

Influence of moisture content on thermophysical properties of enzyme clarified sapota (*Achras sapota* L.) juice

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Abstract

Investigation was carried out to evaluate thermophysical properties such as density, Newtonian viscosity, thermal conductivity, specific heat and thermal diffusivity of enzyme clarified sapota (*Achras sapota* L.) juice at different moisture contents ranging from 38.01% to 88.64% (wet basis) corresponding to a water activity in the range of 0.839 to 0.987. The investigation showed that density and Newtonian viscosity of enzyme clarified sapota juice decreased significantly ($p < 0.05$) with increase in moisture content as well as water activity, whereas thermal conductivity increased significantly ($p < 0.05$) with increase in moisture content and water activity. The specific heat and thermal diffusivity were markedly affected by moisture content as well as water activity. Empirical mathematical models were established relating to thermophysical properties of enzyme clarified sapota juice with moisture content/water activity. Results indicated that there was a high significant ($p < 0.0001$) correlation between thermophysical properties with moisture content/water activity of enzyme clarified sapota juice. A significant ($p < 0.0001$) positive correlation between thermal properties and moisture content/water activity, whereas significant ($p < 0.00001$) negative correlation between physical properties with moisture content/water activity was observed. In general, the thermophysical properties of enzyme clarified sapota juice were markedly affected by moisture content/water activity.

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Introduction

The knowledge of thermophysical properties of food and raw agricultural materials is essential for design and periodic improvement food processing machines and equipments. The accurate values of thermophysical properties of foods are very important and essential to estimate the rate of heat transfer during different food processing applications. The information of thermophysical properties of foods is essentially required in design of industrial plants, modelling, and automation of food processing operations to obtain better quality and improve the shelf life of products. A group of thermal and related physical properties known as thermophysical properties provide a powerful tool for design and prediction of heat transfer operations during handling, processing, canning and distribution of foods. The variation in composition of food generally affects the thermophysical properties such as density, viscosity, specific heat, thermal conductivity and thermal diffusivity. The mathematical models that represent the variation of thermophysical properties based on different constituents of food are very useful for implementations of computer-aided process

automation and equipment design (Urbican and Lozano, 1997).

The quality of fruit juices the mouth feel, which is defined as the experience derived from the sensation of skin of the mouth after consumption of beverage relates to physical properties of the sample material such as viscosity, density surface tension etc. as the complex mouth feel function is the physical interaction of the tongue and palate. The physical, rheological and thermal properties of fruit juices are gaining more importance as thermophysical characteristics of fruit juices had been evaluated and quantified (Ingate and Christensen, 1981). Fruit juices and juice concentrates have a major share in the commercialisation of processed fruit juice products. The fruit juice concentrates have higher stability because of low water activity levels and they can be used as basic ingredients in many products such as fruit syrup, squash, ready-to-serve (RTS), carbonated and non-carbonated beverages (Shamsuddin *et al.*, 2007).

Water activity of food is defined as the ratio of the equilibrium vapour pressure exerted by the food to the vapour pressure of pure water at the same temperature and which indicates the amount

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of water available for microbial growth. The water activity is a measure of the energy state of water in the system and it is a measure of free, unbound and available water in the food system. There are several factors that control water activity in a food system, the colligative effect of dissolved species (salts, sugars and acids) interact with water through dipole-dipole, ionic and hydrogen bonds. Influence of water activity may induce profound changes in the quality and stability of a food product and it is an important factor in packaging of food materials. Water activity is a critical factor that determines the shelf life of the food. The water activity of food is important, rather than total water content for deciding the quality and stability of food (Fennema, 2005).

Enzyme clarification is one of the most important techniques to enhance qualitative and quantitative characteristics of juice. Several authors studied the effect of enzyme clarification on physicochemical characteristics of different fruit juices (Rai *et al.*, 2004; Lee *et al.*, 2006; Sin *et al.*, 2006; Abdullah *et al.*, 2007). There are several studies reported, about de-pectinisation using enzymatic treatment such as pectinase enzymes, which could effectively clarify the fruit juices (Chamchong and Noomhorm, 1991; Brasil *et al.*, 1995; Ceci and Lozano, 1998; Kashyap *et al.*, 2001; Vaillant *et al.*, 2001; Matta *et al.*, 2004; Singh and Gupta, 2004; Vandana and Das Gupta, 2006; Cassano *et al.*, 2007; Aliaa *et al.*, 2010).

Sapota (*Achras sapota* L.) is a tropical fruit belonging to the family *Sapotaceae* native to Mexico, Central America, and is extensively grown in other parts of world such as southern Florida in the U.S., India, Sri Lanka, Indonesia, Philippines and Caribbean Islands (Salunkhe and Desai, 1984). Kulkarni *et al.* (2007) evaluated the chemical composition and antioxidant activity of sapota juice. The total phenolic content and antioxidant potential of *Mamey sapota* (*Pouteria sapota*) during postharvest were evaluated and found that hydrophilic extract of sapota fruit showed higher antioxidant capacity than that of lipophilic portion (Rodriguez *et al.*, 2011). The sapota fruit contains appreciable amount of total soluble phenolic content in the form of p-hydroxy benzoic acid has been reported (Yahai *et al.*, 2011). Sapota juice can be used as nutritional as well as nutraceutical health beverage, which contains large amount of polyphenols. Sapota juice can be used as a health-promoting beverage due to its multifunctional properties. There is lack of information on thermophysical properties of enzyme clarified sapota juice and its concentrates, which is essentially required for development of novel sapota juice products with better quality in large scale commercial production. The present investigation

was aimed at studying the thermophysical properties of enzyme clarified sapota juice at different moisture contents and modelling of these properties.

