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RESEARCH PAPER
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Rheological behaviour of three varieties of Indian mango - Langra, Chausa and Dashehari by using power law model

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SUMMARY :

Mango is one of the popular tropical fruits of great commercial importance, due both to its pleasant aroma and flavour and its nutritional value, with high caloric, vitamins and mineral salts contents. To handling these products in the food industry the pulp is submitted to a complete industrialization process. Among the many factors influencing the rheological behaviour of fruit pulps, the measuring systems' geometry is one of the most important, having great influence on rheological parameters definition that describe the fruit pulps, because these materials are non-newtonians. Rheological properties of mango pulp from three North Indian varieties (Chausa, Dashehari and Langra) were investigated for their consistency constant (K), flow behaviour index (n) and yield stress (C) using a Brookfield synchrolectric rotary viscometer (LVT model). The power law model was used to describe the flow behaviour of the mango pulp samples. The magnitude of consistency constant was found to be 25.92, 38.30 and 49.82 (dynes sec^n/ cm^2), respectively. The flow behaviour index and yield stress were found to be 0.345, 0.323 and 0.288 and 79.30, 84.94 and 193.86 (dynes/cm^2), respectively.

KEY WORDS : Mango, Physico-chemical properties, Rheology, Consistency constant, Flow behaviour index, Yield stress

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Of the many epicurean pleasures associated with India, the one that is probably relished the most is the mango. *Mangifera indica* L. is one of the most versatile, widely grown fruits in India which is processed into jams, jellies, chips etc and also consumed as a delicious dessert in Indian households. It is rich in Vitamin A and C, also contains 10-20 per cent sugar, small amounts of proteins, fats, fibres, iron, calcium, magnesium, phosphorus and other nutrients (Hamdard *et al.,* 2004). Indian mangoes come in many shapes, sizes and colours. Its production during 2010-2011 was 2,297,000 metric tonnes which increased to about 18,02,000 metric tonnes during 2013-2014 (Handbook Govt. of India, 2014). The raw fruit is used for preparing pickles, chutneys (spices or otherwise flavoured paste in fresh or preserved form) and fruit drinks. Rheological measurements are very essential and relevant in the food industry as a tool for physical characterization of raw material prior to processing (Tabilo-Munizaga and Barbosa-Cánovas, 2005).

Rheology deals with the flow and deformation of substances on application of an external force. The rheological properties of fluid foods are required for designing and modeling purposes. Furthermore, rheology is critically important for products like fruit pulps, in which the rheological parameters are considered as an indicator of product quality. In processes involving fluid flow, such as pumping, extraction or filtration, the calculations require knowledge of the rheological data and the rheology of the product, in order to analyze the flow conditions of various food processes. The knowledge of the rheological parameters is important in industrial applications not only to determine the energy consumption required to pump a highly viscous fruit pulp, but also to solve problems with air incorporation, which causes difficulties in the pumping operation and with undesirable reactions such as oxidation and contamination (Haminiuk *et al.,* 2006). Fruit pulps are generally non-newtonian fluids in which the apparent viscosity decreases with increasing shear rate and, therefore, they exhibit a shear-thinning behaviour (Steffe, 1996). Several models have been used to characterize the flow behaviour of fruit pulps, amongst which the most used are the Power Law, Casson, Bingham, Herschel-Bulkley and Mizrahi-Berk models. The consistency of non-newtonian fluids can be expressed by the power law equation.

$$^{2} = \mathbf{K}\ (¥)^{n} + \mathbf{C} \qquad \text{......(1)}$$

where,

τ = Shear stress (Pa)

γ = Shear rate (s–1)

K = Consistency co-efficient (dynes sec^n/ cm^2)

n = Flow behaviour index (dimensionless)

C = Yield stress (dynes/ cm^2)

Yield stress is also an important property of many foods whose determination requires considerable care (Vitali and Rao, 1997). In one method, known as relaxation method, determination using rotational viscometers is done by recording the shear stress level at a low rpm at which stress relaxation occurs on reducing the rpm to zero (Rao *et al.,* 1984). Yield stress measurement offers a principle alternative in determining the flow behaviour of frozen products. This parameter can be strongly correlated to body, texture and scoopability of numerous products (Briggs *et al.,* 1966).

In this study, Power law has been used to describe the flow behaviour of the mango pulp samples. The reason that this law has been used during study is its applicability over the shear rate range: 101 –104 s-1 that can be obtained with many commercial viscometers (Rao, 2014). Often, the magnitudes of the consistency and the flow behavior indexes of a food sample depend on the specific shear rate range being used so that when comparing the properties of different samples, an attempt could be made to determine them over a specific range of shear rates (Rao, 2014). Usually, the power law is used to indicate pseudoplasticity due to dissolved solids, through the fluid behavior index *n*. A study on the rheological behavior of mango pulp suggested that the pulp presented pseudoplastic behavior, and the suspended solids had great influence on the consistency index (Pelegrine *et al.,* 2002).

