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Rheological behavior of litchi juice concentrates during storage

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Abstract

The rheological behavior of litchi juice concentrate prepared from two cultivars viz. cv. *Dehradun* and cv. *Seedless late* was studied as a function of storage temperature, storage period and preservative used during storage for six months. The rheological behavior of prepared juice concentrate was studied at temperature range of 20-50°C over the shear rate of 0.6-145.80 s^{-1} and the data was fitted to power law equation. Consistency index varied between 29.6-1559.7 Pa.s and 18.9-3218.1 Pa.s whereas, the flow behavior index (n) varied between 0.65-0.96 and 0.72-0.97 for cv. *Dehradun* and cv. *Seedless late*, respectively. The values of consistency index were found to increase with the increase in storage period and the increase was more prominent for concentrates stored at low temperature for both the varieties. Flow behavior index decreased during storage however, the decrease was slightly higher in juice concentrate prepared from *Deharadun* variety at the end of storage period. The increase in viscosity was higher in the concentrate stored at low temperature as compared to the samples stored at ambient temperature in both varieties. The activation energy ranged between 29.38-44.27 kJ/mol and 28.88-42.45 kJ/mol for cv. *Dehradun* and cv. *Seedless late*, respectively.

Introduction

Litchi (*Litchi chinensis* Sonn.) is a subtropical fruit that is preferred for its characteristic sweet-acidic taste, excellent aroma and high nutritive value (Mahayothee *et al*., 2009). Litchi is mostly liked as a table fruit; however, it can be utilized for processing into different products such as canned litchi, squash, cordial, syrups, ready to serve drinks, wine, jam, jelly and concentrates. After harvesting, litchi deteriorates rapidly due to pericarp browning thus, low temperature storage, sulfur dioxide fumigation, dipping in wax emulsions are used to extend the shelf life in commercial situations (Chand and Pal, 2006; Sharma and Pongener, 2010; Marboh *et al*., 2012). So, the processing of litchi fruit into juice concentrate during the peak season results in the reduction of bulk volume and concentrate can be used for reconstituting to the single strength juice or blending with other juices in off season. The economy in packaging, transportation, storage and the readiness with which they can be used are responsible for the early interest in fruit juice concentrates (Vijayanand *et al.*, 2010).

Rheological measurements are quite relevant in the food industry as a tool for physical characterization of raw material prior to processing, for intermediate products during manufacturing and for finished foods (Tabilo-Munizaga and Barbosa-Canovas, 2005). The processing of commercialised juice is subjected to tight supervision because its properties, such as viscosity, concentration and temperature vary during processing (Chin *et al.*, 2009). The knowledge of rheological behavior of fruit juices and concentrates is useful in quality control, sensory evaluation and engineering applications while designing industrial plants (Rao *et al*., 1981; Alvarado and Romero, 1989; Walker and Prescott, 2000) and also in determining the power requirements for pumping and sizing of pipes in its processing (Telis-Romero *et al.*, 1999).

The rheological behavior of fruit juices and concentrates has extensively been studied by Saravacos (1970) for fruit juices and purees; Ibarz *et al.* (1987) for apple and pear juices; Ibarz and Pagan (1987) for raspberry juices; Constenla *et al.* (1989) for clarified apple juice; Bayindirli (1992; 1993) for apple and grape juice; Peleg and Noble (1999) for cranberry juice; Sogi (2003) for watermelon juice; Altan and Maskan (2005) for pomegranate juice concentrate; Nindo *et al*. (2005) for blueberry and Raspberry juices; Belibagli and Dalgic (2009) for cherry juice concentrate; Dak *et al.* (2007) for mango juice and Fiyas *et al.* (2012) for mango juice concentrate.

Viscosity is an important factor during the concentration of juices, especially in the production of high density concentrates due to the inefficiency of the operation when the product becomes highly viscous (Magerramov *et al.*, 2007). Therefore, experimental measurements of viscosity are necessary for the characterization of fluid foods (Juszczak

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and Fortuna, 2004; Krokida *et al.*, 2001). Keeping in view the commercial importance of litchi fruit and non-availability of information regarding the rheological behavior of the litchi juice concentrate, the present study was conducted to study the effect of variety, preservative, storage temperature and storage period on the rheological behavior of litchi juice concentrate.

Materials and Methods

Procurement of Litchi fruits and juice extraction

The fresh mature fruits of two litchi varieties viz. cv. *Dehradun* (scented variety) and cv. *Seedless late* (small seeded variety) were selected and procured from Regional Fruit Research Station, Punjab Agricultural University, Ludhiana, Punjab (India). The fruits were processed at the pilot plant of Department of Food Science and Technology, Punjab Agricultural University, Ludhiana (India). After sorting, the fully matured and healthy fruits were peeled and destoned manually. The juice was extracted with the help of screw type juice extractor (Make: Kalsi, Ludhiana, India) followed by filtration through muslin cloth. The juice was kept overnight at 4±1°C for settling of suspended particles.

Preparation and storage of Litchi juice concentrate

The clear litchi juice was decanted carefully and divided into two batches. One batch was subjected to immediate concentration (untreated), while the other batch was treated with potassium metabisulphite (350 ppm) and processed for subsequent concentration (Khamrui and Pal, 2004). The brix was measured using hand held digital refractometer (Pal-1, Atago, Japan, range 0–53°Brix, least count 0.2°Brix). The concentrate was prepared using laboratory scale batch type vacuum glass evaporator (Heidolph Elektro GmbH and Co KG, Germany; temperature range: 20-180°C; rotation speed: 20-170 rpm) to a final concentration of 80°Brix. The juice concentration was done at 40±1°C temperature, 60 rpm and a vacuum of 660-730 mm mercury (Singh *et al.*, 1999). The prepared concentrate was packed in air tight polyethylene terephthalate (PET) jars and stored at ambient (28-32°C) and low temperature (4±1°C) for a period of six months.