Material and Methods

Raw material

Sapota fruits were procured from local market, Mysore, India with proper maturity and allowed 24 hrs for proper ripening at room temperature.

Juice extraction

Fruits were washed with water twice and allowed to dry at room temperature. The washed and dried fruits were peeled, deseeded and blended using a commercial blender (Waring Laboratory, Torrington, CT) for 5 min until a homogenous fruit pulp was obtained. The sapota pulp was pasteurized in water bath at 95°C for 5 min to inactivate the enzymes. Enzymatic clarification was carried out using commercial enzyme, Pectinex ultra SPL (Novozyme, Denmark). The concentration of enzyme, incubation temperature and time was fixed and clarification was carried out as reported (Sin *et al.*, 2006). The enzyme was inactivated by placing the material in water bath maintained at 95°C for 3 minutes followed by cooling in ice cold water. The sapota pulp was filtered with four fold muslin cloth and pressed in tincture press (Hafio, West Germany). The filtered sapota juice was centrifuged at relative centrifugal force 15000 rpm using continuous centrifuge (CEPA, Lahr/Baden, and West Germany). The clarified sapota juice was subjected for concentrations/modification.

Juice concentration

The enzyme clarified sapota juice was concentrated by vacuum evaporation technique using laboratory rotary vacuum evaporator (Model: Laborata 4001, Heidolph, Germany) with reduced pressure, at 60°C and rotation speed of 60 rpm. Sapota juice was concentrated to different concentration levels and subjected to rheological and thermophysical properties measurements.

Analytical methods

The Moisture, protein, ash contents and acidity of enzyme clarified sapota juice determined by vacuum oven, micro-Kjeldahl, gravimetric and titration method respectively as described (Raganna, 1986). Reducing sugar and total sugar of sapota juice were determined colorimetrically using 3-5, dinitro salicylic acid reagent (Miller, 1959). The total soluble solids content of sapota juice was determined using digital hand-held refractometer (Atago co,

Ltd., Tokyo, Japan) was expressed as °Brix. A digital pH meter was used to measure the pH of sapota juice (Cyber scan, India) at 25°C. The water activity of sapota juice at different concentration was measured using digital water activity meter at 25°C (Aqua Lab, model 3T E, Decagon Devices, USA) and was calibrated using standard solutions obtained from original manufacturers (Decagon, Pullman WA, USA).

Colour measurement

The colour parameters of clarified sapota juice were measured using Hunter colour meter (Mini scan XE plus, model 45/0-S Hunter laboratory Inc, Baton). Measurement was carried out at 10° observations, D65 illuminating source and instrument was calibrated using standard black and white tile provided by manufacturer.

Density

The density (ρ) of enzyme clarified sapota juice was measured at 25°C using 25 ml pycnometer (Constenla *et al.*, 1989), the pycnometer was previously calibrated with distilled water and expressed as kg m^{-3} .

Rheological measurements

The rheological measurements were carried out using MCR100 controlled stress rheometer (Paar Physica, Anton paar, GmbH, Austria) equipped with coaxial cylinders (CC 27) and the radii ratio of coaxial cylinders was 1.08477. The rheometer was equipped with an electric temperature controlled peltier system (TEZ-15P-C) to control the experimental temperature and to maintain constant temperature, 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 750 s^{-1} with 25 shear stress-shear rate data points were collected and analyzed using universal software US200 (Paar Physica, Anton paar GmbH, Austria). The rheological measurement of enzyme clarified sapota juice at different moisture contents were carried out in triplicate and fresh sample was used in each measurement. The viscosity values were calculated by experimental shear stress-shear rate data fitting Newton's equation.

Thermal conductivity

The thermal conductivity of enzyme clarified sapota juice was determined using a thermal properties analyzer type KD2 (Decagon Devices, USA). It was operated based on line heat source method. The measurement was carried out by placing

liquid sample in 50 ml test tube and a rubber cork was inserted into the test tube. The needle of thermal conductivity meter was inserted into the sample through rubber cork and sample was kept in water bath maintained at 25°C and thermal resistivity values were obtained directly from the digital readout. The thermal conductivity was calculated from thermal resistivity values and expressed in $\text{W m}^{-1}\text{K}^{-1}$.

Specific heat

The specific heat of enzyme clarified sapota juice was measured by the method of mixtures using Joule's calorimeter. The unknown specific heat of sample (C_s) was computed from the heat balance equation. The temperature of the mixture was measured by multiple probes at different locations of the mixture using temperature monitoring system (CTF 9008, ELLAB A/S, Denmark). Temperature of the mixture was recorded at equilibrium (T_{eq}) point and specific heat of liquid was calculated by heat balance equation as described (Mohsenin, 1980; Kocabiyik *et al.*, 2009) and specific heat of sapota juice was expressed in $\text{J kg}^{-1}\text{K}^{-1}$.

Thermal diffusivity

The thermal diffusivity (α) of enzyme clarified sapota juice was from the combination of three thermophysical properties such as thermal conductivity, density and specific heat from the following equation which was derived from Laplace equation of conduction

$$\alpha = k / \rho C_p \text{ ----- (1)}$$

where α is thermal diffusivity ($\text{m}^2 \text{ s}^{-1}$), k is thermal conductivity ($\text{W m}^{-1}\text{K}^{-1}$), ρ is density kg m^{-3} and C_p is the specific heat ($\text{J kg}^{-1}\text{K}^{-1}$) of enzyme clarified sapota juice.

