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Rheological characteristics of muskmelon (cantaloupe) pulp

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ABSTRACT : The rheological characteristics of musk melon (cantaloupe) pulp was evaluated with a view to determine its flow behaviour, yield stress and applicability of common rheological models. The experimental data on rheological behaviour were analyzed on the basis of four models *viz.*, Ostwald, Casson, Bingham and Herschel-Bulkley (H-B). However, Herschel-Bulkley model showed best fit. Consistency index (K) was found to decrease with increase in temperature. The yield stress value determined by three methods showed in the range of 3.6 to 4.1 Pa. Yield stress calculated from stress-strain plot showed the maximum value. Overall the rheological behaviour of musk melon pulp followed the pseudo plastic with yield stress.

KEY WORDS : Fruit pulp, Rheology, Muskmelon, Flow behaviour, Modelling

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Rheological characteristics of fluid foods are determined for a number of purposes such as quality control, understanding the structure, process engineering applications and correlation with sensory evaluation (Rao, 1986). Considering the importance of rheological measurements flow properties of fruit and vegetable products such as juices, pulps, concentrate, sauces and paste were studied extensively. Rheological characterization of apple sauce (Qiu and Rao, 1988), clarified mango and banana juices (Khalil *et al.*, 1989 and Gunjal *et al.*, 1987) juice concentrates (Mizrahi and Berk, 1970; Vitali and Rao, 1984; Pagan *et al.*, 1989; Singh and Eipson, 2000 and Manohar *et al.*, 1990) pulp, purees and paste (Rao *et al.*, 1974; Lozano and Ibarz, 1994; Rao *et al.*, 1985; Pelegrine *et al.*, 2002 and Ahmed, 2004) are already reported. However, flow behaviour of some of the uncommon product like muskmelon (Cantaloupe) pulp was not reported. One of the objectives to characterize flow behaviour is to measure yield stress. The concept of yield stress in food rheology is useful because of its many applications like designing of food products, sensory assessment and engineering modeling. It is also directly related to the spreadability of fluid foods (Danbert, 1998). Considering its importance numerous techniques such as stress relaxation, vane method, uniaxial compression etc was reported for the determination of yield stress (Steffe, 1992).Frequently yield stress is determined by extrapolation of the shear rate/shear stress curve (Rao and Steffe, 1997) using common flow models (Qiu and Rao, 1988). However, to obtain an yield stress value without ambiguity, it is better to be determined experimentally (Bhattacharya and Bhattacharya, 1996). Several studies were carried out on the muskmelon (Cantaloupe) products such as canned, jams and juices, osmotically and vacuum puff dried, juice concentrate, minimally processed etc. (Kalra *et al.*, 1987; Bindra *et al.*, 1973; Ubaidullaev *et al.*, 1985; Candalaria and Raymundo, 1995; Galeb, 1994; Scalzo *et al.*, 2001 and Sapers *et al.*, 2001).

In all these processing determination of rheological behaviour may play an important role for design and development of equipment for large scale processing. However, there is little information available on the rheological characteristics of muskmelon pulp. Therefore, the present study was undertaken to (1) study the rheological behaviour of muskmelon pulp on the basis of common rheological models, (2) determine yield stress experimentally.

RESEARCH METHODS

Muskmelon of proper maturity and variety was purchased from the local market, washed thoroughly in running tap water, cut into eight segments, inner core collected with stainless steel knife and pulped in a pulper (Raylons, Mumbai, India) fitted with 30 mesh screen. The pulp had a total solid content of 6.5 per cent (5.6 °Brix). The average proximate composition, as determined by AOAC (1980) was: 93.5 per cent moisture, 0.5 per cent protein, 0.2 per cent fat, 0.5 per cent crude fibre and 0.4 per cent ash.

Rheometer :

A controlled stress Rheometer (Model MCR-100, Paar Physica, Physica Messtechnik GmbH, Stuttgart, Germany) with cone and plate measuring device of 50 mm diameter and 1° cone angle was used for rheological measurement with 2.3 software version for data acquisition. The sample and measuring system was maintained at a constant temperature using a water bath/ circulator supplied with the rheometer. All measurements were conducted at 25°C + 0.1°C.

Flow models :

The rheological models that have been used for time independent flow behaviour of a pseudoplastic liquid are Power law, Casson, Bingham or Herschel-Bulkley models.

Power law relationship can be represented by the equation:

$$\sigma = k\ddot{Y}^n \quad .....(1)$$

where, $\ddot{Y}$ is the shear rate (Sec^{-1}), σ is the shear stress (N/m^2), K is consistency index ($N\ sec/m^2$) and n is the flow behaviour index.

