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Thermorheological characteristics of chickpea flour slurry as affected by moisture content

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ABSTRACT

Dynamic and thermal properties of chickpea flour (CF) slurry and paste were evaluated to understand CF behavior before incorporating it into other foods. Viscoelastic properties of CF slurry were investigated as a function of flour to water ratio (1:5, 1:4, 1:3, and 1:2), using vane geometry. Heat-induced gelatinization of CF was studied by rheometric measurement under both isothermal and non-isothermal heating processes. Isothermally induced paste behaved like a weak gel. CF gelatinization kinetics were evaluated by a non-isothermal technique as a function of G', and G' vs. time (t) data from the cross-over of G' and G'' up to the G'_{max} value were considered for rate estimation. Zero-order reaction kinetics described CF gelatinization process well, with activation energies ranging between 19.5 ± 0.4 and 22 ± 0.5 kJ mol^{-1}. Differential scanning calorimetry (DSC) analysis revealed that gelatinization enthalpy of CF slurry was significantly affected by the moisture content.

1. Introduction

The interest in legumes and their constituents is growing in many developed countries because of the demand for healthy foods. Among common legumes, chickpea is a legume widely consumed throughout Spain because of its ideal cell wall polysaccharide composition and starch properties (Aguilera et al., 2009). Foods based on this legume are prepared by a wide range of recipes and preparation methods. Various traditional oriental foods are prepared using CF slurry, both at household and industrial levels (Ravi and Bhattacharya, 2004). Product development and the science associated with it are giving rise to increasing demands for quantitative characterization of most of the physical properties of food materials. Rheological properties are among the more important characteristics, particularly for dispersions, where a discontinuous phase is dispersed in a continuous phase, mostly water.

The formation of a gel/paste is one of the principal factors that control the quality of starch-containing foods (Jena and Bhattacharya, 2003). The rheological properties of such a chickpea gel are, on the one hand, important for its processing (e.g., breaking of a gel by stirring, pumping of broken gel, etc.). On the other hand, and more importantly, the rheological properties determine product texture, thereby affecting sensory perception and ultimately the acceptance of a product by the consumer. However, among legumes and legume starches, there is only a small amount of data available on the rheological properties of CF and starches during gel formation. Only a limited number of investigations have indicated the shear-thinning behavior of CF dispersions (Ravi and Bhattacharya, 2004). The gelling ability of CF and the viscous nature of cooked paste are important for the manufacture of CF-based convenience food gels and purees.

Gelatinization – a thermal transition of hydrated starch – remains an important phenomenon for cereal and legume starches (Ahmed and Auras, 2011; Ahmed, 2012). The process causes disruption of the starch granule structure and swelling up to several times the original size. The process occurs in a non-equilibrium state, and thus the reaction kinetics pertaining to gelatinization provide a definite set of parameters (temperature, time, concentration, viscosity, shear rate/oscillation frequency, etc.) for a specific starch (Ahmed et al., 2013). Starch gelatinization has mostly been followed by DSC analysis, where the degree of gelatinization is directly measured from the gelatinization enthalpy (Adebowale and Lawal, 2003; Kaur and Singh, 2005). However, DSC measurement has not been able to detect gelatinization temperature for all the specimens studied, and the endotherm depends on the starch to water ratio and some other factors (Ahmed, 2012).

Rheometric measurement (small amplitude oscillation shear (SAOS) measurement) has advantages over DSC and can successfully detect the gelatinization temperature (Ahmed et al., 2008;

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Nomenclature

Symbols and abbreviations

ANOVA	analysis of variance
CF	chickpea flour
C_0	concentration at zero time, mol L^{-1}
C	concentration at time t, mol L^{-1}
C^*	close packing concentration
DSC	differential scanning calorimetry
dG'	change of elastic modulus, Pa
dG'/dt	derivative of elastic modulus with respect to time, Pa s^{-1}
ΔH_{gel}	gelatinization enthalpy, J g^{-1}
E_a	activation energy, J mol^{-1}
η^*	complex viscosity, Pa s
G'	elastic modulus, Pa
G'_0	intercept of linear regression of power-type relationship of $\ln\omega$ vs. $\ln G'$, Pa $s^{n'}$
G''	viscous modulus, Pa
G''_0	intercept of linear regression of power-type relationship of $\ln\omega$ vs. $\ln G''$, Pa $s^{n''}$
$G'_0 - G''_0$	gel strength, Pa s^n
G^*	complex modulus, Pa
γ	shear strain, dimensionless
γ_{max}	limit value of shear strain, dimensionless
I	gelatinization temperature interval, °C
k_0	frequency factor, dimensionless
LSD	least significant difference
LVE	linear viscoelastic region
n	order of the kinetic reaction
n'	slope of linear regression of power-type relationship of $\ln\omega$ vs. $\ln G'$, dimensionless
n''	slope of linear regression of power-type relationship of $\ln\omega$ vs. $\ln G''$, dimensionless
PHI	peak height index, J g^{-1} °C^{-1}
ω	angular frequency, rad s^{-1}
R	universal gas constant, J mol^{-1} K^{-1}
R^2	determination coefficient, %
RVA	rapid visco-analyzer
SAOS	small amplitude oscillation shear
SD	standard deviation
σ	shear stress, Pa
σ_{max}	limit value of shear stress, Pa
t	time, s
T	absolute temperature, K
t_{gel}	starting gel point time in the rheogram (G'–t), s
T_{gel}	starting gel point temperature in the rheogram (G'–t), °C
$T_{G'max}$	temperature where G' achieves its maximum value in the rheogram (G'–t), °C
T_o	onset gelatinization temperature, °C
T_p	peak gelatinization temperature, °C
T_c	conclusion gelatinization temperature, °C
WHC	water holding capacity, %