Modelling

Several empirical models were suggested by different authors for establishing the relationship between thermophysical properties and moisture content/water activity. These model parameters were evaluated by method of least square approximation (Telis-Romero *et al.*, 1998; Muramatsu *et al.*, 2005; Fontan *et al.*, 2009; Jagannadha Rao *et al.*, 2009; Garza and Ibarz, 2010)

$$\begin{aligned} T P &= a + b X_w \\ T P &= a + b X_w + c X_w^2 \\ T P &= a \exp(b X_w) \\ T P &= a (X_w)^b \text{ ----- (2)} \\ T P &= a + b a_w \end{aligned}$$

$$\begin{aligned}
 TP &= a + b a_w + c a_w^2 \\
 TP &= a \exp(b a_w) \\
 TP &= a (a_w)^b
 \end{aligned}$$

where TP is thermophysical property, a, b and c are empirical constants, X_w is moisture content (% wet basis) and a_w is the water activity.

Statistical analysis

The experimental results and data analysis were carried out using statistical software (Statistica 7.0, Stat Soft Tulsa, USA). The fitting and estimates were calculated at 5% significance level ($p \leq 0.05$). The suitability of the empirical models were evaluated by determining the correlation coefficient (r) and root mean square error percent (rmse %) using the following equation

$$\text{rmse \%} = 100/n [\sum((W_{\text{exp}} - W_{\text{cal}})/W_{\text{exp}})^2]^{1/2} \text{ ----- (3)}$$

where W_{exp} is the experimental value, W_{cal} is the calculated value and n is number of data sets. The suitability of the model was decided based on higher correlation coefficient (r) and low percent root mean square error (rmse %) values and level of significance ($p < 0.05$).

Results and Discussion

Physico-chemical characteristics

The nutritional composition of enzyme clarified sapota juice such as moisture, protein, ash, reducing and total sugar contents were found to be 80.30%, 0.0918%, 0.398%, 10.89% and 16.91% respectively. The total soluble solid content and water activity was found to be 18.0°brix and 0.984, respectively. The pH and acidity were found to be 4.70 and 0.199% as citric acid respectively. The CIE colour L^* , a^* and b^* values were 2.981, 0.050 and 3.051, respectively. The colour values were very low which indicated that the clarification was appreciable.

Density

The density of liquid is defined as mass per unit volume, plays an important role in heat, mass and momentum transfer phenomena in several food processing unit operations. The density of liquid foods depends on the nature and amount of solvent, solute (sugars, organic acids and other macromolecules) and their interaction with solvent (water). The density of enzyme clarified sapota juice was decreased significantly ($p < 0.05$) from 1266.27 to 1042.24 kg m^{-3} with increase in moisture content and water activity as reported in Table 1. The decrease

Table 1. Thermophysical properties of enzyme clarified sapota (*Achras sapota* L.) juice at different moisture/water activity levels at 25°C

Moisture content (% wb)	Water activity	Density (ρ) (kg m^{-3})	Viscosity (η) (mPa.s)	Thermal conductivity (k) ($\text{W m}^{-1} \text{K}^{-1}$)	Specific heat (c_p) ($\text{J kg}^{-1} \text{K}^{-1}$)	Thermal diffusivity (α) ($\text{m}^2 \text{s}^{-1} \times 10^7$)
38.01	0.839	1266.27 ^a ± 0.47	39.553 ^a ± 0.119	0.3989 ^a ± 0.0009	3019.64 ^a ± 33.47	1.043 ^a ± 0.013
48.98	0.891	1215.79 ^b ± 1.83	18.078 ^b ± 0.057	0.4178 ^b ± 0.0010	3213.68 ^b ± 19.90	1.071 ^b ± 0.008
51.16	0.920	1186.30 ^c ± 2.34	13.450 ^c ± 0.104	0.4399 ^c ± 0.0011	3262.25 ^c ± 8.58	1.137 ^c ± 0.002
61.37	0.950	1163.43 ^d ± 1.39	8.306 ^d ± 0.004	0.4532 ^d ± 0.0012	3355.79 ^d ± 8.50	1.161 ^d ± 0.002
70.98	0.977	1122.88 ^e ± 0.77	7.021 ^e ± 0.007	0.4566 ^e ± 0.0000	3459.69 ^e ± 17.22	1.175 ^e ± 0.006
80.30	0.984	1087.25 ^f ± 2.76	6.033 ^f ± 0.013	0.5272 ^f ± 0.0016	3709.59 ^f ± 14.01	1.307 ^f ± 0.008
88.64	0.987	1042.24 ^g ± 2.69	5.221 ^g ± 0.007	0.5703 ^g ± 0.0018	3926.64 ^g ± 20.22	1.394 ^g ± 0.009

Mean ± SD (n = 3), Different superscripts in column shows significantly different at $p \leq 0.05$

Table 2. Parameters of the different models relating to density (ρ) to moisture content/water activity levels of enzyme clarified sapota juice

Model	a (kg m^{-3})	b ($\text{kg m}^{-3} \text{ brix}^{-1}$)	c ($\text{kg m}^{-3} \text{ brix}^{-2}$)	r	rmse%
$\rho = a + b X_w$	1417.53 ^{***} ± 3.89	-4.188 ^{**} ± 0.060	-	0.9938	0.252
$\rho = a + b X_w + c X_w^2$	1437.91 ^{***} ± 9.45	-4.876 ^{**} ± 0.385	0.0066 ^{ns} ± 0.003	0.9941	0.250
$\rho = a (a_w)^b$	2800.40 ^{***} ± 31.02	-0.216 ^{**} ± 0.003	-	0.9875	0.379
$\rho = a \exp(b X_w)$	1448.49 ^{***} ± 4.46	-0.00364 ^{***} ± 0.00005	-	0.9940	0.252
$\rho = a a_w$	2577.34 ^{***} ± 356.93	-1307.15 ^{***} ± 15.09	-	0.9463	0.793
$\rho = a a_w + c a_w^2$	-2910.55 ^{ns} ± 358.27	10259.93 ^{ns} ± 794.77	-6303.41 ^{ns} ± 438.38	0.9663	0.631
$\rho = a (a_w)^b$	1076.77 ^{***} ± 1.24	-0.998 ^{**} ± 0.011	-	0.9365	0.859
$\rho = a \exp(b a_w)$	3222.82 ^{***} ± 35.91	-1.099 ^{**} ± 0.012	-	0.9416	0.827