Several works are available on assessing the rheology of different fluid food products including mango concentrates (Haminiuk *et al.,* 2006; Barbana and El-Omri, 2012), fruit purees and juices (Sobowale *et al.,* 2012; Jiménez-Sánchez *et al.,* 2015) and concentrated milk (Vélez-Ruiz and Barbosa-Cánovas, 1998). Flow characteristics of pulp, juice and nectar of 'Baneshan' and 'Neelum' mangoes were studied by Gunjal and Waghmare (1987). The consistency co-efficient values were found to be considerably lower for pulp, juice, and nectar of 'Baneshan' than those of 'Neelum' and the consistency co-efficient decreased with increase in temperature, while there was no appreciable effect on the values of flow behaviour index (Ravani and Joshi, 2013). A study on flow dynamic rheology of pressure treated (100-400 MPa/20°C/15 min and 30 min) mango pulps obtained from two different varieties (Alphonso and Chausa) was carried out. For Fresh Chausa pulp, flow behaviour index (n) decreased with applied pressure and ranged between 0.25 and 0.34 and the consistancy constant increased significantly with pressure treatment (Ahmed *et al.,* 2012). Another study observed the effect of concentration and temperature on the rheological behaviour of clarified mango juice concentrates and it was concluded that consistency co-efficient increased with concentration and decreased with temperature. The flow behaviour index decreased with concentration and generally increased with temperature beyond 40°C (Iboyaima and Eipeson, 2002).

Presently, India harbours more than 1000 mango varieties in different diversity regions and represents the biggest mango germplasm in the world (Singh *et al.*, 2012). The three varieties of mango *i.e.* Chausa, Dashehari and Langra are very commonly found and consumed in all parts of the country and their manufacturing into products, such as juices, nectars, ice creams and jellies, utilize its pulp which is used in the unit operations, such as pumping, mixing and separation processes. For such industrial processes to be technically and economically feasible, it is important to have the knowledge of their physico-chemical properties, of which rheological behavior is one of the most important (Pelegrine *et al.*, 2002). Thus, this work focusses on investigating the rheological properties of mango pulp from three North Indian varieties using the Power law model.

EXPERIMENTAL METHODS

Sample preparation :

The mango fruit (*Mangifera indica* L.) used in this work was obtained from Horticulture Research Centre, Pattharchatta, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. The fruits were chosen based on their skin colour, appearance and ripeness (determined from the ratio of °Brix/ Titratable acidity). Because every fruit liquid product is composed of solid particles dispersed in an aqueous phase, its rheological behaviour will be influenced by the concentration, chemical composition, size, shape and arrangement of these particles in the dispersed phase (Pelegrine *et al.*, 2002). The fruits (20 kg) were processed in a pulper (Narang Co., New Delhi) with a 0.5 mm screen. This mesh was chosen in order to achieve maximum yield in the pulp extraction, according to industrial practice, producing a homogeneous pulp. The pulp was packed in plastic air tight containers (10 kg) to reduce contact with the air and then quickly deep-frozen and stored at – 20 °C, to avoid the formation of large ice crystals on the surface and damage to the cell structures, and also to inhibit enzyme action. The packed and frozen material was preserved for a period of 2 months. Before analysis, the samples were thawed at room temperature (25 °C).

Physico-chemical measurements :

Ripe mangoes (Chausa, Langra and Dashehari) were weighed and the pulp, stone and peel percentages were calculated from each variety. Their colours and respective tastes were assessed by a panel of judges. The experiment was performed in triplicates. Three mangoes from each variety were chosen randomly and analysed for TSS, Acidity, Ascorbic acid, Reducing sugars, Non-reducing sugars and Total sugars. TSS was found using hand refractometer (0-32 ^{0}Brix). Reducing, non-reducing and total sugars were calculated by standard AOAC methods (2002). The acidity of the three pulp samples was determined by alkali-titration method and expressed in per cent. Ascorbic acid content was found using AOAC official method (2010).

Rheological measurements :

The Rheological measurements were carried out of using a Brookfield Synchrolectric Rotary Viscometer (LVT Model) (Brookfield Engineering Laboratories, Stoughton, MA, USA) equipped with spindle (seven numbers). The properties of spindle bob, length and diameter were measured by vernier calipers and thermocouple based Data scanner was used for monitoring the temperature of the product while recording the observations. The experiments were repeated twice, at least, always using new sample. All the Graphs were plotted and observations calculated using ORIGINLAB61 software v6.1052 OriginLab Corporation, Northampton, USA.

EXPERIMENTAL FINDINGS AND ANALYSIS

Brookfield synchrolectric viscometer is widely used for determining consistency constants as it can handle many fluids that cannot be treated with other viscometers as the maximum shear rate is normally less than 100 (1/sec) (Ranganna, 1968). The values for the physical measurements for the spindle length, diameter and end effect correction are presented in Table 1. The drag end of the cylinder has to be corrected for the calibration of the spindle (bob) for the end effect. It was calculated by varying the heights to which the spindle was dipped in the pulp (Table 2). The torque *vs* depth of immersion was plotted on XY scale and the linear fit was extrapolated (Fig. 1, 6 and 11) to find the intercept on the negative portion of the X axis. The corrected length of the spindle

(L) is found from the expression:

$$L = h + h_0 \qquad ......(2)$$

where h= Actual length and h_0 = Corrected length.