Rheological measurements

Flow behavior of litchi juice concentrate was determined using Rheotest 2 viscometer (VEB MLW Prufgerate-werk, Medingen, Germany) with coaxial cylinder attachment. The torque data were obtained at shear rates between 0.6 and 145.8 s^{-1}. A measured amount of concentrates (17 ml) was introduced into the cylinder slowly to avoid air bubbles. The samples were maintained at rest for 15 minutes to equilibrate with the experimental temperatures variable (20, 30, 40 and 50°C) before measuring the rheological parameters. Temperature was controlled with a thermostatic-circulating water bath. Shear stress data were recorded first in the ascending order, followed by a rest of 5 minutes and then in the descending order (Harnanan *et al.*, 2001). The values for consistency index (Pa.s) and flow behavior index (dimensionless) were calculated from log-log plots of shear stress versus shear rate as slope and intercept, respectively using power law. The respective viscosities were calculated by dividing the respective shear stress by shear rate (Chin *et al.*, 2009). The activation energy (E_a) was derived from the regression of inverse of the absolute temperature versus log consistency index (Singh *et al.*, 1999). The rheological parameters were determined with at least three replications at an interval of 2 months each during six months storage.

Statistical analysis

Duncan's multiple range test (DMRT) was used to find significant differences in mean values of the measured parameters (Ananthan *et al.*, 2012). The analysis of variance test (ANOVA) was carried out using SPSS 7.5 software and statistical procedures described by Gomez and Gomez (1984) to examine the effect of variety, preservative, storage temperature and storage period on the viscosity, consistency index and flow behavior index of the developed litchi juice concentrate.

Results and Discussions

Effects of variables on viscosity

The effect of temperature and storage period on viscosity of litchi juice concentrate prepared from cv. *Dehradun* and cv. *Seedless late* is shown in Figures 1 and 2 respectively. The viscosity ranged between 1.80-96.44 Pa.s and 1.26-108.22 Pa.s for cv. *Dehradun* and cv. *Seedless late*, respectively during storage. The viscosity decreased with the increase in temperature. Similar results were obtained by Ibarz *et al.* (1995), Kaur *et al.* (2002), Khalil *et al.* (1989) and Togrul and Arslan (2004). Altan and Maskan (2005) reported that the viscosity of pomegranate juice was strongly dependent on solid content and temperature irrespective of the method of concentration. However, viscosity of litchi juice concentrate increased during storage. The increase in viscosity with the lapse of storage period indicated the rebuilding of the internal structure which continued to increase during storage

Table 1. Effect of treatments, storage conditions and experimental temperature on consistency index of litchi juice concentrate cv. *Dehradun*

Treatments	Storage temperature	Experimental temperature	Storage period (months)			
			0	2	4	6
Untreated	Ambient	20	576.8±1.56^{aH}	580.8±1.29^{bN}	588.8±2.14^{cM}	590.6±1.87^{dM}
		30	181.7±1.33^{aF}	190.6±2.12^{bJ}	199.5±1.54^{cH}	206.9±2.47^{dI}
		40	73.1±0.89^{aD}	77.1±1.44^{bF}	81.2±2.31^{cD}	84.7±1.17^{dE}
		50	45.2±1.74^{aB}	46.5±2.12^{bB}	47.7±1.67^{cB}	49.1±1.54^{dB}
	Low	20	576.8±1.56^{aH}	710.1±1.66^{bO}	760.4±1.94^{cN}	823.7±2.55^{dO}
		30	181.7±1.33^{aF}	247.3±1.98^{bK}	255.9±2.32^{cJ}	312.9±1.98^{dK}
		40	73.1±0.89^{aD}	83.2±2.15^{bG}	93.2±2.54^{cE}	102.8±1.69^{dF}
		50	45.2±1.74^{aB}	47.5±1.66^{bC}	48.8±2.14^{cC}	49.9±1.65^{dC}
Treated	Ambient	20	478.4±2.08^{aG}	502.2±1.54^{bM}	519.1±2.15^{cL}	526.8±2.04^{dL}
		30	143.4±1.65^{aE}	159.8±2.18^{bI}	161.4±1.33^{cG}	176.7±1.58^{dH}
		40	57.6±1.47^{aC}	62.9±1.85^{bD}	65.3±2.06^{cD}	68.1±1.54^{dD}
		50	29.6±2.08^{aA}	30.3±1.21^{bA}	32.2±1.52^{cA}	35.1±2.11^{dA}
	Low	20	478.4±1.65^{aG}	874.9±5.48^{bP}	1271.4±4.65^{cO}	1559.7±5.64^{dP}
		30	143.4±4.98^{aE}	295.4±6.25^{bL}	447.4±8.45^{cK}	644.5±2.45^{dN}
		40	57.6±1.47^{aC}	132.8±4.62^{bH}	208.2±3.84^{cI}	232.9±4.84^{dJ}
		50	29.6±2.08^{aA}	67.2±2.65^{bE}	104.9±5.78^{cF}	108.3±6.58^{dG}

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p < 0.05$ (n = 3)

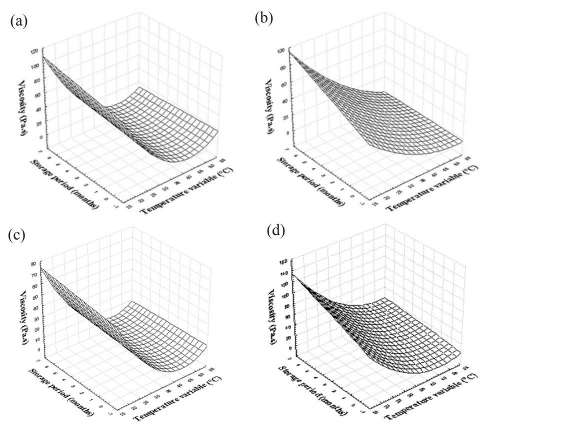

Figure 1. Effect of storage period and experimental temperature on viscosity of litchi juice concentrate (LJC) cv. *Dehradun* (a) Untreated LJC stored at ambient temperature (b) Untreated LJC stored at low temperature (c) Treated LJC stored at ambient temperature (d) Treated LJC stored at low temperature