Mean ± S D (n = 3), *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, ns $p > 0.05$, (ρ is density in kg m^{-3} , MC is moisture content in %, a_w is water activity dimensionless).

in magnitude of density of sapota juice is due to increase in moisture content by dilution phenomena. The increase in water content resulted in a substantial decrease of water-solute aggregations which reduces the density of sapota juice. The soluble solids of sapota juice interact with substantial number of water molecules, resulting in non-ideal solution behaviour. The specific volume of solvent (water) is markedly higher compared to that of solute. Therefore, the density of sapota juice decreased with increase in water content which tend to cause increase in specific volume. The specific volume of water contributes mainly from structured free-solvent regions and that of solute is affected by hydration as well as solute-water interactions. In sapota juice the soluble solid content mainly consists of sugars, organic acids and marginal quantities of other macro molecules. The magnitude of density values of enzyme clarified sapota juice was comparable to that of other juices and other liquid food products such as pineapple, sugar cane, palmyra-palm, date-palm, orange, guava, yellow mombin, pummelo, lime, mango puree, peach, apple, passion fruit, lemon, Malus floribunda, cherry, grape, cashew, noni, umbu pulp, blackberry, fresh and dried onion slices, coconut milk, plain yoghurt (Constenla et al., 1989; Bayindirli and Ozsan, 1992; Rapusas and Driscoli, 1995; Kim and Bhowmik, 1997; Ramos and Ibarz, 1998; Telis-Romero et al., 1998; Cepeda and Villaran, 1999; Shamsudin et al., 2005; Pundes et al., 2005; Azoubel et al., 2005; Gratao et al., 2005; Assis et al., 2006; Tansakul and Chaisawang, 2006; Cabral et al., 2007; Chin et al., 2008; Bonomo et al., 2009; Jagannadha Rao et al., 2009; Minim et al., 2009; Souza et al., 2010; Bon et al., 2010; Garza and Ibarz, 2010; Gundurao et al., 2011; Kumoro et al., 2011; Manjunatha et al., 2012c).

Different empirical models were fitted relating

to the density and moisture content/water activity of enzyme clarified sapota juice. The parameters of the models and correlation coefficients of the models and root mean square error percent (rmse%) were reported in Table 2. The exponential type equation ($r = 0.9940$, $\text{rmse}\% = 0.252$, $p < 0.001$) was appropriate to describe the relation between density and moisture content, whereas linear equation ($r = 0.9463$, $\text{rmse}\% = 0.793$, $p < 0.001$) was found better to describe the relation between densities of enzyme clarified sapota juice with water activity. The correlation coefficient (r) was 0.9940 and 0.9463, respectively. The suggested models were reported as

$$\rho = 1448.49 * \text{Exp}(-0.00364 X_w)$$

($r = 0.9940$, $\text{rmse}\% = 0.252$, $p < 0.001$)

$$\rho = 2577.34 - 1307.15 a_w$$

($r = 0.9463$, $\text{rmse}\% = 0.793$, $p < 0.001$)

where ρ is density of sapota juice kg m^{-3} , X_w is moisture content in % wb and a_w is the water activity (-). The coefficient of X_w and a_w were negative which indicated that the density of sapota juice decreased significantly ($p < 0.001$) with increase in moisture content/water activity levels. Similar type relation was reported in case of passion fruit juice, lime juice (Gratao *et al.*, 2005; Manjunatha *et al.*, 2012c). The density of Brazilian orange juice decreased linearly with moisture content as well as temperature and water content of orange juice had significant effect on density than temperature (Telis-Romero *et al.*, 1998). Several researchers reported second order polynomial equations for relating density of juice with moisture content for different food products such as lemon juice, umbu pulp, stone fruits such as plum, peach and Nectarine juices (Phomkong *et al.*, 2006; Minim *et al.*, 2009; Souza *et al.*, 2010). The density of mango pulp decreased significantly with increase in moisture content as well as temperature and was described by linear multivariate model. The average variation in density 28 kg m^{-3} was reported for 20 to 80°C temperature variation whereas 173.1 kg m^{-3} was reported for variation between moisture contents of 1.1 to 9 kg kg^{-1} (db) (Bon *et al.*, 2010). The bulk density of yoghurt decreased linearly above 50% moisture content and decreased non-linearly by power law relation below 50% moisture content. This was due to increased amount of free water content above 50%, whereas below 50% moisture content the bound water would increase which lead to deviation and bulk density of plain yoghurt was significantly affected by fat content as well as solid not fat (SNF) content (Kim and Bhowmik, 1997). The density of

