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Rheological characteristics of reconstituted spray dried beetroot (*Beta vulgaris* L.) juice powder at different solid content, temperatures and carrier materials

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Abstract

Investigation was carried out to study the effect of different carrier materials namely, maltodextrin (MD) and gum Arabic (GA) with original juice (OJ) on viscosity of reconstituted beetroot (*Beta vulgaris* L.) juice powder at different solid contents (X_s) 10 to 50% and wide range of temperature 10 to 85°C. The rheological parameter shear stress was measured up to the shear rate of 1000 s^{-1} by controlled stress rheometer using concentric cylinders. The investigation showed that all the reconstituted beetroot juice behaved like a Newtonian fluid. The Newtonian viscosity (η) ranges from 4.47 to 86.99, 4.76 to 176.15 and 5.60 to 1561.77 mPa s for original, maltodextrin (MD) and gum Arabic (GA) based juices respectively, depending upon the solid content and temperature used. The investigation showed that the Newtonian viscosity increased significantly ($p<0.05$) with increase in solid content, whereas it decreased significantly ($p<0.05$) with increase in temperature. Of all the carrier materials gum Arabic showed maximum viscosity followed by maltodextrin and original juice at same solid content and temperature studied. The temperature dependency of Newtonian viscosity of beetroot juice was described by Arrhenius equation. The flow activation energy (E_a) was markedly affected by type of carrier material and is increased significantly ($p<0.05$) with increase in solid content. The Newtonian viscosity of reconstituted spray dried beetroot juice increased with solid content and a significant ($p<0.05$) change was observed with different temperatures used and also markedly affected by type carrier material. A combined single equation relating Newtonian viscosity (η) to solid content and temperature was established. The results indicated dependency of the Newtonian viscosity of reconstituted beetroot juice on solid content, temperature and type of carrier material.

Introduction

Beetroot is an important vegetable crop available throughout the year in all parts of the world. Beetroot or Red beet is a potential source of valuable water soluble nitrogenous pigments, called betalains, which composed of two main groups known as primarily of red betacyanins and yellow betaxanthins. Beetroot contains appreciable amount of nitrates and nitrites which are free radical scavenging compound and prevent active oxygen-induced free radical mediated oxidation of biological molecules. The high level of nitrates and nitrites facilitates vasodilatation in humans, a desired property to enhance oxygen supply in body which energizes the entire body with better oxygen supply to brain, body muscles and vital organs (Pedreno and Escribano, 2001). Beetroots are rich in active, valuable bioactive compounds such as carotenoids, saponins, glycine betaine, folates, polyphenols and flavonoids (Jastrebova *et al*., 2003; Vali *et al*., 2007). Betalains are natural colorants in different fruits and vegetables and used to enhance the redness of different products such as tomato paste, ice cream and yoghurt, soups, sausages, sauces, jams, jellies biscuit cream and a range of dessert products (Koul *et al*., 2002; Roy *et al*., 2004; Stintzing and Carle, 2007). A large number of value added products can be prepared from red beetroot such as salads, concentrate, natural pigment, nectars and juices (Patkai and Barta, 1997).

Fruit/vegetable juice powders have several benefits and commercial economic potential compare to that of original juices in terms of reduced volume and weight, easier in handling, transportation, higher shelf-life and reduced packing system. The fruit juice powder is stable physical state and can be used as flavoring and coloring agents in many food and pharmaceutical products. The dehydration of fruit juices is not an easier task due to its stickiness and hygroscopicity due to low molecular sugars and organic acids that leads to problems in controlling the drying time, adhesion dryer wall, caking and subsequent

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handling of the product. Spray drying is one of the most complex methods of drying for fruit/vegetable juice. The wall stickiness, thermo plasticity and other operating related problems are main consideration during spray drying process. Encapsulation is one of the main techniques to increase the stability of pigments and other bioactive compounds. In food processing applications encapsulation is directly related to coating of minute particles of ingredients as well as whole ingredients by micro encapsulation and macro encapsulation techniques. Encapsulation technology has been used widely in food processing industry and it provide liquid and solid ingredients as on effective barrier to protect bioactive and important phytochemicals from the environment as well as chemical interactions. Microencapsulation is most important technique in terms of protecting core material from degradation by reducing reactivity to environmental conditions (Schrooyen *et al.*, 2001). There are several kinds of encapsulating agents in polysaccharides such as starch, maltodextrin, corn syrup, gum Arabic etc, lipids and proteins such as gelatin, whey and soy protein, casein, wheat proteins. Other wall materials like hydrophobic starch, carboxy methyl cellulose, microcrystalline cellulose, sodium alginate, sodium caseinate, pectin, guar gum, chitosan etc were used (Barbosa *et al*., 2005). The most common approach to deal with the problem of stickiness in spray drying of sugar rich foods is addition drying-aid agents. The maltodextrin and gum Arabic are the main drying-aid agents in spray drying process due to their high molecular weight and high glass transition temperature (Tg). Maltodextrins are basically defined as hydrolyzed starch buildup by units of α-D- glucose bound together. It consists of a mixture of saccharides, mainly D-glucose, maltose and a series of oligosaccharides and polysaccharides and resulting to wide distribution of molecular mass. Commercially maltodextrin is produced from native starch by partial hydrolysis, purification and spray drying. The granular structure of starch was lost due to enzymatic as well as physical treatments. Maltodextrins are soluble in water which leads to many applications in food industry, where they are used as gelling agent, fat replacer, texture modifier, bulking agent, cryo-protecting agent and extend the product shelf life as encapsulation agent (Chronakis, 1998). Gum Arabic is water soluble polysaccharide and forms dispersions with concentration up to 50% and has Newtonian behaviour. It is a natural polysaccharide and extracted from the trees of the *Acacia* family. It was exuded mainly from *Acacia senegal,* Acacia *seyal, Acacia laeta* and *Acacia tragacanthum* and it is used in the food industry as good stabilizer as well as good emulsifier. Gum Arabic is a polysaccharide of high molecular weight with primary chain of β-galactopyranose units linked with 1-3 linkage, galactopyranose ramification linked with 1-6 linkage and β-D-glucuronopyranose and 4-O-methyl - β-D- glucuronopyranose terminations (Cui *et al.*, 2007).

