Journal of Food Engineering 100 (2010) 357–365

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Rheological, textural, micro-structural and sensory properties of mango jam

Santanu Basu *, U.S. Shivhare

University Institute of Chemical Engineering and Technology, Panjab University, Chandigarh 160014, India

ARTICLE INFO

Article history:
Received 18 November 2009
Received in revised form 23 April 2010
Accepted 24 April 2010
Available online 28 April 2010

Keywords:
Jam
Rheology
Texture
Microstructure
Sensory evaluation
Mango

ABSTRACT

Mango jam behaved as pseudoplastic fluid exhibiting yield stress. The Herschel–Bulkley (HB) model described adequately the steady-state rheological behavior of jam. Temperature dependence of the consistency index followed Arrhenius relationship. Time dependent structural breakdown characteristics of mango jam followed Hahn model. Hardness of mango jam increased with pectin concentration and acidity. Hardness increased up to 60% sugar concentration but decreased with further increase in sugar concentration at all pH and pectin levels. Stickiness, work of shear, and adhesion did not show any systematic trend with pH, pectin, and sugar concentration. The overall acceptability was rated highest for mango jam prepared with 65% sugar, 1% pectin at pH 3.4. Principal component analysis (PCA) revealed that hardness and work of shear are the most relevant among all the characteristics (physicochemical, sensory, textural, rheological, and compositional) studied for mango jam. Microstructure of mango jam was found to be composed of network regions with large pores as well as dense, compact regions with small pores.

1. Introduction

Jam is an intermediate moisture food prepared by boiling fruit pulp with sugar (sucrose), pectin, acid, and other ingredients (preservative, coloring, and flavoring materials) to a reasonably thick consistency, firm enough to hold the fruit tissues in position (Lal et al., 1998; Baker et al., 2005). According to Bureau of Indian Standards (BIS) and Prevention of Food Adulteration (PFA) specifications, jam should contain more than 68.5% total soluble solids (TSS) and at least 45% fruit (A.16.07.287, PFA, 2004). Whereas, the Codex Alimentarius Commission (Standard 79, 1981) specify that the finished jam should contain more than 65% TSS. Sugar constitutes more than 40% of total weight and 80% of total solids in jam (Lal et al., 1998). In addition to its sweetening effect, sugar contributes to soluble solids, an effect that is essential for the physical, chemical, and microbiological stability; provides body and mouthfeel; improves appearance (color and shine); and makes gelation of pectin possible (Hyvönen and Törmä, 1983). The added sugar acts as a dehydrating agent for the pectin molecules, permitting closer contact between the chain molecules (Suutarinen, 2002). Sucrose in jam reduces water activity to below 0.8, thus the spoilage organisms in jam do not survive. It is therefore necessary to incorporate 40–75% sucrose in jam to prevent microbial spoilage. High methoxyl pectin (HM pectin, DE > 50%) is widely used in high sugar jams as gelling agents, mainly due to its characteristic gelation at low pH and high content of soluble solids, and to their natural sources (Lopes da Silva et al., 1992; Thakur et al., 1997). Product development or formulation is an immensely important activity for the fruit jam industry, as it is governed by consumer choices. Product quality is the major determinant of consumer choice. The ingredients affect the jam quality in terms of both subjective (sensory) and objective (textural and rheological) attributes.

For a product like fruit jam, it is important to understand the relationships between the perception of food gel texture and structure (Renard et al., 2006). Variation in ingredients or their concentration levels usually lead to changes in gel structure in jam that are often perceived by consumers through texture or mouthfeel. Texture influences the mouthfeel of a product. Mouthfeel is the sensory experience derived from the sensation in the mouth or on the tongue after ingestion of a food material. The consumer judges the quality (fresh, stale, tender, ripe) when the food produces a physical sensation (hard, soft, crisp, moist, dry) in the mouth (Szczesniak, 1963a,b; Kokini and Cussler, 1987). Understanding the factors that influence the texture of processed food items is essential to food scientists. Sensory analysis in combination with mechanical measurements (textural and rheological) could represent the jam quality more precisely. Rheological properties are useful in determining ingredient functionality in the product development, quality control, and correlation of food texture to sensory attributes (Saravacos, 1970; Kokini and Plutchok, 1987; Dervisi et al., 2001). Rheological behavior of jam have been widely studied (Carbonell et al., 1991a,b; Gabriele et al., 2001; Álvarez et al., 2006). It has been established that the rheological properties of jam are mainly affected by the amount and type of sugar added, proportion and kind of gelling agent used, fruit pulp content, and process temperature. However, optimization of

* Corresponding author. Tel.: +91 172 2534917; fax: +91 172 2779173.
E-mail address: santbasu@gmail.com (S. Basu).

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doi:10.1016/j.jfoodeng.2010.04.022

ingredient composition for jam manufacturing process is rather limited (Abdullah and Cheng, 2001; Gajar and Badrie, 2001; Acosta et al., 2008). Further, no scientific information is available in literature on variation of rheological and textural properties and microstructure of fruit jam with ingredients composition.

Mango jam is highly popular in India. The present work was aimed to investigate the effects of pulp to sugar ratio, pectin concentration, and pH on the rheological, textural, micro-structural, and sensorial properties of mango jam and to optimize the ingredient composition for best quality jam production.