coconut milk decreased significantly with increase in fat content as well as increase in temperature. This was due to density of fat is markedly lower than that of water and fat content of coconut milk had marked significant effect on density of coconut milk than temperature (Tansakul and Chaisawang, 2006). The density of mango and papaya purees were increased linearly with increase in soluble solid content and decreased linearly with increase in temperature (Gundurao *et al.*, 2011; Tansakul *et al.*, 2012). The density of orange and peach juices were increased quadratically with total soluble solid content and decreased linearly with temperature whereas in case of apple and quince puree density decreased linearly with temperature (Ramos and Ibarz, 1998). Gratao *et al.* (2005) reported that the density of passion fruit juice decreased exponentially with moisture content and decreased linearly with temperature. The density of lemon juice was markedly affected by moisture content as well as temperature and second order polynomial equation was proposed to relate the density with moisture content and temperature (Minim *et al.*, 2009). Garza and Ibarz (2010) reported that the density of clear pineapple juice was significantly affected by total soluble solid content and temperature, a new model relating to density with total soluble solid content and temperature was proposed. Jagannadha Rao *et al.* (2009) proposed linear model relating to density with total soluble solid content of sugarcane, palmyra-palm and date-palm juices. The density of enzyme clarified sapota juice was decreased linearly with increase in water activity. Similar type of result was reported in case of clarified lime juice (Manjunatha *et al.*, 2012c). The magnitude of density of each food constituent is different which lead to change in magnitude of density of food with change in mass fraction of food constituents. The different models reported in literature for different foods were might be due to nature of solute, its size and shape, molecular weight, solute-solvent interaction, state of hydration, temperature and range of moisture content studied.

Newtonian viscosity

Viscosity of a fluid is defined as the internal friction of a liquid or its tendency to resist flow. The rheogram of enzyme clarified sapota (*Achras sapota* L.) juice at different moisture contents were reported in Figure 1. The Figure 1 showed that there is a linear increase in shear stress with increase in shear rate and it passes through the origin which indicated that the flow is Newtonian in nature. The Newtonian viscosity of enzyme clarified sapota juice was evaluated using shear stress-stress rate data by the Newtonian model

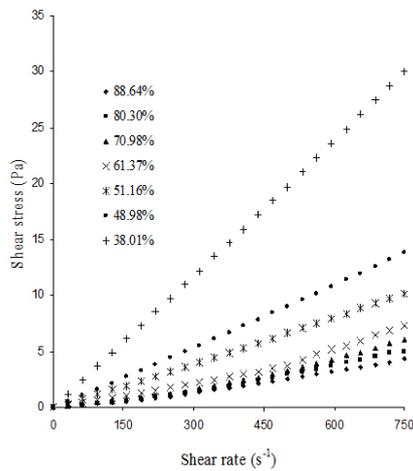


Figure 1. The rheogram of enzyme clarified sapota (*Achras sapota* L.) juice at different moisture contents at 25°C

($\sigma = \eta \dot{\gamma}$). The Newtonian viscosity of sapota juice at different moisture contents and water activity was in the range 39.553 to 5.221 mPa s depending upon the moisture content/water activity as reported in Table 1. The magnitude of viscosity of sapota juice decreased significantly ($p < 0.05$) with increase in moisture content as well as water activity. The viscosity of enzyme clarified sapota juice was strongly depended on the solute-solvent interactions and inter-molecular forces, which results from the inter-molecular spacing and the strength of bonds. The water-solute interactions and inter-molecular forces were markedly affected by concentration and temperature. As the water content increases, the viscosity decreases due to decrease in hydrated molecules and bonding with solute molecules. The increase in moisture content leads to decrease in intermolecular forces, hydration state and solute aggregation mechanisms. In the case of sapota juice total soluble solid content consists mainly of low molecular weight sugars and marginally organic acids, which plays an important role in the magnitude of viscosity. The moisture content of sapota juice has a strong non-linear effect on viscosity of Newtonian fluids. The magnitude of viscosity of enzyme clarified sapota juice was comparable to that of other juices such as cherry juice (Juszczak and Fortuna, 2004), pineapple juice (Shamsudin *et al.*, 2007), orange juice (Ibarz *et al.*, 2009), pomegranate juice (Kaya and Sozer, 2005; Altan and Maskan, 2005), beetroot juice (Juszczak *et al.*, 2010), lime juice (Manjunatha *et al.*, 2012a), Indian goose berry juice (Manjunatha *et al.*, 2012b), tender coconut water (Manjunatha and Raju, 2013), kiwi fruit juice (Goula and Adamopoulos, 2011), clarified fruit juices such as orange, peach, black currant, pear, apple, banana (Khalil *et al.*, 1989; Ibarz *et al.*, 1989; Ibarz *et al.*, 1992a; 1992b; Ibarz *et al.*, 1994; Ibarz *et al.*, 1996), carrot juice (Vandresen *et*

Table 3. Parameters of the different models relating to viscosity (η) to moisture content/water activity levels of enzyme clarified sapota juice

Model	a (mPa s)	b (mPa s bxix ⁻¹)	c (mPa s bxix ⁻²)	r	rmse%
$\eta = a + b X_w + c X_w^2$	48.754 [†] ± 0.090	-0.5539 [†] ± 0.0013	-	0.8273	21.56
$\eta = a + b X_w + c X_w^2$	139.190 [†] ± 0.596	-3.6048 [†] ± 0.0183	0.0239 [†] ± 0.0002	0.9729	13.92
$\eta = a (X_w)^b$	2127503.10 [†] ± 94450.33	-3.00 [†] ± 0.01	-	0.9906	8.27
$\eta = a \text{Exp}(b X_w)$	412.76 [†] ± 6.22	-0.0627 [†] ± 0.0003	-	0.9754	11.41
$\eta = a + b a_w$	208.800 [†] ± 0.639	-208.268 [†] ± 0.673	-	0.9491	10.99
$\eta = a + b a_w + c a_w^2$	1523.73 [†] ± 14.96	-3084.64 [†] ± 32.02	1567.46 [†] ± 17.09	0.9969	3.57
$\eta = a (a_w)^b$	4.7181 [†] ± 0.0190	-12.0808 [†] ± 0.0403	-	0.9988	2.18
$\eta = a \text{Exp}(b a_w)$	3331287.40 [†] ± 141323.14	-13.53 [†] ± 0.05	-	0.9981	2.60