Casson, Herschel-Bulkley and Bingham models are represented as equation 2 and 3, respectively (Qiu and Rao, 1988)

$$\sigma^{0.5} = Koc + (Kc)\ddot{Y}^{0.5} \quad ....(2)$$

$$\sigma = \sigma_o + K_H\ddot{Y}^n \quad ....(3)$$

$$\sigma = \sigma_{ob} + K\ \ddot{Y} \quad ....(4)$$

where, K_C, K_H are constants and σ_O is yield stress predicted by the H-B model. In case of Casson model yield stress can be calculated as K_{OC}^2 and for Bingham model σ_{ob} is the yield stress. Flow curves were generated using controlled shear rate (CR) experiments over the range of 5-65°C. Rheological equations (1), (2), (3) and (4) were then fitted to the shear rate and shear stress data. The curve fitting to the model was based on correlation co-efficient (r) and with statistical significance at $p \leq 0.01$.

Yield stress:

Yield stress was determined experimentally by (a) controlled stress experiment (b) stress-strain plot and (c) stress relaxation method as described by Bhattacharya (1999). In the stress relaxation method the technique used by Vitali and Rao (1984) as well as by Bhattacharya and Bhattacharya (1996) was followed. Yield stress was also calculated form the plots corresponding to Casson model , H-B model and Bingham model. The experiment on stress relaxation was carried out at shear rates of 2, 5 and 10 per second. The experimental yield stress value was the separated curve obtained during relaxation period.

In the controlled shear stress experiment the yield stress was noted as the point when the curve moves away steeply from a constant value of the shear stress. The stress-strain relationship was also used to determine the yield stress. The intersection of two linear segments gives the yield stress, as the change of slope indicates the cross over from static to flow.

RESEARCH FINDINGS AND DISCUSSION

The findings of the present study as well as relevant discussion have been presented under following heads :

Rheological behaviour :

Controlled shear rate rheogram of muskmelon pulp at 25°C represented in Fig. 1 which showed that it is a pseudoplastic fluid with yield stress. The rheological behaviour of the pulp when analyzed on the basis of four models *i.e.* Ostwald, Casson, Bingham and Herschel-Bulkley, the H-B model showed the best fit. The corresponding correlation co-efficients were found to be ≥ 0.996, ≥ 0.992, ≥ 0.846 and ≥ 0.999 ($p \leq 0.01$). Flow behaviour index (n) and consistency co-efficient (K) calculated according to H-B model (at 25°C) were 0.28

and 3.25, respectively. Bhattacharya (1999) also found the HB model fitted best in case of mango pulp. However, he reported a flow behaviour index of 0.39. Flow behaviour index of most of the fruit and vegetable products are in the range of 0.20 to 0.70 depending on the total solids and temperature (Steffe and Mohamed, 1986) and muskmelon pulp also showed the same trend. However, consistency co-efficient (3.25) was found to be quite low as compared to most of the fruits and vegetable products. In case of tomato juice concentrate it showed a similar value of 3.16 at 16 °Brix at 32.2°C and Pelegrine *et al.* (2002) reported a K value of 3.63 at 30°C for whole mango pulp. Ahmed (2004) also reported a low value of consistency co-efficient, 1.18 for ginger paste of 11.6 °Brix and at 20°C. It was also observed (Table 1) that consistency index decreased and

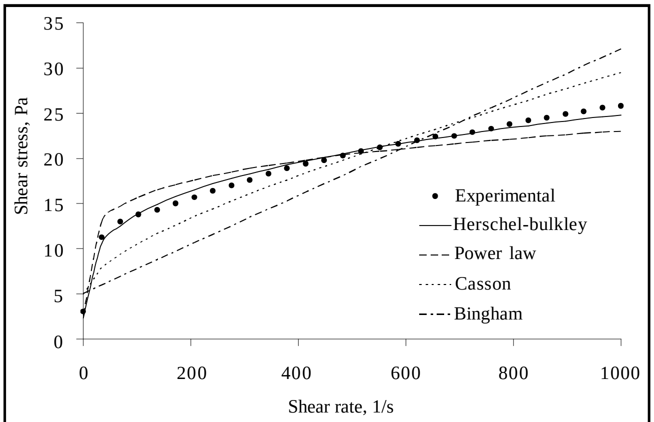

Fig. 1 : Typical controlled shear rate rheogram of muskmelon pulp and the fit of rheological models *i.e.* power law, casson, herchel-bulkley and bingham measured at 25°C