The solubility and reconstitution properties are the important quality factors of spray dried juice powders and these depend upon the nature of raw material, type of carrier material, drying conditions and addition of other additives. The quality parameter of fluid food which is related to rheology is known as mouth-feel. It is defined as the mingled experience deriving from the sensation of skin of the mouth after ingestion of a food or beverage and is related to physical properties such as viscosity, density, surface tension and other related properties of the fluid foods. The physical properties of fluid foods have gained more importance as rheological attributes of fluid foods have been developed and quantified (Ingate and Christensen, 1981).

The rheological properties of liquid foods are evaluated by the measurement of shear stress-shear rate and representing the experimental data using rheograms. The empirical equations were used to characterize the rheological properties of as a function of concentration, temperature, particle size, processing techniques etc. These properties are very much helpful in understanding the flow mechanism of complex fluid systems and as well as structural understanding and interactions of molecules. The viscosity of fluid is markedly affected by temperature, nature of solute, concentration of solute, its molecular weight, pressure and suspended matter (Bourne, 2002). The general relationship between shear stress and shear rate was described by the following Hershel-Bulkley equation

$$\sigma = \sigma_0 + K\dot{\gamma}^n \quad \text{-------} \ (1)$$

where σ is shear stress (Pa), σ_0 is the yield stress (Pa), K is consistency index (Pa s^n), $\dot{\gamma}$ is shear rate (s^{-1}) and n is flow behaviour index (-) which indicate the nature of flow of the fluid. If yield stress σ_0=0, the Hershel-Bulkley equation reduces to Ostwald-De-Waele model or power law equation (Tavares *et al*., 2007; Sanchez *et al.*, 2009)

$$\sigma = K\dot{\gamma}^n \text{ - - - - - - - - - } (2)$$

If the fluid is Newtonian in nature, n=1 and hence K becomes viscosity η (Pa s) of the fluid. In general, liquid food such as fruit and vegetable juices behave like Newtonian fluids; so their flow behaviour would be Newtonian in nature. Several investigators reported that clarified and depectinated juices and their concentrates exhibit Newtonian flow behaviour (Ibarz *et al.*, 1992a, 1992b; Cepeda and Villaran, 1999; Juszczak and Fortuna 2004)

$$\sigma = \eta \dot{\gamma} \quad \text{------ (3)}$$

where σ is shear stress (Pa), η is coefficient of viscosity (Pa s) and is shear rate (s^{-1}).

Several investigators have used Newtonian equation for describing rheological behaviour of liquid food products like liquorice extract (Maskan, 1999), Pekmez (Kaya and Belibagli, 2002), pomegranate juice (Altan and Maskan, 2005; Kaya and Sozer, 2005), black chokeberry (Aronia melanocarpa) juice (Juszczak *et al.*, 2009), beetroot juice (Juszczak *et al.*, 2010) lime juice (Manjunatha *et al.*, 2012a), gooseberry juice (Manjunatha *et al.*, 2012b), Tender coconut water (Manjunatha and Raju, 2013), sapota juice (Pranjal *et al.*, 2015).

The rheological behaviour of Josapine pineapple juice with various maturity stages was studied at a wide range of temperatures and concentrations. The results indicated that Josapine pineapple juice exhibited Newtonian behaviour and the viscosity of pineapple juice was influenced by maturity stage, temperature and concentration (Shamsudin *et al.*, 2009). The rheological behaviour of freeze-dried-concentrated pummelo juice was modelled to investigate the effect of concentration and temperature of fluid type and viscosity. The results indicated that pummelo juice behaved like shear thinning or pseudoplastic behaviour and modelled using master curve (Chin *et al.*, 2009). Rheological properties of carrot puree were investigated as a function of time of shearing, temperature and addition potato flakes. Carrot puree exhibited shear thinning behaviour and time dependent behaviour was characterized by a second order structural kinetic model. The decay of the structural parameter with time was found to be independent of shear rate (Hecke *et al.*, 2012). Effect of particle size, temperature and total soluble solids on the rheological properties of watermelon juice was investigated by response surface methodology (Sogi *et al.*, 2010). The effect of high pressure treatment on the rheological properties of fresh and canned mango pulp was evaluated and reported that the rheological parameters were markedly affected by pressure treatment (Ahmed *et al.*, 2005). The influence of peach fibre addition on the rheological behaviour of peach juice was investigated and addition of fibre is markedly changing the rheological properties (Augusto *et al.*, 2011). Bhattacharya and Rastogi (1998) studied the rheological properties of enzyme-treated mango pulp and rheological parameters markedly affected enzyme treatment conditions. Rheological characteristics of commercial baby fruit purees were investigated and all the fruit based baby purees exhibited pseudoplastic behaviour (Alvarez *et al.*, 2008). Viscosity of aqueous carbohydrate solutions such as glucose, fructose and sucrose was investigated at wide range of temperatures and concentrations (Telis *et al.*, 2007). Effect of temperature, total soluble solids, pH and α-amylase concentration on rheological properties of papaya puree were studied by the application of response surface methodology (Ahmed and Ramaswamy, 2004). Rheological properties of bulking agent syrups such as maltodextrin and polydextrose along with aspartame were studied and Hershel-Bulkley model was found suitably describe the flow behaviour of syrups (Chetana *et al.*, 2004). Effect of temperature and soluble solids content on the viscosity of beetroot juice concentrate was investigated and beetroot concentrate behaved like Newtonian fluid. The effect of temperature on viscosity of beetroot juice concentrate was described by Arrhenius equation. A combined effect of temperature and soluble solid content was described by exponential equation (Juszczak *et al.*, 2010). The rheological behaviour of reconstituted juice is one of the important quality factors of beetroot juice powder in order to structural understanding as well as molecular interaction with water with other solute molecules. The present study was undertaken to study the effect type of carrier material, temperature and solid content on rheological characteristics reconstituted spray dried beetroot juice powder with original juice.