Mean ± S D (n = 3), [†]p ≤ 0.001, [‡]p ≤ 0.01, [§]p ≤ 0.05, ns p > 0.05, (η is viscosity in mPa s, MC is moisture content in %, a_w is water activity dimensionless).

al., 2009), Sole juice (Ibarz *et al.*, 1996), blueberry and raspberry juices (Nindo *et al.*, 2005), Apple and pear juices (Ibarz *et al.*, 1987), black chokeberry juice (Juszczak *et al.*, 2009), Liquorice extract (Maskan, 1999), Aqueous carbohydrate solutions (Telis *et al.*, 2007). The viscosity of fluid depends on nature of solute, size, shape, state of hydration and solute-solvent interactions (Nindo *et al.*, 2005). The viscosity of aqueous carbohydrate solutions such as sucrose, glucose and fructose were reported at different temperatures and concentrations and the aqueous solution behaved like a Newtonian liquid. The magnitude of viscosity was decreased in the following order of solutes; sucrose, glucose, and fructose at same temperature and concentration (Telis *et al.*, 2007).

Different empirical models were fitted, relating Newtonian viscosity to water content/water activity of enzyme clarified sapota juice. The parameters of the models and correlation coefficients of the models and root mean square error percent (rmse%) were reported in Table 3. The exponential model ($r = 0.9754$, $\text{rmse}\% = 11.41$, $p < 0.05$) was optimal to describe the relation between Newtonian viscosity and water content of sapota juice, whereas power law type equation ($r = 0.9988$, $\text{rmse}\% = 2.18$, $p < 0.001$) was better to describe the relation between Newtonian viscosity and water activity. The suggested model equations were

$$\eta = 412.76 * \text{Exp}(-0.0627 X_w) \\ (r = 0.9754, \text{rmse}\% = 11.41, p < 0.05)$$

$$\eta = 4.7181 * (a_w)^{-12.081} \\ (r = 0.9988, \text{rmse}\% = 2.18, p < 0.001)$$

where, η is the Newtonian viscosity in mPa s, X_w is the water content in % w b and a_w is water activity of sapota juice. In the above two equations, the coefficients of water content and water activity were negative, which indicated that viscosity of sapota juice decreased exponentially ($p < 0.05$) with moisture content where as it decreased by power law with water activity. Similar type of result was reported for clarified lime juice and coefficients of

moisture content and water activity were comparable with lime juice (Manjunatha *et al.*, 2012c). Several authors reported exponential relationship between viscosity and total soluble solid content for different fruit juices such as beetroot juice (Juszczak *et al.*, 2010), cherry juice (Juszczak and Fortuna, 2004), clarified peach juice (Ibarz *et al.*, 1992a), choke berry (*Aronia melanocarpa*) juice (Juszczak *et al.*, 2009), pineapple juice (Shamsudin *et al.*, 2007), clarified orange juice (Ibarz *et al.*, 2009), clarified cherry juice (Giner *et al.*, 1996) and pomegranate juice (Kaya and Sozer, 2005; Altan and Maskan, 2005). Gooseberry juice (Manjunatha *et al.*, 2012b). In the present investigation it was observed that exponential decrease in viscosity of enzyme clarified sapota juice with increase in water content. The viscosity of sapota juice decreased significantly ($p < 0.01$) with water activity by power law relation. Several authors reported similar power law relation for variation of viscosity with water activity of different liquid foods (Manjunatha *et al.*, 2012a; Manjunatha and Raju, 2013). The magnitude of exponent of power law model was found to be -18.54 at 25°C in case of blackcurrant juice, whereas -21.89 and -19.85 at 20°C and 30°C respectively in case of orange juice (Ibarz *et al.*, 1992b, 1994). The exponent of power law model varies from -14.311 to -5.588 for viscosity of lime juice at temperatures 20 to 80°C, whereas in case of tender coconut water it varies from -15.662 to -6.046 at temperatures ranges 10 to 85°C (Manjunatha *et al.* 2012a; Manjunatha and Raju, 2013). The variation in the coefficients is significantly temperature dependent. The viscosity of liquid was markedly affected by soluble solid content and temperature. The deviations in models were due to variation in nature of solute, its molecular weight, shape, solute-solvent interaction and state of hydration (Fennema, 2005; Nindo *et al.*, 2005; Telis *et al.*, 2007).

Thermal conductivity

Thermal conductivity is an intrinsic thermal property which is defined as the quantity of heat that flows in unit time through unit thickness and unit area having unit temperature difference between faces. The thermal conductivity of food material is highly dependent on composition of food constituents, physical state such as density, porosity, temperature and structure of the food material. The thermal conductivity of enzyme clarified sapota juice was increased significantly ($p < 0.05$) from 0.3989 to 0.5703 W m⁻¹K⁻¹ with increase in moisture content and water activity as reported in Table 1. The magnitude of thermal conductivity of food and their products strongly depends on moisture

content/water activity, structure, state of hydration. The moisture content of sapota juice was the most important factor in determining thermal conductivity than that of non-aqueous phase. The magnitude of thermal conductivity of pure water is markedly about 2.5 times higher than other food constituents and thermal conductivity of carbohydrate is about 2.5 times lower than water. So the mass fraction of water present in the food markedly decides the thermal conductivity of food material. The total soluble solid content of enzyme clarified sapota juice (mainly low molecular sugars and organic acids) which has lower thermal conductivity values than water, and it showed increased magnitude of thermal conductivity with increase in water content/water activity. The magnitude of thermal conductivity of enzyme clarified sapota juice at different moisture content and water activity levels was comparable with other fruit juices and other food products as reported (Rapusas and Driscoll, 1995; Telis-Romero *et al.*, 1998; Tavman and Tavman, 1999; Azoubel *et al.*, 2005; Shamsudin *et al.*, 2005; Muramatsu *et al.*, 2005; Assis *et al.*, 2006; Phomkong *et al.*, 2006; Jagannadha Rao *et al.*, 2009).