2. Materials and methods

2.1. Jam Manufacturing

Canned mango pulp (*Totapuri* variety) was procured from M/s Nirmal Services, New Delhi. The pH of the pulp and TSS was 3.6 and 14°Brix, respectively. Lal et al. (1998) suggested that a good quality jam can be made using 1% pectin, 40–70% sugar at pulp pH between 2.8 and 3.5. Mango jam was therefore prepared using different concentrations of sugar (50%, 55%, 60%, 65%, and 70%) and pectin (0.8%, 1.0%, and 1.2%), and pH (3.0, 3.2, and 3.4). Sugar was procured from the local market while pectin (degree of esterification (DE) = 75%, methoxyl content = 6%) was procured from SD Fine Chemicals (Mumbai, India). Citric acid, sodium bicarbonate, and sucrose were purchased from Loba Chemie (Mumbai, India).

Mango pulp was weighed using a balance (least count ± 0.1 mg, CP-220, Sartorius, Germany), and TSS (±1°Brix) was measured using a hand refractometer (Erma, Tokyo, Japan). The pH of the pulp was adjusted by addition of 10% (w/v) citric acid or sodium bicarbonate solution and measured using a pH meter (Elico, New Delhi, India). Jams were prepared according to experimental plan reported in Table 1. Desired amount of sugar and pectin (on pulp basis) were added to the pulp and mixture was transferred in an open stainless steel pan. The mix was heated on a gas burner at low flame temperature (190 ± 1 °C) and TSS was monitored during boiling. Pulp–pectin–sugar–acid mix was stirred continuously with a glass-rod during boiling. Heating was stopped when TSS reached 65–66°Brix and the mixture was poured into 100 mL glass beakers and cooled under ambient condition. The beakers were then covered with the ethanol dipped butter paper to prevent microbial growth and stored for 24 h in an incubator (Narang Scientific Works, New Delhi, India) at 30 °C for proper setting of jam to 68.5°Brix. Analytical grade sucrose was used to prepare jam samples for scanning electron microscopic study.

2.2. Rheological measurements

Rheological properties of mango jam were measured using a rheometer (Model MC1, Paar Physica, Germany). Yield stress of the mango jam samples was measured in duplicate by the direct yield measurement program of the MC1 Paar Physica rheometer. Ramp logarithmic profile was used with the shear stress as the set variable, which was chosen between 1 and 120 Pa for mango jam samples, respectively. The measurement duration was 263 s, where the initial interval of data recording was 30 s, which logarithmically decreased to 1 s. These experiments permitted the measurement of yield stress as the point when the shear stress–shear rate curve started showing departure of shear rate from zero. This condition indicated initiation of flow and the corresponding shear stress was considered as the yield stress.

Table 1
Detailed experimental plan of mango jams preparation with sugar.

S. No.	Parameter	Level	Details
1	Mango pulp	–	Base material
2	Sugar	5	50%, 55%, 60%, 65%, and 70%
3	pH	3	3.0, 3.2, and 3.4
4	Pectin	3	0.8%, 1.0%, and 1.2%

The jam sample (approximately 3 mL) was placed in a concentric cylinder arrangement (Z4 probe with cup radius = 7.59 mm, bob radius = 7.0 mm, angle of measuring bob cone, α = 120°). Temperature control system (TEZ-180/MC1) was used to maintain constant temperature of the sample during the measurement. A controlled temperature bath (±0.1 °C) fitted with the circulation pump circulated water through the jacket surrounding the rotor and cup assembly to maintain the desired temperature. Sample was allowed to rest for 5 min for temperature equilibration after it was loaded in the sample cell. This time was found to be sufficient to achieve a maximum temperature variation of ±0.5 °C between the specified- and sample-temperature in each run. All the tests were replicated thrice and average values were used in analysis.

Steady-state rheological behavior of mango jam was studied at 20, 30, 40, 50, and 60 °C. Shear rate was increased linearly from 0.1 to 150 s^{-1}. Steady-state relationship between shear stress–shear rate of food materials is expressed in terms of Herschel–Bulkey model (Eq. (1)).

$$\tau = \tau_o + K\dot{\gamma}^n \tag{1}$$

where, τ is shear stress (Pa), τ_o is yield stress (Pa), $\dot{\gamma}$ is shear rate (s^{-1}), K is consistency index (Pa s^n), and n is flow behavior index (dimensionless) signifying the extent of deviation from Newtonian behavior.Dependence of the flow behavior of fluid foods on temperature can be described by the Arrhenius relationship (Saravacos, 1970; Steffe, 1996):

$$K = A_K \exp(E_K/RT) \tag{2}$$

where, A_K is frequency factor (Pa s^n), E_K represents activation energy (kJ/mol), R is gas law constant (R = 8.314 J/mol K), and T is absolute temperature (K).

2.2.1. Time dependent rheology

Time dependent rheology was studied by subjecting the jam to constant shear rates (10, 50, and 100 s^{-1}). All the experiments were done 5 min after loading of the sample for temperature equilibration. Time dependent rheological properties (shear stress and apparent viscosity) of the mango jam were measured in triplicate at selected temperatures (20, 30, and 40 °C). Equilibrium shear stress values were experimentally determined and then used in time dependent rheological modeling and computation of model parameters. Samples were sheared at a particular shear rate and temperature for 3 h and the corresponding shear stress and apparent viscosity values were considered as the equilibrium shear stress and viscosity values at a given shear rate and temperature.

Time dependent shear stress decay characteristics have been mathematically described by several researchers (Weltman, 1943; Hahn et al., 1959; Figoni and Shoemaker, 1983; Nguyen et al., 1998). To quantify time dependency of mango jam at selected shear rates and temperatures, shear stress and time of shearing data were fitted to the Weltman, Hahn, Figoni and Shoemaker, and structural kinetic models.

2.2.2. Weltman model

Weltman model (1943) is expressed as

$$\tau = A - B \ln t \tag{3}$$

where τ is shear stress (Pa) at any given time of shearing (t). The parameter A represents the initial stress while B is time coefficient of structure breakdown.