Material and Methods

Raw material

Beetroot of good quality with good firmness was procured from local market Mysore, India and washed twice with water. The beetroot was peeled with abrasive peeler (Continental India Ltd, New Delhi, India). Peeled beetroot was diced in the form of cubes size 6 mm using Urschel dicer (Model: G 1656, Urschel laboratories Inc, Valparaiso, USA). Steam blanching was carried out using pressure cooker at 103.4 KPa pressure for 1 min to inactivate the enzymes and cool to room temperature. The blanched beetroot cubes were pureed using a waring blender (Model:W, Waring Laboratory, Torrington, CT, USA) for 10 min until a homogenous puree was obtained and subjected for enzyme clarification

Enzyme clarification

The enzyme based clarification was carried out using commercial enzyme, pectinex ultra SPL (Novozyme, Denmark). The concentration of enzyme, incubation temperature and time was fixed and clarification carried out as reported (Thakur and Das Gupta, 2006). The enzyme was inactivated by placing the material in water bath maintained at temperature 90°C for 3 min and quickly cooled in ice cold water. The beetroot puree was filtered with four fold muslin cloth and pressed in tincture press (Hafio, Germany). The filtered beetroot juice was centrifuged at a relative centrifugal force of 6285.75 x g using continuous centrifuge (Model: LE 711368, CEPA, Lahr/Baden, and Germany). The clarified beetroot juice was subjected to various concentrations and spray drying.

Juice concentration

The enzyme clarified beetroot juice was concentrated by vacuum evaporation technique using laboratory rotary vacuum evaporator (Model: Laborata 4001, Heidolph, Germany) with reduced pressure, at temperature of 60°C and rotation speed of 60 rpm. Beetroot juice was concentrated up to 55 °brix concentration and suitably diluted to different solid content using distilled water and subjected to rheological measurements.

Spray drying

The clarified beetroot juice was subjected for spray drying using table top mini spray dryer (Model; B-190, Buchi, Switzerland). The carrier materials used were maltodextrin (DE 20) (Riddhi Siddhi Gluco Biols Ltd, Belgaum, Karnataka, India) and gum Arabic (Kolety Gums Pvt Ltd, Dadara, Maharastra, India). The amount of carrier materials added to beetroot juice was equal to solid content of juice in dry weight basis. The mixture was homogenized for 10 min with domestic hand blender (model: HR1350/C, Philips, India) and subjected for spray drying. The spray dryer was operated at an inlet temperature of 140°C and outlet temperature of 80-85°C. The drying conditions include drying air flow at 700 l/h at a pressure of 6 bars. The dried powder was collected after drying.

Moisture

Moisture content of enzyme clarified beetroot juice was carried out by vacuum oven method as reported (Ranganna 1986).

Ash

The ash content of the juice was measured gravimetrically by drying the juice in hot air oven in silica crucible, ignited in hot plate and placed in muffle furnace at 550°C for 16 h and the ash content was calculated by difference in weight and expressed as % (Ranganna, 1986).

Total soluble solid content

The total soluble solids content of beetroot juice was determined using digital hand-held refractometer (Model: PAL-1, Atago co, Ltd., Tokyo, Japan) at 25°C with an accuracy of 0.1 and calibrated using distilled water and total soluble solid content was expressed as °brix.

pH

A digital pH meter was used to measure the pH of beetroot juice (Model: pH tutor, P/N 54X002606, Cyber scan, India) at 25°C with an accuracy of 0.01. The instrument was calibrated using standard buffers provided by manufacturer.

Density

The density (ρ) of enzyme clarified beetroot juice was measured at 25°C using 25 ml pycnometer (Constenla *et al.*, 1989).

Water activity

The water activity of beetroot juice was measured using digital water activity meter at 25°C (Aqua Lab, model: 3T E, Decagon devices, USA). The water activity meter was calibrated using standard solutions at water activity levels of 0.250, 0.500, 0.760 and 0.984 obtained from original manufacturers (Decagon, Pullman WA, USA).

Acidity

The acidity of enzyme clarified beetroot juice was determined using pH meter with standard 0.01N NaOH solution and expressed as % citric acid.

Sugars

Reducing sugar and total sugar of enzyme clarified beetroot juice were determined colorimetrically using 3-5, dinitro salicylic acid reagent and expressed as percentage (Miller, 1959).

Ascorbic acid

Ascorbic acid content of the enzyme clarified beetroot juice was determined using N-bromosuccinimide and expressed as mg/100 ml of juice (Evered, 1960).

Betalain content

Betalain content was measured by

spectrophotometrically as described (Nilsson, 1970)

Colour measurement

The color parameters of clarified beetroot juice were measured using Hunter color meter (Mini scan XE plus, model 45/0-S Hunter laboratory Inc, Baton, USA). Measurement was carried out at 10° observations, D65 illuminant source and instrument was calibrated using standard black and white tile provided by manufacturer. The colour values were expressed in CIE scale. where L^* refers to lightness, a^* refers to redness, $-a^*$ refers to greenness, b^* refers to yellowness and '-b' refers to blueness. The saturation index (Chroma) C^* and hue angle h^* were calculated using following equations:

$$\text{Saturation index (Chroma): } C^*= (a^{*2} + b^{*2})^{1/2}$$

$$\text{Hue angle: } h^*= \text{Tan}^{-1}(b^*/a^*) \text{ - - - - - } (4)$$

Rheological measurements

The rheological measurement of reconstituted beetroot juice at different solid contents were carried out using controlled stress rheometer (Model: MCR100, Paar Physica, Anton paar, Gmbh, Austria) equipped with concentric cylinders (CC 27) and the radii ratio of coaxial cylinders was 1.08477. The rheometer was equipped with an electric peltier temperature controlled system (TEZ-15P-C) to control the experimental temperature with an accuracy of 0.01°C and a circulating water bath was used (Viscotherm VT-2, Paar Physica, Anton paar Gmbh, Austria). The rheological parameter shear stress (Pa) was measured linearly increasing up to a shear rate of 1000 s^{-1} with 10 min duration and 30 shear stress-shear rate data points were collected and analyzed using universal software US200 (Paar Physica, Anton paar Gmbh, Austria). The shear rate range used encompasses most of the food processing applications such as pumping, in-pipe flow, mixing, stirring and grinding (Steffe 1992). The rheological measurements were carried out at different temperatures. All the measurements were done in triplicate and fresh sample was used in each measurement.