Different empirical models were fitted, relating thermal conductivity to water content/water activity of enzyme clarified sapota juice. The parameters of the model, correlation coefficient (r) and root mean square error % (rmse%) of the models were reported in Table 4. The exponential model equation ($r = 0.9614$, rmse% = 1.27, $p < 0.001$) was better to describe the relation between thermal conductivity and water content of enzyme clarified sapota juice where as power law equation ($r = 0.8318$, rmse% = 2.40, $p < 0.05$) was better to describe the relation between thermal conductivity and water activity of sapota juice because of high correlation coefficient, low root mean square errors percent and significance level ($p < 0.05$) as compared to other models. The suggested model equations were

$$k = 0.2991 * \text{Exp}(0.0070 X_w) \\ (r = 0.9614, \text{rmse}\% = 1.27, p < 0.001)$$

$$k = 0.5281 * (a_w)^{1.9065} \\ (r = 0.8318, \text{rmse}\% = 2.40, p < 0.05)$$

where, k is thermal conductivity in W m⁻¹ K⁻¹, X_w is the water content in % w b and a_w is water activity of sapota juice. In this present study it was observed that the thermal conductivity of enzyme clarified sapota juice at different water content followed the exponential equation, whereas it followed power law relation with water activity. Some authors reported

Table 4. Parameters of the different models relating to thermal conductivity (k) to moisture content/water activity levels of enzyme clarified sapota juice

Model	a (Wm ⁻¹ K ⁻¹)	b (Wm ⁻¹ K ⁻¹ brix ⁻¹)	c (Wm ⁻¹ K ⁻¹ brix ⁻²)	r	rmse%
k = a + b X _w	0.2656 ^{***} ± 0.0014	0.00320 ^{***} ± 0.00002	-	0.9514	1.40
k = a + b X _w + c X _w ²	0.4646 ^{***} ± 0.0061	-0.0035 ^{ns} ± 0.0002	0.000052 ^{ns} ± 0.000002	0.9771	1.01
k = a (X _w) ^b	0.0828 [*] ± 0.0010	0.4197 ^{***} ± 0.0028	-	0.9347	1.61
k = a Exp(b X _w)	0.2991 ^{***} ± 0.011	0.0070 ^{***} ± 0.0000	-	0.9614	1.27
k = a + b a _w	-0.3840 ^{ns} ± 0.0029	0.9090 [±] ± 0.0029	-	0.8254	2.43
k = a + b a _w + c a _w ²	6.443 ^{ns} ± 0.070	-14.025 ^{ns} ± 0.154	8.138 ^{ns} ± 0.084	0.8837	2.05
k = a (a _w) ^b	0.5281 ^{***} ± 0.0001	1.9065 [*] ± 0.0075	-	0.8318	2.40
k = a Exp(b a _w)	0.0655 ^{ns} ± 0.0005	2.0918 [*] ± 0.0083	-	0.8387	2.35

Mean ± S D (n = 3), *** p ≤ 0.001, ** p ≤ 0.01, * p ≤ 0.05, ns p > 0.05, (k is thermal conductivity in W m⁻¹K⁻¹, MC is moisture content in %, a_w is water activity dimensionless).

linear relationship between thermal conductivity and water content of fruit juices and other food products such as passion fruit juice (Gratao *et al.*, 2005), Brazilian orange juice (Telis-Romero *et al.*, 1998), lemon juice (Minim *et al.*, 2009), onion slices (Rapusas and Driscoll, 1995), Borage seeds (Yang *et al.*, 2002), stone fruits such as plum, peach and nectarine juices (Phomkong *et al.*, 2006). The thermal conductivity of mango pulp increased significantly with moisture content as well as temperature and thermal conductivity is more dependent on moisture content than on temperature. The multivariate linear model was established between thermal conductivity with moisture content and temperature of mango pulp (Bon *et al.*, 2010). Several authors reported linear decrease of thermal conductivity with increase in total soluble solid content and the magnitude of decrease was in the range 0.0041 to 0.0097 per degree increase in °brix (Assis *et al.*, 2006; Jagannadha Rao *et al.*, 2009; Marumatsu *et al.*, 2010). Gratao *et al.* (2003) reported that thermal conductivity of passion fruit juice increased linearly with water content and in the present study it increased exponentially with moisture content whereas it increased by power law relation with water activity. The thermal conductivity of yoghurt increased logarithmically with moisture content and linearly with temperature (Kim and Bhowmik, 1997). The thermal conductivity of several dairy products increased linearly with moisture content where as it decreased linearly with fat and protein content (Tavman and Tavman, 1999). Thermal conductivity of coconut milk increased linearly with temperature but decreased linearly with fat content and the influence of fat content on thermal conductivity was stronger than that of temperature. Among all basic food components, water has the highest thermal conductivity and fat has lowest (Tansakul and Chaisawang, 2006). The thermal conductivity of mango and papaya puree decreased linearly with increase in soluble solid content and increased with temperature, the soluble solid content had significant effect on thermal conductivity than temperature (Gundurao *et al.*, 2011; Tansakul *et al.*, 2012). The deviation in models may be due to nature