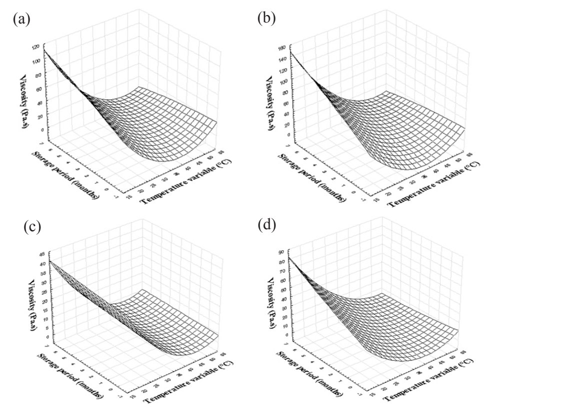

Figure 2. Effect of storage period and experimental temperature on viscosity of litchi juice concentrate (LJC) cv. Seedless late (a) Untreated LJC stored at ambient temperature (b) Untreated LJC stored at low temperature (c) Treated LJC stored at ambient temperature (d) Treated LJC stored at low temperature

(Hendrix and Ghegan, 1980; Crandall *et al.*, 1987). The viscosity is strongly dependent on inter-molecular forces between molecules and water-solute (sugars and acids) interactions, which result from the strength of hydrogen bonds and inter-molecular spacing as both were strongly dependent on concentration and temperature (Manjunatha and Raju, 2013). An increase in total solids leads to increase in hydrated molecules and hydrogen bonding with hydroxyl groups of solute, which would enhance the flow resistance that leads to increase in viscosity of liquid. Whereas, with the increase in temperature of liquid, the magnitude of viscosity significantly decreased, because of increase in thermal energy of the molecules which leads to increase in mobility of molecules and also increases in inter-molecular spacing which decrease the flow resistance (Krokida *et al.*, 2001). The increase was more prominent in the concentrate stored at low temperature as compared to the samples stored at ambient temperature in both the varieties. This might be due to the effect of lower storage temperature that led to decrease in mobility of the molecules and decrease in intermolecular spacing, which increased the flow resistance (Manjunatha and Raju, 2013). However, the variation in viscosity was found higher for the untreated samples than the treated samples. This might be due to the effect of preservative in the treated samples that retained and preserve the inherent quality and caused least variation in the measured parameter. Khamrui and Pal (2004) also observed that addition of potassium metabisulfite was found to preserve the quality of whey based kinnow juice concentrate for at least 9 months under refrigeration, and 4 months at ambient conditions. The same author also observed that the deteriorative changes were significantly faster in control sample and at ambient

Table 2. Effect of treatments, storage conditions and experimental temperature on consistency index of litchi juice concentrate cv. *Seedless late*

Treatments	Storage temperature	Experimental temperature	Storage period (months) 0	2	4	6
Untreated	Ambient	20	352.9 ± 5.65^{aI}	613.9 ± 4.11^{bO}	780.8 ± 2.48^{cO}	874.9 ± 3.45^{dN}
		30	111.9 ± 6.12^{aG}	182.5 ± 3.15^{bK}	236.1 ± 2.45^{cK}	253.5 ± 4.74^{dJ}
		40	48.3 ± 4.22^{aD}	72.2 ± 3.45^{bG}	89.3 ± 2.15^{cF}	111.4 ± 2.32^{dG}
		50	26.5 ± 2.63^{aB}	33.6 ± 1.56^{bC}	40.8 ± 1.65^{cD}	45.6 ± 1.58^{dD}
	Low	20	352.9 ± 5.65^{aI}	708.4 ± 2.85^{bP}	1063.9 ± 6.92^{cP}	3218.1 ± 5.25^{dP}
		30	111.9 ± 6.12^{aG}	273.3 ± 7.21^{bL}	362.7 ± 8.25^{cM}	1152.6 ± 4.88^{dO}
		40	48.3 ± 4.22^{aD}	90.3 ± 2.85^{bH}	132.3 ± 5.45^{cH}	277.2 ± 3.58^{dL}
		50	26.5 ± 2.63^{aB}	40.5 ± 2.52^{bE}	54.5 ± 4.12^{cE}	74.4 ± 3.39^{dE}
Treated	Ambient	20	272.4 ± 2.43^{aH}	279.3 ± 3.77^{bM}	286.2 ± 2.52^{cL}	292.6 ± 2.89^{dK}
		30	88.7 ± 2.78^{aE}	99.7 ± 3.21^{bF}	110.8 ± 0.24^{cG}	112.3 ± 1.05^{dF}
		40	37.1 ± 1.25^{aC}	38.8 ± 0.65^{bD}	40.5 ± 1.08^{cC}	41.4 ± 0.65^{dC}
		50	18.9 ± 1.54^{aA}	20.2 ± 0.29^{bA}	21.5 ± 0.32^{cA}	24.6 ± 1.44^{dA}
	Low	20	272.4 ± 2.43^{aH}	396.8 ± 2.16^{bN}	521.2 ± 3.58^{cN}	729.2 ± 4.52^{dM}
		30	88.7 ± 2.78^{aE}	101.3 ± 3.87^{bI}	193.7 ± 2.69^{cI}	234.9 ± 1.86^{dH}
		40	37.1 ± 1.25^{aF}	48.7 ± 2.15^{bJ}	60.3 ± 2.36^{cJ}	67.9 ± 1.13^{dI}
		50	18.9 ± 1.54^{aA}	25.3 ± 1.29^{bB}	31.6 ± 0.24^{cB}	32.4 ± 0.74^{dB}