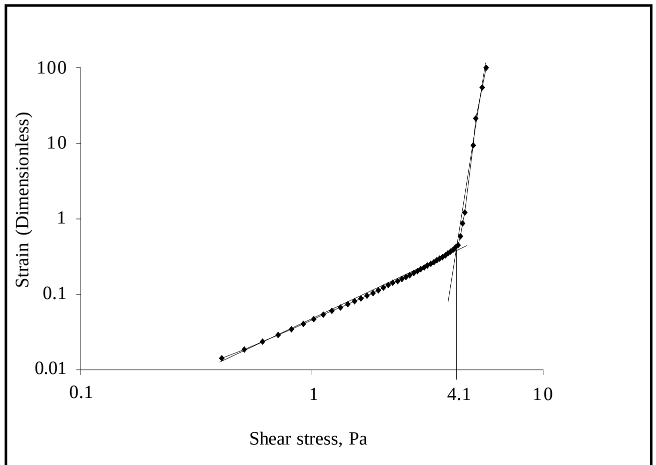

Fig. 3 : Stress- strain plot for the detemination of yield stress of muskmelon pulp (at 25°C)

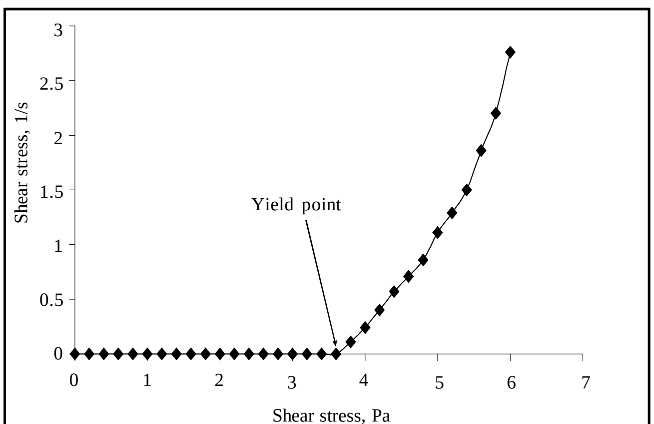

Fig. 2 : Controlled shear stress rheogram of muskmelon pulp at 25°C

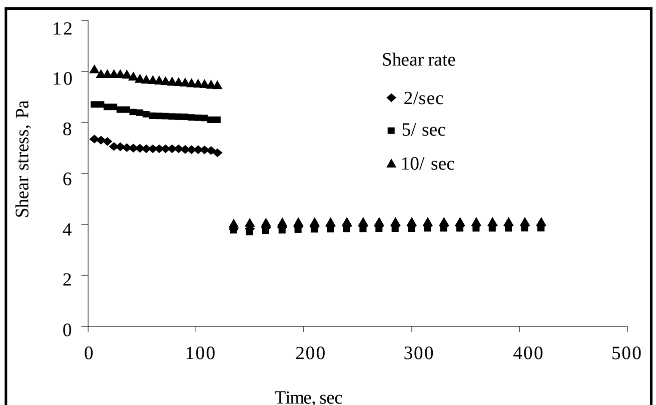

Fig. 4 : Measurement of yield stress of muskmelon pulp by stress relaxation method (at 25°C) at shear rates of 2/sec, 5/sec and 10/sec

Table 1 : Consistency index (K) and flow behaviour index (n) of muskmelon pulp at different temperatures according to H-B model

Temperature (°C)	Consistency index (K), Pa S^n	Flow behaviour index (n), dimensionless	Correlation co-efficient (r)
5	4.065	0.28	0.996
25	3.25	0.28	0.999
45	2.83	0.29	0.981
65	2.34	0.32	0.974

flow behaviour index increased slightly as the temperature was increased from 5 to 65 °C.

Yield stress :

The yield stress values determined by controlled stress (Fig. 2), stress-strain plot (Fig. 3) and stress relaxation (Fig. 4) were found to be in the range of 3.6 to 4.1 Pa (Table 1). Yield stress, calculated from Casson, H-B and Bingham models were found to be 4.9 Pa, 2.87 Pa and 5.07 Pa, respectively. Yield stress calculated from H-B model was almost similar to the yield stress obtained by controlled stress, stress-strain and stress relaxation techniques. According to Bhattacharya and Bhattacharya (1994) and Bhattacharya (1999) experimental methods give more reliable results than the use of rheological models and extrapolation of flow curves. However, yield stress values of most of the fluid foods were reported to be high as compared to the muskmelon pulp obtained in the present study.

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