Statistical analysis

The experimental results and data analysis was carried out and analysis of variance of different means were evaluated at 95% confidence level ($p<0.05$) using statistical software (Statistica 7.0, Stat Soft Tulsa, USA).

Results and Discussion

Physico-chemical characteristics

The moisture content of beetroot juice is about 89.12%, ash content is 0.66% which indicated that an appreciable amount minerals present in the clarified beetroot juice. The pH of the juice is about 4.42 and acidity is about 0.523 % citric acid. The total soluble solid content is about 9.37 °brix which indicated that the soluble solid content is of sugars and organic acids. The betalain content is about 14.84 mg/100 ml and ascorbic acid content is 6.43 mg/100ml which exhibits the appreciable amount of antioxidant potential. The density and water activity of the clarified beetroot juice was about 1024.4 kg/m3 and 0.988 respectively. The CIE colour values such as lightness (L^*), redness (a^*), blueness (b^*) and chroma (c^*) of enzyme clarified beetroot juice were 0.240, 0.333, -0.177, 0.143 and 332.1 respectively and the colour values were very low where as hue angle is very high which indicated that better clarification and appreciable amount of pigments. The reducing and total sugar content of clarified beetroot juice was about 4.28% and 8.63% respectively. The reported values of beetroot juice were with in the reported results (Gopalan *et al*., 1989; Thakur and Das Gupta, 2006; Azeredo *et al.*, 2007).

Flow behaviour

The relation between shear stress and shear rate of reconstituted beetroot juice for different carrier materials such as maltodextrin (MD), gum Arabic (GA) and original juice (OJ) at constant temperature of 25°C and at a solid content of 40% was reported in Figure 1. Similar type of shear stress-shear rate relation was observed with other concentrations and temperatures studied. The rheogram showed that the shear stress increased markedly with increase with shear rate in case of gum Arabic based beetroot juice compared to that of maltodextrin and original juice. The marginal increase was observed in shear stress with shear rate in case of maltodextrin based juice compared to that of original juice (OJ). The shear stress was increased markedly with shear rate at lower temperatures and same trend was observed in higher temperatures with low magnitude of variation. The shear stress was increased markedly with shear rate at higher level of solid content and similar trend was observed with lower magnitude of increase at lower levels of solid content. The rheogram of reconstituted beetroot juices showed that there was linear increase in shear stress with respect to increase in shear rate, passed through origin while indicating the flow behaviour is Newtonian in

Table 1. Newtonian viscosity values of reconstituted spray dried beetroot juice powder at different solid content, temperatures and wall materials

Solid content (X_s) (%)	Temperature (°C)	Newtonian viscosity (η) (mPa s		
		Original juice (OJ)	Maltodextrin (MD)	Gum Arabic (GA)
10	10	7.52 ± 0.01	7.73 ± 0.01	9.00 ± 0.01
	25	6.32 ± 0.01	6.39 ± 0.01	8.02 ± 0.01
	40	5.57 ± 0.01	5.70 ± 0.00	7.12 ± 0.01
	55	5.14 ± 0.00	5.22 ± 0.01	6.38 ± 0.01
	70	4.77 ± 0.01	4.93 ± 0.00	6.02 ± 0.01
	85	4.47 ± 0.01	4.76 ± 0.01	5.60 ± 0.01
20	10	9.54 ± 0.01	10.10± 0.00	18.69 ± 0.01
	25	8.23 ± 0.01	8.70 ± 0.01	13.23 ± 0.02
	40	7.21 ± 0.01	7.79 ± 0.01	10.90 ± 0.01
	55	6.53 ± 0.01	7.15 ± 0.01	9.84 ± 0.01
	70	5.93 ± 0.01	6.51 ± 0.01	9.35 ± 0.01
	85	5.80 ± 0.01	6.17 ± 0.01	9.16 ± 0.01
30	10	14.55 ± 0.05	18.31 ± 0.01	66.86 ± 0.04
	25	10.93 ± 0.01	12.11 ± 0.01	41.89 ± 0.01
	40	9.63 ± 0.02	10.36 ± 0.04	29.96 ± 0.03
	55	8.77 ± 0.01	9.46 ± 0.01	23.18 ± 0.02
	70	8.30 ± 0.01	9.10 ± 0.01	18.69 ± 0.01
	85	8.08 ± 0.01	8.62 ± 0.01	15.83 ± 0.01
40	10	33.92 ± 0.04	45.48 ± 0.06	307.64± 0.83
	25	20.56 ± 0.05	26.51 ± 0.05	166.15± 1.34
	40	14.31 ± 0.03	17.74 ± 0.03	104.90± 0.90
	55	11.81 ± 0.01	13.38 ± 0.01	73.40 ± 0.08
	70	10.93 ± 0.01	12.07 ± 0.02	56.22 ± 0.05
	85	10.11 ± 0.01	10.89 ± 0.01	49.08 ± 0.09
50	10	86.99 ± 0.38	176.15 ± 0.36	1561.77 ± 23.76
	25	47.31 ± 0.07	85.55 ± 0.18	761.10 ± 12.82
	40	29.12 ± 0.10	49.78 ± 0.26	424.73 ± 8.15
	55	20.50 ± 0.11	32.81 ± 0.10	267.55 ± 6.54
	70	15.16 ± 0.05	23.60 ± 0.09	191.28 ± 2.30
	85	13.09 ± 0.03	19.15 ± 0.01	155.88 ± 2.47

Mean ± S D (n=3)