Torque was calculated at different speeds corresponding to the dial reading observed on the instrument by the use of the formula.

A = Dial reading × Torque for full scale in dynes cm/ Full scale reading on the dial.

√A/L and √N was calculated (Table 4) and plotted on an XY scale. Intercept for Chausa, Langra and Dashehari (Fig. 2, 7 and 12) was determined by extrapolation of the linear fit. Yield stress (C) was calculated by the equation (Charm, 1962).

C = $(A/L)_0$ (1/2®R_1^2) ....(3)

$$N \text{ vs } \left(\frac{A}{2\pi L R^2 C} - 1\right)$$ was plotted on a log-log scale and the slope (Y/X) was calculated (Fig. 3, 8 and 13).

Flow behaviour index (n) was then calculated by the slope which is equal to (1/n). Different R values were assumed and at any N value and the corresponding A value was substituted in the following equation.

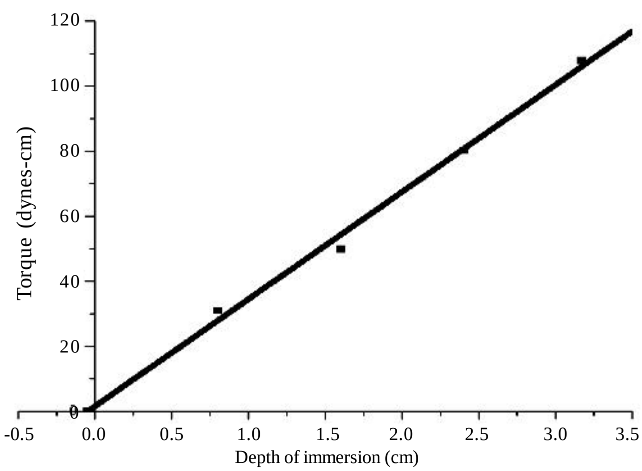

Fig. 1 : Determination of end effect (cv. CHAUSA) from the data found by immersing the spindle to various depths

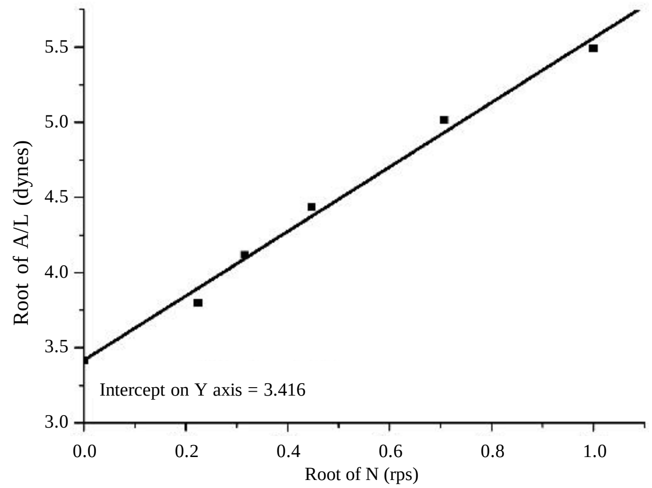

Fig. 2 : A/L vs N for determining (A/L) and yield stress C for (cv. CHAUSA)

Table 1 : Determination of rheological properties *viz.*, consistency constants, K, η and C of north Indian varieties of mango pulp (Chausa, Langra and Dashehari) using Brookfield Viscometer (LVT)

Variety	Chausa	Langra	Dashehari
Spindle	Number 4	Number 4	Number 4
Diameter	0.306cm	0.306cm	0.306cm
Radius of spindle	0.153cm	0.153cm	0.153cm
Length of the spindle upto mark	3.17cm	3.17cm	3.17cm
End effect correction required	0.047	0.201	0.363
Corrected length of the spindle (L)	3.217	3.371	3.533
Torque on full scale	673.7 dynes cm	673.7 dynes cm	673.7 dynes cm
Temperature of the product	25°C	25°C	25°C

Table 2 : Effect of varying depth of immersion of spindle in mango pulp on scale reading (at 30 rpm)

Depth of immersion (cm)	Scale reading			Torque (Dyne cm)		
	Chausa	Langra	Dashehari	Chausa	Langra	Dashehari
0.2	-	2.7	2.9	-	18.190	19.537
0.8	4.6	5.3	4.9	30.990	35.706	33.011
1.6	7.4	8.2	7.18	49.854	55.243	48.372
2.4	11.9	14.9	10.6	80.170	100.381	71.412
3.17	16	18	15.5	107.792	121.266	104.424

$$\left(\frac{\mathbf{A}}{\mathbf{2\pi LR^2C}}-\mathbf{1}\right)^{\mathbf{1/n}}\left(\frac{\mathbf{1}}{\mathbf{R}}\right) \qquad ....(4)$$

The assumed R values were plotted *vs* the Eq. 3 and Graphical integration of the equation was used to calculate the area under the peak (Fig. 4, 9 and 14). The assumed R values and calculated values for graphical integration are presented in Table 5.