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p < 0.05$ (n = 3)

Table 3. Effect of treatments, storage conditions and experimental temperature on flow behavior index of litchi juice concentrate cv. *Dehradun*

Treatments	Storage temperature	Experimental temperature	Storage period (months) 0	2	4	6
Untreated	Ambient	20	0.93 ± 0.01^{aG}	0.89 ± 0.03^{bJ}	0.87 ± 0.01^{cH}	0.82 ± 0.01^{dE}
		30	0.90 ± 0.01^{aD}	0.88 ± 0.02^{bI}	0.86 ± 0.04^{cG}	0.80 ± 0.02^{dD}
		40	0.89 ± 0.03^{aC}	0.88 ± 0.02^{bI}	0.86 ± 0.02^{cG}	0.79 ± 0.01^{dC}
		50	0.84 ± 0.01^{aA}	0.84 ± 0.03^{aE}	0.83 ± 0.01^{bE}	0.79 ± 0.02^{bC}
	Low	20	0.93 ± 0.01^{aG}	0.87 ± 0.01^{bH}	0.84 ± 0.01^{cF}	0.80 ± 0.03^{dD}
		30	0.90 ± 0.01^{aD}	0.86 ± 0.02^{bF}	0.84 ± 0.02^{bF}	0.80 ± 0.01^{cD}
		40	0.89 ± 0.03^{aC}	0.84 ± 0.02^{bE}	0.83 ± 0.01^{cE}	0.80 ± 0.02^{dD}
		50	0.84 ± 0.01^{aA}	0.82 ± 0.04^{bD}	0.80 ± 0.02^{cE}	0.80 ± 0.03^{cD}
Treated	Ambient	20	0.96 ± 0.01^{aH}	0.91 ± 0.02^{bK}	0.89 ± 0.03^{cJ}	0.87 ± 0.01^{cH}
		30	0.92 ± 0.02^{aF}	0.89 ± 0.01^{bJ}	0.87 ± 0.01^{bH}	0.87 ± 0.02^{bH}
		40	0.90 ± 0.01^{aD}	0.87 ± 0.01^{bH}	0.86 ± 0.01^{cG}	0.84 ± 0.01^{dG}
		50	0.87 ± 0.03^{aB}	0.87 ± 0.02^{aH}	0.86 ± 0.02^{bG}	0.83 ± 0.02^{cF}
	Low	20	0.96 ± 0.01^{aH}	0.85 ± 0.03^{bF}	0.73 ± 0.02^{cD}	0.66 ± 0.03^{dB}
		30	0.92 ± 0.02^{aE}	0.81 ± 0.01^{bC}	0.71 ± 0.03^{cC}	0.65 ± 0.02^{dA}
		40	0.90 ± 0.01^{aD}	0.80 ± 0.02^{bB}	0.70 ± 0.03^{cB}	0.65 ± 0.01^{dA}
		50	0.87 ± 0.03^{aB}	0.77 ± 0.01^{bA}	0.69 ± 0.01^{cA}	0.65 ± 0.03^{dA}

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p < 0.05$ (n = 3)

Table 4. Effect of treatments, storage conditions and experimental temperature on flow behavior index of litchi juice concentrate cv. *Seedless late*

Treatments	Storage conditions	Experimental temperature	Storage period (months) 0	2	4	6
Untreated	Ambient	20	0.91 ± 0.01^{aD}	0.90 ± 0.01^{bF}	0.88 ± 0.01^{bE}	0.86 ± 0.01^{cG}
		30	0.90 ± 0.00^{aC}	0.89 ± 0.01^{bD}	0.88 ± 0.00^{bE}	0.86 ± 0.00^{cG}
		40	0.90 ± 0.01^{aC}	0.89 ± 0.01^{bD}	0.86 ± 0.01^{cD}	0.84 ± 0.01^{dE}
		50	0.87 ± 0.02^{aA}	0.86 ± 0.01^{bB}	0.85 ± 0.01^{cC}	0.83 ± 0.01^{dG}
	Low	20	0.91 ± 0.01^{aD}	0.86 ± 0.02^{bC}	0.82 ± 0.01^{cA}	$0.76\pm.03^{dB}$
		30	0.90 ± 0.00^{aC}	0.86 ± 0.01^{bC}	0.82 ± 0.02^{cA}	0.76 ± 0.01^{dB}
		40	0.90 ± 0.01^{aC}	0.85 ± 0.02^{bB}	0.82 ± 0.02^{cA}	0.72 ± 0.01^{dA}
		50	0.87 ± 0.02^{aA}	0.84 ± 0.01^{bA}	0.82 ± 0.02^{cA}	0.72 ± 0.02^{cA}
Treated	Ambient	20	0.97 ± 0.02^{aG}	0.94 ± 0.01^{bG}	0.91 ± 0.02^{cH}	0.86 ± 0.03^{dG}
		30	0.94 ± 0.01^{aF}	0.89 ± 0.02^{bE}	0.89 ± 0.01^{bF}	0.86 ± 0.02^{dG}
		40	0.92 ± 0.02^{aE}	0.89 ± 0.02^{bE}	0.86 ± 0.01^{cD}	0.85 ± 0.01^{dF}
		50	0.89 ± 0.01^{aB}	0.85 ± 0.01^{bB}	0.83 ± 0.01^{cB}	0.81 ± 0.02^{dD}
	Low	20	0.97 ± 0.02^{aG}	0.93 ± 0.01^{bF}	0.90 ± 0.01^{cG}	0.85 ± 0.02^{dF}
		30	0.94 ± 0.01^{aF}	0.89 ± 0.03^{bE}	0.87 ± 0.01^{cE}	0.84 ± 0.03^{dE}
		40	0.92 ± 0.02^{aE}	0.89 ± 0.02^{bE}	0.87 ± 0.01^{cE}	0.84 ± 0.02^{dE}
		50	0.89 ± 0.01^{aB}	0.84 ± 0.03^{bA}	0.82 ± 0.03^{cA}	0.79 ± 0.01^{dC}

*Means in same row with same small letters and in same column with same capital letters do not differ significantly at $p < 0.05$ (n = 3)

conditions. Statistically, the process variables had significant ($p < 0.05$) effect on viscosity of litchi juice concentrate (Table 7).