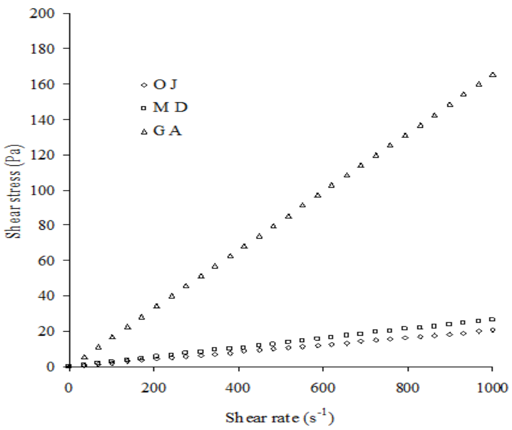

Figure 1. Rheogram of reconstituted beetroot juice for different carrier materials with original juice at constant temperature of 25°C and at constant solid content of 40%

nature. The Newtonian model was able to describe the relationship between shear stress and shear rate data and Newtonian viscosity (η) was estimated by using Newtonian model equation (equation 3). The magnitude of Newtonian viscosity values of original juice (OJ), maltodextrin (MD) and gum Arabic (GA) based reconstituted beetroot juices were reported in Table 1. The Newtonian viscosity (η) varies from 4.47 mPa s to 86.99 mPa s, 4.76 mPa s to 176.15 mPa s and 5.60 mPa s to 1561.77 mPa s for original, maltodextrin and gum Arabic based reconstituted beetroot juices respectively at different solid content and temperature studied. The magnitude of Newtonian viscosity of reconstituted beetroot was decreased significantly with increase in temperature and it was increased significantly with increase solid content. The Newtonian viscosity of reconstituted beetroot juice was higher in case of gum Arabic based juices followed by maltodextrin and original reconstituted juices. This indicated that the magnitude of viscosity of reconstituted beetroot juice dependent on nature solute, solid content and temperature studied. The viscosity of liquid foods strongly depends on inter-molecular forces between molecules and water-solute (sugars, acids and other macro molecule) interactions, which result from the inter-molecular spacing and strength of bonds as both are strongly affected by temperature and concentration. An increased solid content leads to increase in hydrated molecules and strength of bonding with functional groups of solute, which would increase the viscosity of juice. In case of reconstituted beetroot juice the nature of solute, amount of solute and temperature plays a vital role in magnitude of viscosity. The increase in temperature significantly decreases the magnitude of viscosity, because of increase in thermal energy of the molecules which enhances mobility of molecules and increases inter-molecular spacing (Steffe, 1992; Krokida *et al*., 2001; Rao, 2007). Similar type of result was reported in case concentrated beetroot juice (Juszczak *et al*., 2010). Salazar-Montoya *et al.* (2012) reported

Table 2. Parameter of Arrhenius equation on viscosity of reconstituted beetroot juice powder at different solid contents and wall material

Solid content (X_s) (%)	Arrhenius equation $\eta = \eta_\delta \, Exp(E_a/RT)$						r
	Frequency factor (η_δ) (mPa s)			Flow activation energy (E_a) (kJ/mol)			
	Original juice	Maltodextrin	Gum Arabic	Original juice	Maltodextrin	Gum Arabic	
10	$0.583^{aA}\pm0.006$	$0.661^{aB}\pm0.004$	$0.879^{aC}\pm0.0060$	$5.96^{aA}\pm0.03$	$5.70^{aAB}\pm0.02$	$5.47^{aB}\pm0.02$	>0.980
20	$0.738^{bA}\pm0.004$	$0.901^{bB}\pm0.006$	$0.375^{bC}\pm0.0025$	$5.99^{aA}\pm0.001$	$5.66^{aA}\pm0.01$	$9.04^{bB}\pm0.02$	>0.958
30	$0.676^{cA}\pm0.012$	$0.328^{cB}\pm0.001$	$0.035^{cC}\pm0.0002$	$7.08^{bA}\pm0.05$	$9.27^{bB}\pm0.01$	$17.75^{cC}\pm0.01$	>0.933
40	$0.029^{dA}\pm0.0002$	$0.011^{dB}\pm0.0002$	$0.0093^{dB}\pm0.00035$	$16.48^{cA}\pm0.02$	$19.55^{cB}\pm 0.04$	$24.44^{dC}\pm0.09$	>0.974
50	$0.002^{eA}\pm0.0001$	$0.0006^{dA}\pm0.00002$	$0.0051^{dA}\pm0.0011$	$24.89^{dA}\pm0.09$	$29.61^{dB}\pm0.08$	$29.63^{eB}\pm0.56$	>0.996

Mean ± S D (n=3)
Different first superscripts a, b, c… in a column shows significantly different at $p < 0.05$
Different second superscripts A, B, C in a row shows significantly different at $p < 0.05$

that the flow behaviour of gum Arabic dispersions upto the concentration of 35% showed Newtonian behaviour and at 45% gum concentration it showed non-Newtonian behaviour and it was confirmed from our investigation the flow behaviour of reconstituted beetroot juice was Newtonian in nature since solid content was studied from 10 to 50%. The flow behaviour of josapine pineapple juice at different maturity levels was Newtonian in nature and viscosity of pineapple juice increased with concentration and decreased with maturity stage and temperature (Shamsudin *et al.,* 2009). The flow behaviour of carrot puree was pseudoplastic (shear thinning) in nature and described by power law model. The power law model parameters were markedly affected by temperature and amount of potato flakes addition (Hecke *et al*., 2012). The rheological properties of watermelon juice were dependent on particle size, solid content and temperature. The consistency coefficient k is increased with total soluble solid content as well as particle size and is decreased with increase temperature of watermelon juice (Sogi *et al*., 2010). The viscosity of goldenberry juice was markedly affected by enzyme treatment and as well as temperature (Sharoba and Ramadan, 2011). The Newtonian viscosity of pomegranate juice is significantly affected by total soluble content and temperature while it was not affected by the method of concentration (Altan and Maskan, 2005). Juszczak *et al*., (2010) reported that beetroot juice concentrate had a lower viscosity than concentrated fruit juices with same soluble solid content and at the same temperature studied. This deviation was attributed to its different levels of individual constituent sugars present in the juice. The rheological properties of aqueous carbohydrate solutions such as sucrose, glucose and fructose were reported at different temperatures and concentrations, the aqueous carbohydrate solution behaved like a Newtonian liquid. The magnitude of viscosity decreased in following order of solutes; sucrose, glucose, and fructose at same temperature and concentration studied and these differences were reduced with increase in temperature and decreasing solution concentration (Telis *et al*., 2007). The sugar and sorbital solutions behaved like Newtonian fluids; while the other syrups such as polydextrose, maltodextrin and polydextrose combination behaved like non-Newtonian pseudoplastic (shear thinning) flow behaviour with yield stress. The results showed that the flow behaviour of polydextrose and combination of maltodextrin + polydextrose syrups obeyed Hershel–Bulkley model (Chetana *et al*., 2004). The viscosity of liquid depends on nature of solute, its molecular weight, molecular size and shape, solute-solvent interactions, and state of hydration (Nindo *et al*., 2005; Fennema, 2005; Telis *et al*., 2007).