Consistency constant (K) was calculated by the following equation

$$\mathbf{K}=\mathbf{C}\left(\frac{\mathbf{area}}{\mathbf{2\pi N}}\right)^2 \qquad .....(5)$$

A/L vs. N on a log-log paper was plotted and slope was determined, the value of which was substituted in the following equation to calculate the consistency constant without considering the yield stress.

$$\mathbf{K}=\left(\frac{\mathbf{n}}{\mathbf{4\pi N}}\right)^n\left(\frac{\mathbf{A}}{\mathbf{2\pi R^2L}}\right) \qquad .....(6)$$

Shear rate was calculated and the value was

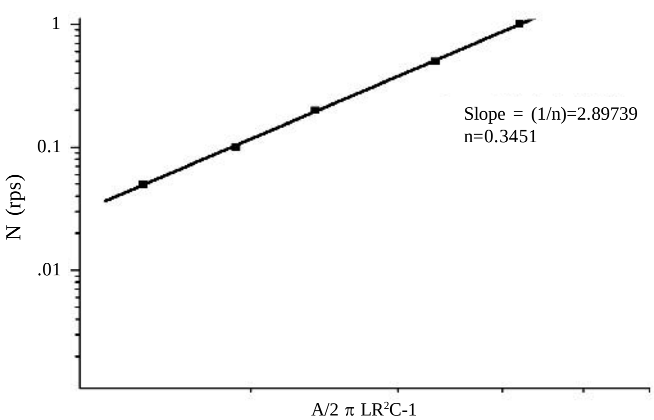

Fig. 3 : Plot of N vs A/2 ® LR^{2}C-1 for mango pulp (cv. CHAUSA) at 25^0 using Brook field LVT viscometry by spindle number 4

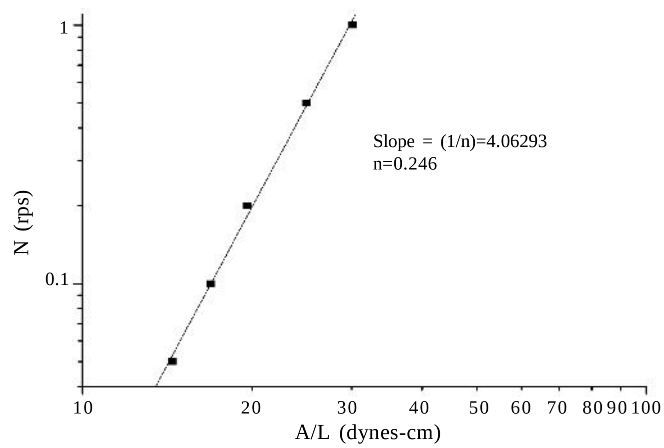

Fig. 5 : Log rotational speed (N) vs log A/L of mango pulp (cv. CHAUSA) detrermined in Brookfield viscometer with spindle number 4

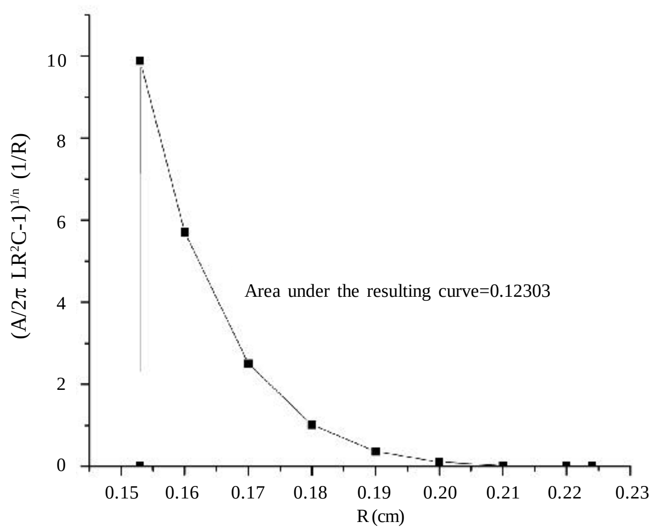

Fig. 4 : Graphical integration of equation for (cv. CHAUSA)

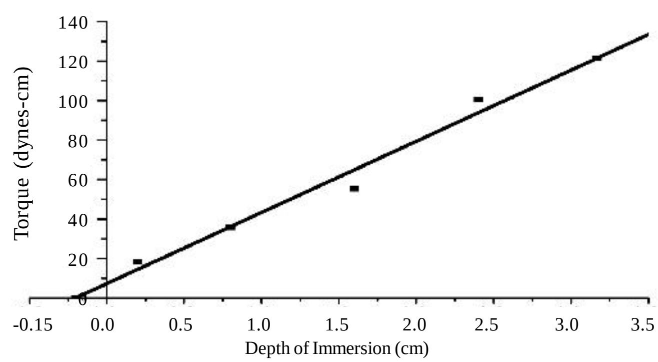

Fig. 6 : Determination of end effect (langra variety) from the data found by immersing the spindle to various depths

Table 3 : Physical characteristics of the three mango pulp samples (average values)