Effects of variables on consistency index

The variation in consistency index of litchi juice concentrate is given in Table 1-2 for cv. *Dehradun* and cv. *Seedless late*, respectively. Consistency index varied between 29.6-1559.7 Pa.s and 18.9-3218.1 Pa.s in cv. *Dehradun* and cv. *Seedless late* variety, respectively during storage. Increases in the temperature from 20-50°C considerably influence the consistency index. The lower values for consistency index for concentrates were observed at 50°C as compared to 20°C temperature. At 50°C the consistency index values were nearly 12-15 folds lower than those at 20°C temperature. The variation was not so prominent among the treated

Table 5. Effect of treatments and storage conditions on activation energy (kJ/mol) of litchi juice concentrate prepared from cv. *Dehradun* and cv. *Seedless late*

Cultivar	Treatments	Storage temperature	Storage period (months)			
			0	2	4	6
Dehradun	Untreated	Ambient	29.38±0.02^{aB} (0.99)	30.21±0.01^{bC} (0.99)	31.21±0.02^{cC} (0.98)	31.66±0.04^{dB} (0.98)
		Low	29.38±0.02^{aB} (0.99)	30.85±0.05^{bD} (0.99)	30.99±0.11^{cB} (0.99)	31.87±0.25^{dC} (0.98)
	Treated	Ambient	31.06±0.33^{aD} (0.99)	31.35±0.31^{bE} (0.99)	31.98±0.41^{cD} (0.99)	32.05±0.17^{dD} (0.99)
		Low	31.06±0.33^{aD} (0.99)	37.23±0.14^{bH} (0.97)	41.21±0.25^{cH} (0.92)	44.27±0.32^{dH} (0.90)
Seedless late	Untreated	Ambient	28.87±0.04^{aA} (0.99)	31.96±0.05^{bF} (0.97)	32.92±0.04^{cF} (0.96)	32.99±0.15^{dE} (0.98)
		Low	28.87±0.04^{aA} (0.99)	32.41±0.04^{bG} (0.98)	33.19±0.05^{cG} (0.96)	42.45±0.04^{dG} (0.96)
	Treated	Ambient	29.55±0.15^{aC} (0.99)	29.67±0.05^{bA} (0.99)	29.71±0.04^{cA} (0.98)	29.75±0.03^{dA} (0.97)
		Low	29.55±0.15^{aC} (0.99)	30.19±0.21^{bB} (0.97)	32.06±0.16^{cE} (0.96)	35.44±0.16^{dF} (0.90)

[*] Means in same row with same small letters and means in same column with same capital letters do not differ significantly at $p < 0.05$ ($n = 3$)
Values in parenthesis represent their corresponding coefficient of determination (R^2)

Table 6. Effect of treatments and storage conditions on total solids (%) of litchi juice concentrate prepared from cv. *Dehradun* and cv. *Seedless late*

Cultivar	Treatments	Storage temperature	Storage period (months)			
			0	2	4	6
Dehradun	Untreated	Ambient	81.8±0.12^{aD}	82.4±0.11^{bC}	84.7±0.04^{cH}	85.4±0.12^{dG}
		Low	81.8±0.12^{aD}	83.6±0.15^{bG}	84.2±0.03^{cG}	85.8±0.15^{dH}
	Treated	Ambient	81.6±0.11^{aB}	82.6±0.02^{bD}	83.2±0.11^{cC}	84.3±0.12^{dC}
		Low	81.6±0.11^{aB}	83.8±0.04^{bH}	84.1±0.15^{cF}	85.1±0.11^{dE}
Seedless late	Untreated	Ambient	81.6±0.14^{aC}	82.2±0.03^{bB}	83.1±0.14^{cB}	84.2±0.14^{dB}
		Low	81.6±0.14^{aC}	83.1±0.03^{bF}	83.6±0.05^{cE}	84.8±0.06^{dD}
	Treated	Ambient	81.8±0.06^{aA}	82.1±0.06^{bA}	82.9±0.06^{cA}	83.2±0.05^{dA}
		Low	81.8±0.06^{aA}	82.7±0.02^{bE}	83.4±0.13^{cD}	85.2±0.12^{dF}

[*] Means in same row with same small letters and means in same column with same capital letters do not differ significantly at $p < 0.05$ ($n = 3$)

Table 7. Significance of various parameters on consistency index (k) and flow behavior index (n) of litchi juice concentrate ($p < 0.05$)