Effect of temperature

The temperature had a significant effect on the Newtonian viscosity fluids similar to that of consistency coefficient for non-Newtonian fluids. The increase in temperature of fluid leads to marked increase in mobility of the molecules and increase in intermolecular spacing, which reduces the flow resistance. The viscosity of reconstituted beetroot juice of different carrier materials was decreased markedly with increase in temperature. The variation in viscosity of beetroot juice with temperature was significantly high at higher soluble solid content and dependent on type of carrier material. The effect of temperature on the viscosity of reconstituted beetroot juice with different solid contents was described using the Arrhenius equation. Several authors were used Arrhenius equation to describe the variation of viscosity with temperature (Chetana *et al*., 2004; Altan and Maskan 2005; Kaya and Sozer, 2005; Chin *et al*., 2009; Shamsudin *et al*., 2009; Juszczak *et al*., 2010; Manjunatha *et al*., 2012a, 2012b; Manjunatha and Raju, 2013; Pranjal *et al*., 2015)

$$\eta = \eta_{\infty} EXp(E_a/RT) \qquad ---- (5)$$

where η = Viscosity (Pa s), $\eta\infty$ = pre-exponential coefficient/Material constant/frequency factor (Pa s), E_a= activation energy for viscous flow (J/mol), R= Gas constant (J/mol K) and T= Temperature (K).

The parameters of Arrhenius equation which was determined by least square approximation method with high correlation coefficient ($0.933<r<0.996$) and reported in Table 2. The flow activation energy (E_a) and pre-exponential coefficient were markedly affected by solid content and carrier material of beetroot juice. The activation energy for viscous flow of reconstituted beetroot juice varies from 5.96 to 24.89 kJ/mol, 5.70 to 29.61 kJ/mol and 5.47 to 29.63 kJ/mol for original juice (OJ), maltodextrin (MD) and gum arabic (GA) based beetroot juices respectively and it depending upon the amount of solid content studied. The activation energy for viscous flow (Ea) was defined as minimum energy required which overcomes the energy barrier before the elementary flow can occur. The viscous flow occurs as a sequence of events which are shift of particles in the direction of shear force action from one equilibrium position to another position by overcoming a potential energy barrier. The barrier height determines the free activation energy of viscous flow. Higher activation energy value indicates a greater influence of temperature on the viscosity, i.e. more rapid change in viscosity with temperature. The magnitude of energy of activation for viscous flow increased markedly with increase in solid content of reconstituted beetroot juices, indicating that higher energy was required to overcome potential energy barrier at higher solids content. The flow activation energy was markedly affected by carrier material at higher solid content and, flow activation energy of gum Arabic based beetroot juice was higher compare to that of original and maltodextrin based reconstituted beetroot juice at above 20% solid content. As amount of solid content increased the significant change was observed this was due increase in amount of carrier materials in reconstituted beetroot juice. Therefore, temperature and type of solute had a greater effect on viscosity of fluid at higher 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, 1992; Rao, 2007). The magnitude of flow activation energy of Newtonian fluids increased significantly with increase in total solid content (Krokida *et al*., 2001). The magnitude of activation energy of viscous flow was in conforming to values reported for liquid foods and other fluids (Ibarz *et al*., 1992a, 1992b; Chetana *et al*., 2004; Juszczak and Fortuna, 2004; Altan and Maskan, 2005; Kaya and Sozer, 2005; Telis *et al*., 2007; Tavares *et al*., 2007; Chin *et al*., 2009; Juszczak *et al*., 2009; Shamsudin *et al*., 2009; Falguera and Ibarz, 2010; Juszczak *et al*., 2010; Manjunatha *et al*., 2012a; 2012b; Pranjal *et al*., 2015; Manjunatha and Raju, 2013; Shamsudin *et al*., 2013). The activation energy for viscous flow of goldenberry juice was markedly affected by enzyme treatment and total soluble solid content (Sharoba and Ramadan, 2011). The magnitude of flow activation energy of pineapple juice was not affected by ultraviolet-irradiated and thermally pasteurized treatment as compared to that of untreated sample (Shamsudin *et al*., 2013). Falguera and Ibarz, (2010) reported that the activation energy for viscous flow of orange juice was increased marginally with shear rate. Altan and Maskan (2005) reported the activation energy for pomegranate juice was not affected by the method of concentration and increased with total soluble solid content. The flow activation energy of pineapple juice was markedly increased with total soluble solid content and it decreased with increase in maturity stage of pineapple (Shamsudin *et al*., 2009). The flow activation energy of carrot puree was independent of potato flakes addition upto 5% level (Hecke *et al*., 2012). The flow activation energies of bulk sweeteners such as sorbitol, polydextrose and the combination maltodextrin + polydextrose compared to sugar solution have been studied, the polydextrose solution showed maximum activation energy followed by maltodextrin + polydextrose combination and sugar solution where as sorbitol showed low flow activation energy compared to of sugar solution compared at same concentration (Chetana *et al*., 2004). The Arrhenius equation satisfactorily described the temperature dependency of viscosity of model solutions such as sucrose, glucose, fructose and the flow activation energy was

Table 3. Parameters of exponential model relating to Newtonian viscosity on solid content of reconstituted spray dried beetroot juice powder of different wall material at different temperatures