Variety	Taste	Colour	Fruit weight (g)	Peel (%)	Stone (%)	Pulp(%)
Chausa	Very sweet	Light yellow	246.0	13.1	13.6	70.3
Langra	Very sweet	Green	237.42	18.92	16.85	64.23
Dashehari	Very sweet	Yellow	204.0	14.4	20.4	65.1

substituted in the following equation to calculate apparent viscosity.

$$\eta_{app} = \left(\frac{4\pi N}{n}\right)$$

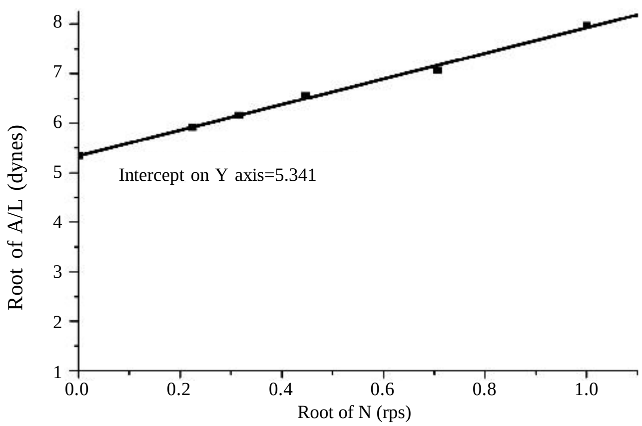

Fig. 7 : A/L vs N for determining (A/L) and yield stress C for (cv. LANGRA)

Values for the consistency constant for all the three mango pulp samples were 25.92, 38.30 and 49.82 (dynes sec^n/ cm^2). The magnitudes of flow behaviour index and yield stress were 0.345, 0.323 and 0.288 and 79.30, 84.94

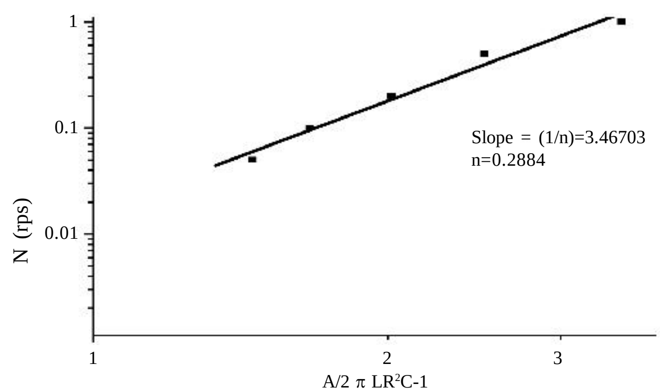

Fig. 8 : Plot of N vs A/2 ® LR^{2}C-1 for mango pulp (cv. LANGRA) at 25^0 using Brookfield LVT viscometer by spindle number 4

Table 4 : Experimental observation and calculated values used in equation 4

Speed (RPM)	3	6	12	30	60
Speed (RPS)	0.05	0.1	0.2	0.5	1
Dial reading with pulp					
Chausa	6.9	8.1	9.4	12	14.4
Langra	17.5	19	21.5	25	31.8
Dashehari	9.8	11.1	12.8	16	20.5
Root of rps	0.223	0.316	0.447	0.707	1
Torque					
Chausa	46.485	54.570	63.328	80.844	97.013
Langra	117.898	128.003	144.846	168.425	214.237
Dashehari	66.023	74.781	86.234	107.792	138.109
Torque/ length of spindle					
Chausa	14.448	16.961	19.683	25.127	30.153
Langra	34.974	37.972	42.968	49.963	63.553
Dashehari	18.687	21.166	24.408	30.510	39.091
Root of A/L					
Chausa	3.801	4.118	4.437	5.013	5.491
Langra	5.914	6.162	6.555	7.068	7.972
Dashehari	4.323	4.601	4.940	5.524	6.252
A/2 π LR^{2}C					
Chausa	2.479	2.910	3.377	4.311	5.173
Langra	2.454	2.665	3.015	3.506	4.460
Dashehari	2.993	3.390	3.909	4.886	6.261
A/2 π LR^{2}C-1					
Chausa	2.993	3.390	3.909	4.886	6.261
Langra	2.454	2.665	3.015	3.506	4.460
Dashehari	1.993	2.390	2.909	3.886	5.261

and 193.86 respectively (Table 6). The apparent viscosity as a function of shear rate was calculated for all the pulp samples and it is evident from Table 6 that as the °Brix varied from the l9 to 21 in the three varieties the apparent viscosity decreased with the increase in the concentration. Similar inferences were also reported that suspended particles presence had great influence on the consistency index in mango pulps indicating that the particles are greatly responsible for viscosity of these pulp (Pelegrine *et al.*, 2002). From Table 6, it is observed that Langra mango had the highest values for consistency constant (49.82) followed by Dashehari (38.30) and Chausa (25.92). Similarly, Langra mango was found to have the highest value for flow index (3.099) followed by Chausa (0.345) and Dashehari (0.325). The values for yield stress was highest for Langra mango (193.869) followed by Dashehari (84.946) and Chausa (79.305). On the basis

Table 5 : Assumed R values and calculated values for graphical integration of equation

