzed according to AOAC methods (AOAC, 2002) for the determination of moisture, ash, and crude fat contents. Protein was calculated as nitrogen content (N) × 5.3. Protein for each particle fraction was estimated by the CHNS analysis based on combustion method (AOAC, 2002). Total soluble solids and pH were measured by a refractrometer (Atago CM-780N-Plus; Bellevue, WA, U.S.A.) and pH-meter (Sension 3, Haach Co, Loveland, Columbia, USA), respectively. The loose bulk density was determined by weighing the mass of the dried powder sample which freely was poured in a 100 ml graduated cylinder and expressed as weight per unit volume (kg/m^3) (ASTM D7481-09). The volume of bulk aggregate material includes the volume of the individual particles and the volume of the voids between the particles.

2.3. Determination of sediment volume fraction

The volume fraction of the PFD of different particle sizes was measured using a simple centrifugation method as described by Hemar et al. (2011) for carrot cell wall particles dispersion with some modification. Simply, 1 g of flour was dispersed in 20 ml deionized water in a graduated centrifuge tube, mixed well in a vortex and kept for 6 h for hydration followed by centrifugation (Beckman GS-6R, USA) at constant centrifugation force (3000g) for 60 min.

After centrifugation, the total height H_T of the sample and the height of the sediment H_S were measured and the effective volume fraction ϕ occupied by the PF particles was expressed as:

$$\phi = \frac{H_S}{H_T} \times 100 \tag{1}$$