Ahmed and Auras, 2011; Ahmed, 2012) in addition to the gel point during non-isothermal heating. According to those authors, the order of reaction and the energy required to achieve critical gel rigidity (activation energy) can be calculated from such thermorheological data. The reaction kinetics in food systems have commonly been studied under isothermal heating conditions. However, the isothermal process has some practical limitations, especially when dealing with samples that are difficult to heat instantaneously to testing temperatures (Ahmed et al., 2008). Especially at higher temperatures, it may take even longer to achieve the target temperature than to hold the material at that temperature to complete the reaction. Some studies have been published on these kinetic approaches under non-isothermal conditions (Ahmed et al., 2008; Ahmed and Auras, 2011; Ahmed, 2012; Yoon et al., 2004), which allow parameter estimation from a single experiment where temperature is varied over the range of interest, and samples are taken at various intervals.

The objective of this work, therefore, was to undertake a comprehensive study of the effect of the flour to water ratio on the dynamic rheological properties of CF slurry and heat-induced paste under either isothermal (at 75 and 90 °C) or non-isothermal (from 30 up to 90 °C) heating conditions, and on thermal properties. Another implicit objective was to evaluate the non-isothermal heating kinetics of CF gelatinization by a rheological approach, with a view to providing information that could contribute to effective utilization of this legume in various food applications.

2. Materials and methods

2.1. Materials

Spanish chickpea (*C. arietinum* cv. Castellano) flour was a commercially available product donated by the Los Pisones flour milling company (Zamora, Spain). CF was supplied packed in polyethylene pouches (500 g) and was stored in watertight containers (10 ± 1 °C and 73 ± 3% relative humidity) until use. Mean values for proximate analysis (g 100 g^{-1}) of CF samples (as analyzed by the AOAC method, 1984) were: moisture, 8.49 ± 0.34, total ash, 2.77 ± 0.24, and crude protein (N × 6.25), 20.64 ± 0.05.

2.2. Sample preparation

CF slurries were prepared at different flour concentrations yielding 1:5, 1:4, 1:3, and 1:2 flour to water ratios. The required amounts of CF and distilled water were placed in a glass 250-mL beaker, hand mixed with a glass rod, and kept for half an hour at room temperature (25 ± 1 °C) for hydration with stirring at 900 rpm. The various concentrations were selected to evaluate changes in rheological properties as influenced by moisture content.

2.3. Rheological measurements

A Bohlin CVR 50 controlled stress rheometer (Bohlin Instruments Ltd., Cirencester, UK) was used to conduct SAOS measurements under isothermal and non-isothermal heating conditions in combination with a four-bladed cruciform vane geometry (diameter = 25 mm and height = 40 mm), rotating inside a 27-mm-diameter serrated cup with serrations 0.5 mm deep, and a solvent trap to minimize moisture loss during tests. The temperature of the sample was controlled internally via a computer using a Bohlin Rheology fluid circulating bath KTB-30 (also from Bohlin Instruments Ltd.). SAOS isothermal measurements were carried out at three selected temperatures (25, 75, and 90 °C). At 25 °C, CF slurry was allowed to rest for 5 min for stress relaxation and temperature equilibration before the actual measurements. Temperatures of paste induction (75 and 90 °C) were selected on the basis of gelatinization temperature ranges of CF slurries as observed from non-isothermal heating. To select appropriate times of paste induction, CF slurries were isothermally heated to 75 and 90 °C and held for 30 min (time sweeps), keeping the periodic shear stress (σ) signal at a constant value (1.23 Pa) within the