R (cm)	$\left(\frac{A}{2\pi LR^{2}C}-1\right)^{1/n}\left(\frac{1}{R}\right)$
For Chausa	
0.153	9.8808180
0.160	5.7053110
0.170	2.4989470
0.180	1.0129430
0.190	0.3602510
0.200	0.1011000
0.210	0.0170050
0.220	0.0004490
0.224	0.0000008
For Langra	
0.153	2.8561160
0.160	1.4334516
0.170	0.4720935
0.180	0.1190471
0.190	0.0161565
0.200	0.0001141
0.201	0.0000250
For Dashehari	
0.153	20.2739713
0.160	11.9322911
0.170	5.4764426
0.180	2.4086333
0.190	0.9880259
0.200	0.3618710
0.210	0.1091805
0.220	0.0226111
0.230	0.0017460
0.238	0.0000018

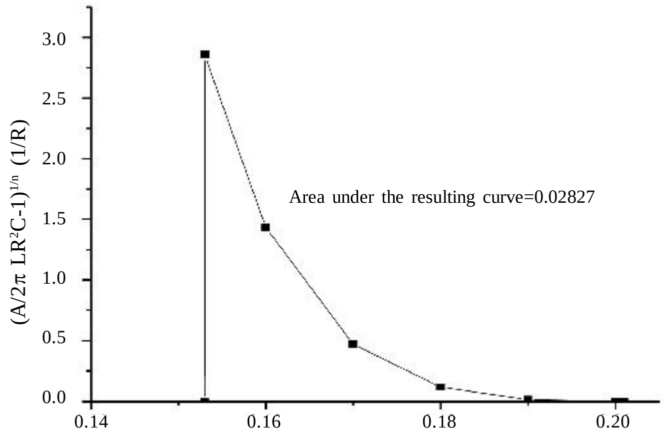

Fig. 9 : Graphical integration of equation for (cv. LANGRA)

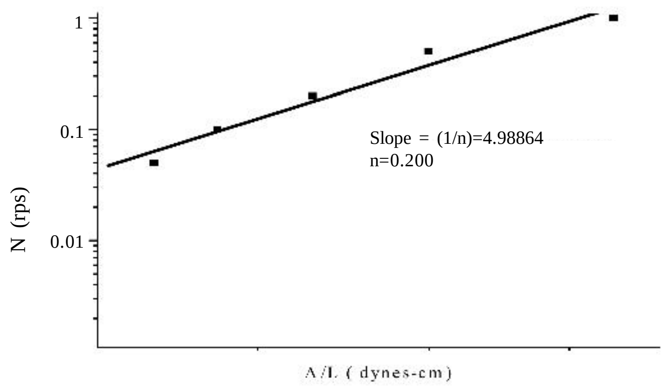

Fig. 10 : Log rotational speed (N) vs log A/L of mango pulp (cv. LANGRA) detrermined in Brookfield viscometer with spindle number 4

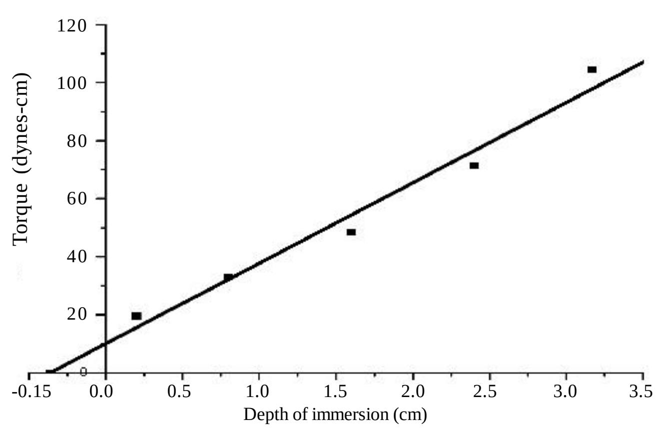

Fig. 11 : Determination of end effect (cv. DASHEHARI) from the data found by immersing the spindle to various depths

of above results, the speed of processing machines can be operated.

As observed the physical attributes (Table 3), Chausa had the highest fruit weight (246.0g/fruit). The pulp content in the three samples ranged between 60-75%. The maximum pulp percentage was found to be in Chausa (70.3%) followed by Dashehari (65.1%) and Langra (64.23%). The peel percentage varied, lowest

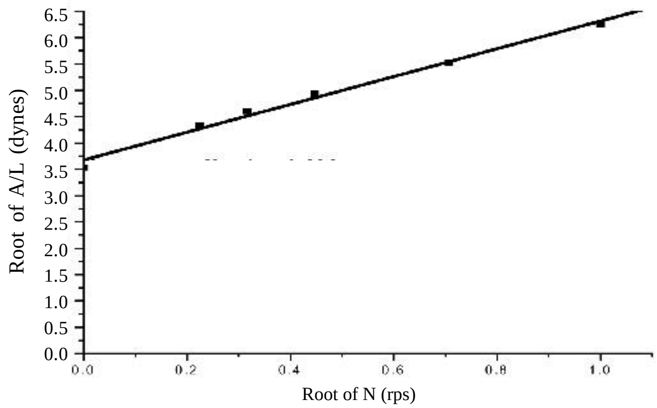

Fig. 12 : A/L vs N for determining (A/L) and yield stress C for (cv. DASHEHARI)