Parameter	$F_{Calculated}$				
	Consistency index (k)	Flow behavior index (n)	Viscosity (s)	Activation energy (kJ/mol)	Total solids (%)
Experimental temperature (E)	3778.7	287.8	12965.4	-	-
Preservative (P)	374.2	3.2 ^{NS}	3969928.5	52536.6	37812.5
Storage period (S)	399.6	1306.4	2400192.2	62440.3	575545.8
Storage temperature (T)	982.6	1445.1	8555213.3	84810.2	103512.5
Variety (V)	25.3	633.4	1213254.6	8692.21	108112.5
E * P	165.7	68.8	208360.1	-	-
E * S	126.4	40.2	2971872.8	-	-
E * T	287.5	4.9	1098522.5	-	-
E * V	1.3 ^{NS}	5.2	32246.7	-	-
P * S	78.7	78.5	1057034.2	4798.6	5345.8
P * T	2.2 ^{NS}	250.3	1118522.2	133360.3	10512.5
P * V	858.3	715.6	6832513.2	42500.7	3612.5
S * T	291.8	270.8	3271705.1	13894.3	18179.2
S * V	91.9	41.51	208582.2	8185.5	7512.5
T * V	2.3 ^{NS}	324.1	792579.0	89232.0	1512.5
E * P * S	40.6	8.3	66822.3	-	-
E * P * T	3.9	11.8	57501.3	-	-
E * P * V	304.3	46.3	2189931.0	-	-
E * S * T	95.4	6.4	520387.1	-	-
E * S * V	39.4	8.9	290921.7	-	-
E * T * V	3.2	10.2	90137.7	-	-
P * S * T	49.5	39.3	1439505.0	21897.2	5312.5
P * S * V	273.1	59.3	130353.9	11539.2	5012.5
P * T * V	416.2	724.2	93344.4	7015.7	612.5
S * T * V	55.4	36.4	295635.1	6826.9	4712.5
E * P * S * T	24.8	6.9	130769.3	-	-
E * P * S * V	101.4	11.5	531998.7	-	-
E * P * T * V	118.1	3.5	1221599.0	-	-
E * S * T * V	23.2	2.9	6453724.8	-	-
P * S * T * V	213.1	174.6	318734.9	1153.6	4879.2
E * P * S * T * V	76.8	8.7	785658.0	-	-

[*]= interaction between parameters, NS = not significant

samples as compared to untreated samples. This might be due to the effect of preservative that helped to maintain the quality (Khamrui and Pal, 2004). But while comparing, the concentrates stored at low temperature, higher consistency index values were observed than those stored at ambient temperature.

However, at the end of storage, the treated concentrate prepared from cv. *Dehradun* stored at both ambient and low temperature showed considerably higher values than the corresponding concentrate prepared from cv. *Seedless late.* The values of consistency index were found to increase with increase in storage period especially for those concentrates stored at low temperature. This effect can be attributed to an increase in the interactions between the particles, because the number of particles that come into contact increases (Chin *et al*., 2009). Sikora *et al.* (2007) also observed an increase in consistency coefficient of dessert sauce during storage. The effect of variables was found significant ($P < 0.05$) for both the varieties (Table 7).

Effects of variables on flow behavior index

The flow behavior index of the litchi juice concentrates of cv. *Dehradun* and cv. *Seedless late* ranged from 0.65-0.96 and 0.72-0.97 during storage (Table 3 and 4) indicating their moderate to mildly non-newtonian nature (Muller, 1973). The flow behavior index is equal to one for newtonian flow. In the present study, flow behaviour index for all the samples were found below one which described that the juice concentrate samples were pseudoplastic, shear thinning liquids (Steffe, 1996). The variation in flow behaviour index values was lower in treated samples as compared to untreated samples in both the varieties. This might be due to the addition of preservative that reduced the scope of changes in total solids, total and reducing sugars probably due to the suppression of microbial activity and thus not affected the rheological properties of juice (Kaur *et al.*, 1991). Decrease in flow behaviour index of juice concentrate during storage indicated the gradual loss of pseudoplasticity (Sikora *et al.*, 2007). The concentrates stored at ambient temperature showed significantly different values from the samples stored at low temperature in both the varieties. Using experimental temperature variable from 20-50°C, the flow behavior index values decreased with increase in temperature. These values were also decreasing during storage period. Significant decrease was observed for the concentrates stored at low temperature as compared to samples stored at ambient temperature. However, the decrease was higher in litchi juice concentrate prepared from *Deharadun* variety. Similar trends for flow behavior index were reported by Rao *et al.* (1981) for tomato juice concentrate. Statistically, except preservative, the effect of all other variables was found significant ($P < 0.05$) (Table 7).

Effects of variables on activation energy

Activation energy is the minimum energy required which overcomes the energy barrier before the elementary flow can occur. The magnitude of energy of activation for viscous flow increased significantly with increase in soluble solid content of the juice concentrate indicating that higher energy was required to overcome potential energy barrier at higher soluble solids content. Therefore, temperature had a greater effect on flow properties at higher soluble solid contents. When temperature increased, the thermal energy of the molecules and intermolecular spacing increased significantly, which lead to decrease in the magnitude of viscosity (Steffe, 1996; Rao, 2007). For newtonian fluids like water it ranges from 14.4 kJ/mol, to more than 60 kJ/mol for sugar solutions and concentrated juices (Krokida *et al.*, 2001). The activation energy ranged between 29.38-44.27 and 28.87-42.45 kJ/mol for cv. *Dehradun* and cv. *Seedless late* respectively (Table 5). The higher values of activation energy might be attributed to higher temperature range and the higher total solids of the product (Ahmed *et al*., 2007). In pseudoplastic fruit products, the activation energy was directly proportional to the flow behaviour index i.e., the more pseudoplastic the product, the less the effect of temperature on its apparent viscosity (Sharoba *et al.*, 2005). However, the activation energy was found lower for the samples stored at lower temperature. Hernandez *et al.* (1995) and Vitali and Rao (1984) also reported a slight decrease in activation energy at lower temperature. For both varieties, the activation energy of litchi juice concentrate increased with the storage period. Higher activation energy values indicate a greater influence of temperature on the viscosity, i.e. more rapid change in viscosity with temperature (Sanchez *et al.*, 2009). The results showed that temperature and total soluble solid content had a significant effect on viscosity of juice concentrates. The magnitude of viscosity increased significantly with increase in soluble solid content. Similar findings were obtained by Akbulut *et al.* (2012); Alpaslan and Hayta (2002) and Arslan *et al.* (2005). Statistically, the effect of variables was found significant ($P < 0.05$) (Table 7).