Temperature (°C)	Exponential model: $\eta = a\,Exp(b\,X_s)$						r
	a (mPa s)			b ($\%^{-1}$)			
	Original juice	Maltodextrin	Gum Arabic	Original juice	Maltodextrin	Gum Arabic	
10	$1.1481^{aA}\pm0.0128$	$0.3269^{aB}\pm0.0031$	$0.5621^{aC}\pm0.0358$	$0.0864^{aA}\pm0.0003$	$0.1257^{aB}\pm0.0002$	$0.1578^{aC}\pm0.0016$	>0.995
25	$1.4886^{bA}\pm0.0087$	$0.4904^{bB}\pm0.0012$	$0.4132^{bC}\pm0.0305$	$0.0687^{bA}\pm0.0003$	$0.1030^{bB}\pm0.0001$	$0.1504^{bC}\pm0.0018$	>0.988
40	$2.1613^{cA}\pm0.0079$	$0.8677^{cB}\pm0.0143$	$0.4434^{bcC}\pm0.0389$	$0.0512^{cA}\pm0.0001$	$0.0805^{cB}\pm0.0004$	$0.1374^{cC}\pm0.0004$	>0.982
55	$2.7873^{dA}\pm0.0173$	$1.4836^{dB}\pm0.0154$	$0.4898^{cdC}\pm0.0436$	$0.0391^{dA}\pm0.0002$	$0.611^{dB}\pm0.0003$	$0.1274^{dC}\pm0.0004$	>0.973
70	$3.3441^{eA}\pm0.0163$	$2.3139^{eB}\pm0.0133$	$0.5095^{acdeC}\pm0.0211$	$0.0301^{eA}\pm0.0002$	$0.0456^{eB}\pm0.0002$	$0.1185^{eC}\pm0.0011$	>0.981
85	$3.5142^{fA}\pm0.0099$	$2.7007^{fB}\pm0.0048$	$0.5607^{aeC}\pm0.0263$	$0.0264^{fA}\pm0.0001$	$0.0383^{fB}\pm0.0001$	$0.1125^{fC}\pm0.0012$	>0.984

Different first superscripts a, b, c… in a column shows significantly different at $p < 0.05$
Different second superscripts A, B, C in a row shows significantly different at $p < 0.05$

correlated with solute content by unique equation as a function of an effective volumetric fraction of solute (Telis *et al*., 2007).

Effect of solid content on flow activation energy

The activation energy for viscous flow of reconstituted beetroot juice was increased markedly with increase in solid content. The variation flow activation energy with solid content was described by non-linear equation and several authors were used the exponential equation to describe to the variation of solid content with flow activation energy (Kaya and Sozer, 2005; Altan and Maskan, 2005; Shamsudin *et al.,* 2007; Shamsudin *et al*., 2009; Juszczak *et al*., 2009; Manjunatha *et al*., 2012a, 2012b; Manjunatha and Raju, 2013; Pranjal *et al*., 2015) and represented as

$$E_a = a\ Exp\ (b\ X_s) \quad \text{--------} \ (6)$$

where E_a is flow activation energy in kJ/mol, a is empirical constant in kJ/mol, b is constant $\%^{-1}$ and X_s is the solid content in %. The parameters of the model were evaluated by the method of least square approximation and model parameter 'a' was 2.317, 2.401 and 5.351 where as the parameter 'b' was 0.0475, 0.0505 and 0.0353 for original, maltodextrin and gum Arabic based reconstituted beetroot juice respectively. The correlation coefficient of model is greater than 0.97. The coefficient of solid content of the relation between flow activation energy with solid content was significantly affected by type of material. The variation was very high in case of gum Arabic based juice followed by maltodextrin and original juice. The coefficient of solid content for variation of solid content with flow activation energy was markedly affected by maturity level of pineapple juice (Shamsudin *et al*., 2009). The coefficient of solid content values of exponential model for variation of flow activation energy with solid content of reconstructed beetroot juices were comparable to that of other liquid foods values such as juices of pomegranate, pineapple, chokeberry, lime, gooseberry, sapota and tender coconut water (Kaya and Sozer, 2005; Altan and Maskan, 2005; Shamsudin *et al*., 2007; 2009; Juszczak *et al*., 2009; Manjunatha *et al*., 2012a; 2012b; Pranjal *et al*., 2015; Manjunatha and Raju, 2013). These variations of magnitude of coefficient of solid content may be due to range solid content, range of temperature studied as well as nature and type of solute, its molecular weight, shape and size of the solute molecules.

Effect of solid content

The concentration of the soluble solids as well as insoluble solid content had a strong marked effect on the viscosity of the Newtonian fluids, whereas in case of non-Newtonian fluids consistency index and apparent viscosity were markedly significantly affected by nature and type of solids (Krokida *et al*., 2001). The viscosity of a fluid food is dependent on nature of solvent, nature of solute, their interaction, and amount of solid content in solution, solute shape, size, molecular weight and state of hydration. The viscosity of reconstituted beetroot juice increased

Table 4. Combined effects of temperature and solid content on Newtonian viscosity of reconstituted spray dried beetroot juice powder of different wall material

Wall material	Combined equation : $\eta = a\,Exp(b/T + c\,X_s)$			r
	a (mPa s)	$b=E_a/R$	c ($\%^{-1}$)	
Original juice	$1.830 \times 10^{-4a} \pm 6.669 \times 10^{-6}$	$2654.24^a \pm 8.56$	$0.0724^a \pm 0.0002$	0.9754
Maltodextrin	$3.616 \times 10^{-6b} \pm 1.223 \times 10^{-7}$	$3396.87^b \pm 7.88$	$0.1133^b \pm 0.0002$	0.9873
Gum Arabic	$2.705 \times 10^{-6b} \pm 7.010 \times 10^{-7}$	$3530.56^c \pm 64.62$	$0.1535^c \pm 0.0012$	0.9986