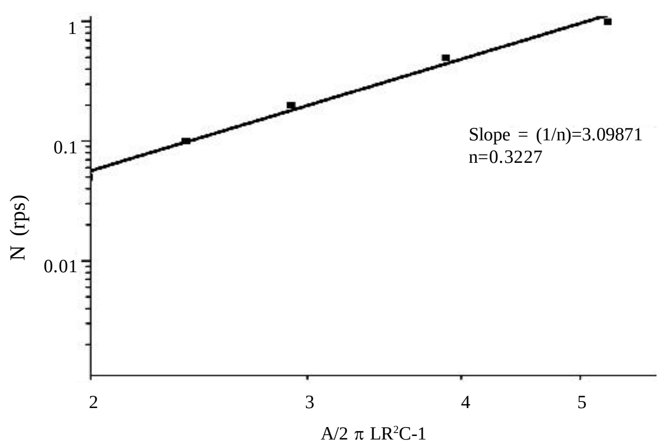

Fig. 13 : Yield stress log-log scale and the slope (Y/X)

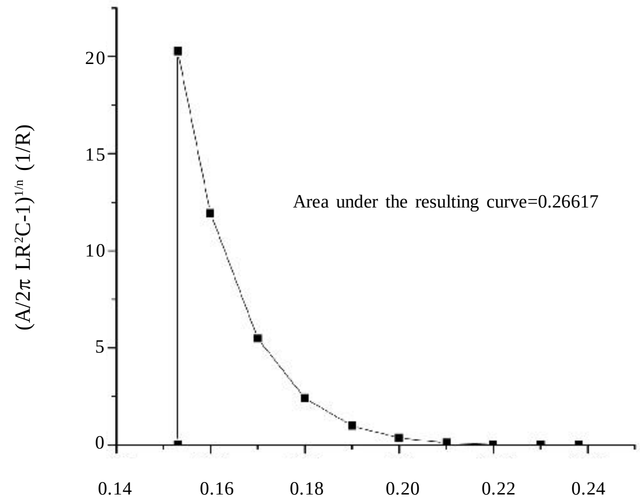

Fig. 14 : Graphical integration of equation for (cv. DASHEHARI)

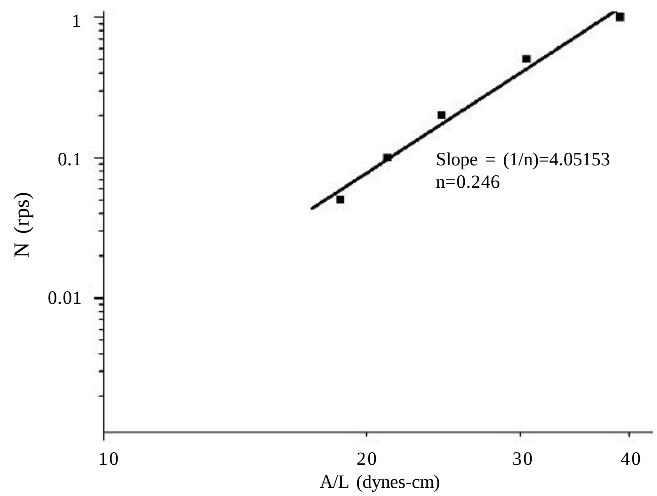

Fig. 15 : Log rotational speed (N) vs log A/L of mango pulp (Dashehari) determined in Brookfield viscometer with spindle number 4

Table 6 : Values of Rheological parameters determined for three mango pulp samples

Varieties	°Brix	K	n	C	n (without considering yield stress)	K without considering yield stress	Shear rate	Apparent viscosity
Chausa	21	25.92	0.345	79.305	0.246	77.21	5.11	2256.96
Dashehari	20	38.30	0.323	84.946	0.247	96.29	5.09	2827.63
Langra	18.5	49.82	3.099	193.869	0.200	178.76	6.27	4115.82

Table 7 : Chemical characteristics of three mango pulp samples (Average values)

Variety	TSS(%)	Acidity (%)	Ascorbic acid (mg/100g)	Reducing sugars(%)	Non-reducing sugars (%)	Total sugars (%)
Chausa	21.75	0.19	16.50	5.95	10.5	16.45
Dashehari	20.75	0.25	19.75	5.10	10.25	15.35
Langra	18.5	0.38	118.7	3.67	10.73	14.40

being in Chausa and highest for Langra mango. The stone percentage was found to be lowest in Chausa (13.6%) and maximum in Dashehari (20.4%). As observed the biochemical properties (Table 7), the highest content of TSS (21.75%) and acidity (0.38) was found to be in Chausa. Maximum amount of total sugars were observed in Chausa (16.45%) followed by Dashehari (15.35%) and Langra (14.40%).