Effects of variables on total solids

The total soluble solids of the juice concentrate of both the litchi varieties increased during storage (Table 6). This increase in the total solids of juice concentrate might be attributed to the loss in moisture as a function of storage temperature and storage conditions. The increase was slightly higher in the var. *Dehradun.* This might be due to varietal effect. The total solids of the litchi juice concentrates of cv. *Dehradun* and cv. *Seedless late* ranged from 81.6-85.8 and 81.6-85.2 respectively, during storage. The concentration of total solids had strong effect on the viscosity of the non – Newtonian fluids (Krokida *et al.*, 2001). The variation in total solids directly affects the viscosity of the juice concentrate due to variation in degree of hydration of the solute molecules, increase in hydrogen bonding with hydroxyl groups of solute and decrease in inter-molecular spacing. Similar finding were reported by Manjunatha and Raju (2013) for coconut juice concentrates.

Conclusions

The results showed that litchi juice concentrate showed moderate to mildly non-Newtonian nature in the temperature range of 20-50°C and was successfully described by power law model. The values of consistency index were found to increase with storage period especially for concentrates stored at low temperature. On the basis of the present study, the litchi juice concentrate could be stored best at low temperature (4±1°C) upto six months. However, the increase in viscosity was more prominent in the concentrate stored at low temperature as compared to the samples stored at ambient temperature in both the varieties. The activation energy for both types of juice concentrates decreased with increase in temperature but increased with the storage period. The magnitude of flow characterises of litchi juice concentrate depends on both temperature and total soluble solid content. At lower temperatures the magnitude of viscosity rapidly increased with soluble solid content and increased marginally at higher temperatures.

References

Ahmed, J., Ramaswamy, H.S. and Sashidhar, K.C. 2007. Rheological characteristics of tamarind juice concentrates. LWT- Food Science and Technology 40: 225–231.

Akbulut, M., Saricoban, C. and Ozcan, M.M. 2012. Determination of rheological behavior, emulsion stability, color, and sensory of sesame pastes blended with pine honey. Food and Bioprocess Technology 5: 1832-1839.

Alpaslan, M. and Hayta, M. 2002. Rheological and sensory properties of pekmez (grape molasses) / tahin (sesame paste) blends. Journal of Food Engineering 54: 89-93.

Altan, A. and Maskan, M. 2005. Rheological behavior of pomegranate juice and concentrate. Journal of Texture Studies 36: 68-77.

Alvarado, J.D. and Romero, C.H. 1989. Physical properties of fruits - III: Density and viscosity of juices as functions of soluble solids content and temperature. Latin American Applied Research 19: 15-21.

Ananthan, P., Sharma, G.K., Srihari, K.A. and Bawa, A.S. 2012. Development of shelf stable protein rich composite cereal bar. Journal of Food Science and Technology 49: 335-341.

Arslan, E., Yener, M.E. and Esin, A. 2005. Rheological characterization of tahin/pekmez (sesame paste/ concentrated grape juice) blends. Journal of Food Engineering 69: 167-172.

Bayindirli, L. 1992. Mathematical analysis of variation of density and viscosity of apple juice with temperature and concentration. Journal of Food Processing and Preservation 16: 23-28.

Bayindirli, L. 1993. Density and viscosity of grape juice as a function of concentration and temperature. Journal of Food Processing and Preservation 17: 147-151.

Belibagli, K.B. and Dalgic, A.C. 2009. Rheological properties of sour-cherry juice and concentrate. International Journal of Food Science and Technology 42: 773-776.

Chand, R. and Pal, R.K. 2006. Influence of active cushioning materials in packaging on shelf-life of litchi fruits. Indian Journal of Horticulture 63: 31-35.

Chin, N.L., Chan, S.M., Yusof, Y.A., Chuah, T.G. and Talib, R.A. 2009. Modelling of rheological behaviour of pummelo juice concentrates using master-curve. Journal of Food Engineering 93: 134-140.

Constenla, D.T., Lozano, J.E. and Crapiste, G.H. 1989 Thermophysical properties of clarified apple juice as a function of concentration and temperature. Journal of Food Science 54: 663-668.

Crandall, P.G., Chen, C.S. and Davis. K.C. 1987. Preparation and storage of 72°brix orange juice concentrate. Journal of Food Science 52: 381-385.

Dak, M., Verma, R.C. and Jaaffrey, S.N.A. 2007. Effect of temperature and concentration on rheological properties of "Kesar" mango juice. Journal of Food Engineering 80: 1011-1015.

Fiyas, A., Kulkarni, S.G. and Vijayanand, P. 2012. Effect of processing conditions on quality characteristics of mango pulp concentrate from different mango cultivars. International Journal of Food Science and Technology Nutrition 6: 59-70.

Gomez, A.K. and Gomez, A.A. 1984. Statistical procedures for agricultural research (2nd edition), John Wiley and Sons Inc., Singapore.

Harnanan, S.W., Singh, T. and Bains, G.S. 2001. Effect of processing, preservation and storage on rheology of guava pulp. Journal of Texture Studies 32: 271-284.

Hendrix, D.L. and Ghegan, R.C. 1980. Quality changes in bulk stored citrus concentrate made from freeze damaged fruit. Journal of Food Science 45: 1570-1572.

Hernandez, E., Chen, C.S., Johnson, J. and Carter, R.D. 1995. Viscosity changes in orange juice after ultafiltration and evaporation. Journal of Food Engineering 25: 387-396.

Ibarz, A. and Pagan. J. 1987. Rheology of raspberry juices.

Journal of Food Engineering 6: 269-289.