Different superscripts in a column shows significantly different at $p < 0.05$

significantly ($p<0.05$) with increase in solid content and also dependent on nature of solute material. The variation in viscosity with solid content was due to variation in degree of hydration of solute molecules, increase in bonding with hydroxyl groups of solute and decrease in inter-molecular spacing. The variation of viscosity of reconstituted beetroot juice with total solid content was non-linear in nature. Several authors used exponential type relation to describe the variation of solid content with viscosity of fluid including fruits and vegetable juices (Juszczak and Fortuna, 2004; Altan and Maskan, 2005; Kaya and Sozer, 2005; Shamsudin *et al.*, 2007; Juszczak *et al.*, 2009; Juszczak *et al.*, 2010) and the equation represented as

$$\eta = a\,Exp\,(b\,X_s) \qquad \text{------ (7)}$$

where η is the Newtonian viscosity in mPa s, X_s is the solid content in %, and a, b are empirical constants. The exponential model parameters relating to Newtonian viscosity with solid content at different temperature of different carrier materials were reported in Table 3. The pre-exponential parameter is significantly ($p<0.05$) affected by type of material present in the beetroot juice. The coefficient of solid content parameter 'b' decreased significantly ($p<0.05$) with increasing temperature and it is high in case of gum Arabic based juice followed by maltodextrin and original beetroot juice. This indicated that the variation of viscosity with solid content were sensitive at low temperatures. Similar type of results was reported for variation of Newtonian viscosity with total soluble solid content (Juszczak and Fortuna, 2004; Altan and Maskan, 2005; Kaya and Sozer, 2005; Shamsudin *et al.*, 2007; Juszczak *et al.*, 2009; Juszczak et al., 2010; Manjunatha et al., 2012a; Manjunatha *et al.*, 2012b; Manjunatha and Raju, 2013: Pranjal *et al.*, 2015). The viscosity of aqueous carbohydrate solution such as glucose, fructose and sucrose were significantly affected by type of sugar at temperature studied and this deviation was attributed based on effective volumetric fraction of solute (Telis 2007). Chetana *et al.*, (2004) reported that the apparent viscosity of polydextrose syrup was higher followed by maltodextrin + polydextrose, sugar and sorbitol syrup at same solid content at different temperatures studied. The viscosity of fluid was markedly affected by nature of solute, solvent, solute-solvent interactions, size and shape of the solute molecule, molecular weight, temperature and state of hydration (Chetana *et al.*, 2004; Nindo *et al.*, 2005; Fennema, 2005; Telis *et al.*, 2007).

Combined effect of temperature and solid content

The rheological properties of fluid food is very important during food processing, from engineering point of view; to obtain a single equation which describes the temperature and soluble solid content on viscosity of reconstituted beetroot juice. Several authors used exponential type equation to describe the combined effect of temperature and solid content on Newtonian viscosity of fluid food including beetroot juice (Giner *et al.*, 1996; Juszczak and Fortuna, 2004; Altan and Maskan, 2005; Kaya and Sozer, 2005; Shamsudin *et al.*, 2007; Juszczak *et al.*, 2009; Ibarz *et al.*, 2009; Juszczak *et al.*, 2010; Manjunatha *et al.*, 2012b) and the model equation was described as

$$\eta = a\,Exp\,(b/T + c\,X_s) \qquad \text{------- (8)}$$

where η is the Newtonian viscosity in mPa s, a is pre-exponential constant in mPa s, $b= E_a/R$, E_a is the flow activation energy in J/mol, R is universal gas constant in J/mol K, T is absolute temperature in Kelvin (K), c is constant is in %-1 and X_s is solid content in %. The parameters of the exponential model equation was evaluated by the method of least square approximation with appreciable correlation coefficient (r>0.975) and reported in Table 4. The pre-exponential coefficient 'a' for original juice is significantly ($p<0.05$) varies compare to that of maltodextrin and gum Arabic based juices, however there is no significant change was observed between maltodextrin and gum Arabic based reconstituted beetroot juices. The parameter 'b' represented as coefficient of temperature was significantly ($p<0.05$) affected by type of material in reconstituted beetroot juice and parameter 'b' is higher in case of gum Arabic based juice and followed by maltodextrin and original beetroot juice. The coefficient of solid content (parameter 'c') was significantly varies with type of wall material in reconstituted beetroot juice. The coefficient of solid content (parameter 'c') is higher for gum Arabic based juice followed by maltodextrin and original reconstituted beetroot juices. This indicated that the variation of viscosity with temperature and solid content of gum Arabic juice was significantly higher, followed by maltodextrin and original reconstituted beetroot juices. This was due to the nature of solute present in the reconstituted beetroot juices. These results showed that the Newtonian viscosity of reconstituted beetroot juice was significantly affected by solid content, temperature and nature of material present in the juice. This investigation is highly useful in understanding the rheological properties and structural properties of beetroot juice, and hence provides useful information required for the development of novel beetroot juice based products with appreciable shelf life and other quality characteristics.

Conclusions

This investigation showed that the original, maltodextrin and gum Arabic based reconstituted beetroot juices behaved like Newtonian fluid. The Newtonian viscosity (η) ranges from 4.47 to 86.99, 4.76 to 176.15 and 5.60 to 1561.77 mPa s for original, maltodextrin (MD) and gum Arabic (GA) based juices respectively, depending upon the solid content and temperature used. The results indicated that the Newtonian viscosity increased significantly ($p<0.05$) with increase in solid content, whereas it decreased significantly ($p<0.05$) with increase in temperature. Among all the carrier materials, gum Arabic based juice showed maximum viscosity followed by maltodextrin and original juice at same solid content and temperature studied. The Arrhenius equation was able to describe the temperature dependency of Newtonian viscosity of beetroot juice. The flow activation energy (E_a) was markedly affected by type of carrier material and is increased significantly ($p<0.05$) with increase in solid content. The Newtonian viscosity of reconstituted spray dried beetroot juice increased with solid content and a significant ($p<0.05$) change was observed with different temperatures used and also markedly affected by type of carrier material. A combined single equation relating Newtonian viscosity (η) to solid content and temperature of different carrier material reconstituted beetroot juice was established. The results showed that the Newtonian viscosity of reconstituted beetroot juice was dependent on solid content, temperature and type of carrier material.

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