Conclusion :

Three North Indian varieties (Chausa, Dashehari and Langra) were selected and pulp samples from these varieties were investigated for their rheological properties. All the pulp samples showed a non-newtonian behaviour. Power law Equations described very well the consistency constant and apparent viscosity at selected shear rates. These results could be used to model heat and mass transfer during pumping of the pulp during concentration or drying process in various food industries using these pulp samples as raw material. It is important to emphasize that if these properties were not adequately determined, this could result in under-processing or an incorrect calculation of equipments dimensions.

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LITERATURE CITED

Ahmed, J., Lobo, M.G. and Ozadali, F. (2012). Postharvest physiology and storage. In: *Tropical and subtropical fruits: postharvest physiology, processing and packaging* (Ed: Siddiq M.) John Wiley & Sons., Inc. pp. 17-34.

A.O.A.C. (2002). *Official methods of analysis.* 14th Edn., Association of Official Agricultural Chemists, Washington, DC.

A.O.A.C. (2010). *Official method of analysis*, 967.21. Ascorbic acid in Vitamin preparation and juices. Association of Official Agricultural Chemists, Washington, D.C., U.S.A.

Barbana, C. and El-Omri, A. (2012). Viscometric behavior of reconstituted tomato concentrate. *Food Bioprocess Technol.*, **5** : 209-215.

Briggs, J.L., Steffe, J.F. and Ustunol, Z. (1966). Vane method to evaluate the yield stress of frozen ice cream. *J. Dairy Sci.*, **79** : 527–531.

Charm, S.E. (1962). The direct determination of shear stress-shear rate behaviour of foods in presence of a yield stress. *Food Res.*, **11**: 356–361.

Gunjal, B.B. and Waghmare, N.J. (1987). Flow characteristics of pulp, juice and nectar of baneshan and neelum mangoes. *J. Food Sci. Technol.*, **24** : 20–23.

Hamdard, M.S., Rafique, M.R. and Farooq, U. (2004). Physico-chemical characteristics of various mango, *Mangifera indica* L. varieties. *J Agric. Res*., **42** (2) : 191-199.

Haminiuk, C.W.I., Sierakowski, M.R. and Maria Lucia Masson, D.R.I. (2006). Rheological characterization of blackberry pulp. *Brazilian J. Food Technol.*, **9** (4): 291–296.

Handbook on Horticulture Statistics (2014). Ministry of Agriculture Government of India, NEW DELHI, INDIA.

Iboyaima, Singh N. and Eipeson, W.E. (2002). Rheological behavior of clarified mango juice concentrates. *J. Text. Stud.*, **31** (3): 287-295.

Jiménez-Sánchez, C., Lozano-Sánchez, J., Segura-Carretero, A. and Fernández-Gutiérrez, A. (2015). Alternatives to conventional thermal treatments in fruit-juice processing. Part 2: Effect on Composition, Phytochemical Content, and Physicochemical, Rheological, and Organoleptic Properties of Fruit Juices. *Cri Rev Food Sci Nutr.*, DOI:10.1080/10408398.2014.914019.

Pelegrine, D.H., Silva, F.C. and Gasparetto, C.A. (2002). Rheological behaviour of pineapple and mango pulps. *LWT- Food Sci Technol.*, **35** (8): 645-648.

Ranganna, S. (1968). In*: Handbook of analysis and quality control for fruit and vegetable products*, IInd Ed. Tata McGraw Hill Publication. Co., NEW DELHI, INDIA.

Rao, K.L., Eipeson, W.E., Rao, P.N.S. and Ramanathan, M.V. (1984). Rheological properties of mango pulp and concentrates. *J. Food Sci Technol.*, **22**: 30–33.

Rao, M.A. (2014). Flow and functional models for rheological properties of Fluid Foods, In: *Rheology of fluid, semisolid, and solid foods, food engineering series*, Springer Science+Business Media, New York, pp: 27.

Ravani, A. and Joshi, D.C. (2013). Mango and it's by product utilization–a review. *Energy* (kcal), **74** : 44.

Singh, N.P., Jerath, N., Singh, G. and Gill, P.P.S. (2012). Physico-chemical characterization of unexploited mango diversity in sub-mountane zone of Northern India. *Indian J. Plant Genetic. Resour.*, **25** (3): 261-269.

Sobowale, S.S., Olatidoye, O.P., Odunmbaku, L.A. and Raji, O.H.A. (2012). Comparative study on physico-chemical and rheological properties of imported tomato paste in Nigeria. *Sustainable Agric. Res*., **1** (2): 51-56.

Steffe, J.F. (1996). Introduction to rheology. In: *Rheological methods in food process engineering*, (2nd Ed), MI: Freeman Press, USA, pp: 1-91.

Tabilo-Munizaga, G. and Barbosa-Cánovas, G.V. (2005). Rheology for the food industry. *J. Food Engg*., **67** (1) : 147-156.

Vélez-Ruiz, J.F. and Barbosa-Cánovas, G.V. (1998). Rheological properties of concentrated milk as function of concentration, temperature and storage time. *J. Food Engg.*, **35** : 177–190.

Vitali, A.A. and Rao, M.A. (1997). Flow properties of low-pulp concentrated orange juice: serum viscosity and effect of pulp content. *J. Food Sci.*, **49** : 876–881.

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