Ibarz, A., Giner, J., Pagan, J., Gimeno, V. and Garza, S. 1995. Rheological behaviour of kiwi fruit juice concentrates. Journal of Texture Studies 26: 137-145.

Ibarz, A., Vicente, M. and Graell, J. 1987. Rheological behavior of apple juice and pear juice and their concentrates. Journal of Food Engineering 6: 257-267.

Juszczak, L., and Fortuna, T. 2004. Effect of temperature and soluble solid content on the viscosity of cherry juice concentrate. International Agrophysics 18: 17-21.

Kaur, B., Sharma, K.P. and Kaur, H. 1991. Studies on the development and storage stability of ready-to-serve bottled sugarcane juice. International Journal of Tropical Agriculture 9: 128-134.

Kaur, S., Kaler, R.S. and Aamarpali, R.P. 2002. Effect of starch on the rheology of molasses. Journal of Food Engineering 55: 319-322.

Khalil, K.E., Ramakrishna, P., Nanjundaswamy, A.M. and Patwardhan, M.V. 1989. Rheological behavior of clarified banana juice: Effect of temperature and concentration. Journal of Food Engineering 10: 231-240.

Khamrui, K. and Pal, D. 2004. Effect of potassium metabisulphite and storage conditions on physico-chemical and microbiological changes of whey based kinnow juice concentrate. Journal of Food Science and Technology 41: 401-404.

Krokida, M.K., Maroulis, Z.B. and Saravacos, G.D. 2001. Rheological properties of fluid fruit and vegetable products: Compilation of literature data. International Journal of Food Properties 4: 179-200.

Magerramov, M.A., Abdulagatov, A.I., Azizov, N.D. and Abdulagatov, I.M. 2007. Effect of temperature, concentration, and pressure on the viscosity of pomegranate and pear juice concentrates. Journal of Food Engineering 80: 476-489.

Mahayothee, B., Udomkun, P., Nagle, M., Haewsungcharoen, M., Janjai, S. and Mueller, J, 2009. Effects of pre-treatments on colour alterations of litchi during drying and storage. European Food Research Technology 229: 329-337.

Manjunatha, S.S. and Raju, P.S. 2013. Modelling the rheological behaviour of tender coconut (*Cocos nucifera* L) water and its concentrates. International Food Research Journal 20: 731-743.

Marboh, E.S., Lal, R.L., Mishra D.S. and Goswami, A.K. 2012. Effect of hot water treatment and oxalic acid on colour retention and storage quality of litchi fruit cv. Rose Scented. Indian Journal of Horticulture 69: 484-488.

Muller, H.G. 1973. An introduction to food rheology. William Heinemann Ltd., Heinemann, London.

Nindo, C.I., Tang, J., Powers, J.R., Singh, P. 2005. Viscosity of blueberry and raspberry juices for processing applications. Journal of Food Engineering 69: 343-350.

Peleg, H. and Noble, A.C. 1999. Effect of viscosity, temperature and pH on astringency in cranberry juice. Food Quality and Preference 10: 343-347.

Rao, M.A, Bourne, N.C. and Cooley, H.J. 1981. Flow properties of tomato concentrates. Journal of Texture Studies 12: 521-538.

Rao, M.A. 2007. Rheology of fluid and semisolid foods. Principles and applications, Second edition, Springer Sciences, New York.

Sanchez, C., Blanco, D., Oria, R. and Sancchez-Gimeno, C. 2009. White guava fruit and purees: textural and rheological properties and effect of the temperature. Journal of Texture Studies 40: 334-345.

Saravacos, G.D. 1970. Effect of temperature on viscosity of fruit juices and purees. Journal of Food Science 35: 122-125.

Sharma, R.R. and Pongener, A. 2010. Natural products for postharvest decay control in horticultural produce: a review. Stewart Postharvest Review 6: 1-9

Sharoba, A.M., Senge, B., El-Mansy, H.A., Bahlol, H.E.M. and Blochwitz, R. 2005. Chemical, sensory and rheological properties of some commercial German and Egyptian tomato ketchups. European Food Research and Technology 220: 142-151.

Sikora, M., Kowalski, S., Tomasik, P. and Sady, M. 2007. Rheological and sensory properties of dessert sauces thickened by starch-xanthan gum combinations. Journal of Food Engineering 79: 1144-1151.

Singh, T., Singh, S., Kaur, B., Kaur, H. and Saini, S.P.S. 1999. Flow properties and physicochemical characteristics of "Perlette" grape juice concentrates. Journal of Food Science and Technology 36: 402-407.

Sogi, D.S. 2003. Effect of concentration and temperature on the viscosity of watermelon juice. Journal of Food Science and Technology 40: 509-511.

Steffe, J.F. 1996. Rheological methods in food process engineering. Freeman Press, East Lansing.

Tabilo-Munizaga, G. and Barbosa-Canovas, G.V. 2005. Rheology for the food industry. Journal of Food Engineering 67: 147-156.

Telis-Romero, J., Telis, V.R.N. and Yamashita, F. 1999. Friction factors and rheological properties of orange juice. Journal of Food Engineering 40: 101–106.

Togrul, H. and Arslan, N. 2004. Mathematical model for prediction of apparent viscosity of molasses. Journal of Food Engineering 62: 281-289.

Vijayanand, P., Kulkarni, S.G. and Prathibha, G.V. 2010. Effect of pectinase treatment and concentration of litchi juice on quality characteristics of litchi juice. Journal of Food Science and Technology 47: 235-239.

Vitali, A.A. and Rao, M.A. 1984. Flow properties of low-pulp concentrated orange juice: effect of temperature and concentration. Journal of Food Science 49: 882-888.

Walker, S. and Prescott, J. 2000. The influence of solution viscosity and different viscosifying agents on apple juice flavor. Journal of Sensory Studies 15: 285–307.