Table 5. Parameters of the different models relating to specific heat (c_p) to moisture content/water activity levels of enzyme clarified sapota juice

Model	a (Jkg ⁻¹ K ⁻¹)	b (Jkg ⁻¹ K ⁻¹ brix ⁻¹)	c (Jkg ⁻¹ K ⁻¹ brix ⁻²)	r	rmse%
c _p = a + b X _w	2370.87 ^{***} ± 49.55	16.729 ^{***} ± 0.716	-	0.9829	0.609
c _p = a + b X _w + c X _w ²	2911.14 ^{***} ± 64.06	-1.385 ^{ns} ± 1.976	0.142 ^{ns} ± 0.017	0.9902	0.448
c _p = a (X _w) ^b	1008.08 ^{***} ± 57.19	0.2973 ^{***} ± 0.0135	-	0.9706	0.738
c _p = a Exp(b X _w)	2505.92 ^{***} ± 38.37	0.0049 ^{***} ± 0.0002	-	0.9865	0.505
c _p = a + b a _w	-1193.61 ^{ns} ± 196.30	4933.19 ^{***} ± 204.88	-	0.8844	1.40
c _p = a + b a _w + c a _w ²	27737.17 ^{ns} ± 3350.90	-58518.50 ^{ns} ± 7452.33	34486.77 ^{ns} ± 3977.74	0.9234	1.16
c _p = a (a _w) ^b	3747.166 ^{***} ± 9.74	1.377 ^{ns} ± 0.062	-	0.8866	1.38
c _p = a Exp(b a _w)	832.059 [±] ± 53.161	1.5098 ^{**} ± 0.0666	-	0.8925	1.35

Mean ± S D (n = 3), *** p ≤ 0.001, ** p ≤ 0.01, * p ≤ 0.05, ns p > 0.05, (k is thermal conductivity in W m⁻¹K⁻¹, MC is moisture content in %, a_w is water activity dimensionless).

of solute, its molecular weight, their interaction with solvent and state of hydration.

Specific heat

Specific heat of a food is defined as the amount of heat required to increase the temperature at unit mass by unit degree at given temperature, which indicates that the variation of temperature with the quantity of heat stored within the substance. The specific heat of liquid food mainly depends on mass fraction of water and solid content. The moisture content of food plays an important role in magnitude of specific heat. The specific heat of enzyme clarified sapota juice increased markedly from 3.019 to 3.926 kJ kg⁻¹ K⁻¹ with increase in moisture content and water activity as reported in Table 1. The increase in specific heat with increase in moisture content was due to magnitude of specific heat of water which was markedly high compared to other food constituents such as fat, protein, carbohydrates and ash. In case of clarified sapota juice and their concentrate the solids consisting mainly of sugars, marginally organic acid and other macro molecules have lower magnitude of specific heat. The specific heat of water is markedly higher by three times compared to that of other solids present in the food and hence the mass fraction of water present in the food decides the specific heat of food material and the average specific heat was about 1.5 kJ kg⁻¹ K⁻¹ of other constituents of food in the food system. The specific heat of food is temperature dependent and increased marginal with increase in temperature (Lewis 1987). The specific heat of several fruits and fruit pulps at different moisture levels were reported and the magnitude of specific heat of enzyme clarified sapota juice was comparable with reported values (Alvarado, 1991; Rapusas and Driscoll, 1995; Telis-Romero *et al.*, 1998; Phomkong *et al.*, 2006; Assis *et al.*, 2006; Jagannadha Rao *et al.*, 2009; Souza *et al.*, 2010).

Different empirical models were fitted relating specific heat to water content/ water activity of enzyme clarified sapota juice. The model parameters, correlation coefficient (r) and percent root mean square errors (rmse%) of the models were reported

in Table 5. The exponential model was found better to describe the relation between moisture content and water activity to specific heat of enzyme clarified sapota juice at different moisture contents and water activity levels. The model equations were

$$c_p = 2502.92 * \text{Exp}(0.0049 X_w) \\ (r = 0.9865, \text{rmse}\% = 0.505, p < 0.001)$$

$$c_p = 832.059 * \text{Exp}(1.5098 a_w) \\ (r = 0.8925, \text{rmse}\% = 1.35, p < 0.05)$$

where, c_p is the specific heat in $\text{J kg}^{-1} \text{K}^{-1}$, X_w is the water content in % wb and a_w is the water activity. The specific heat of enzyme clarified sapota juice increased exponentially with moisture content as well as water activity. Constenla *et al.* (1989) reported that the specific heat decreased linearly with total soluble solid content for clarified apple juice and almost constant with temperature, at high water content specific heat almost equals to specific heat of pure water. Several authors reported similar results for other fruit juices such as pineapple, orange, grape, sugarcane, Palmyra-palm, date-palm juices (Jagannadha Rao *et al.*, 2009; Muramatsu *et al.*, 2010). The specific heat of pineapple and Thai guava juice increased linearly with temperature as reported (Shamsudin *et al.*, 2005; Muramatsu *et al.*, 2010). The linear model was reported relating to specific heat and water content for different fruit juice and other products such as passion fruit juice, orange juice, lemon juice, umbu pulp, stone fruits (plum, peach and nectarine), plain yoghurt and onion slices (Rapusas and Driscoll, 1995; Kim and Bhowmik, 1997; Telis-Romero *et al.*, 1998; Gratao *et al.*, 2005; Phomkong *et al.*, 2006; Minim *et al.*, 2009; Souza *et al.*, 2010;). Minim *et al.* (2009) reported that specific heat of lemon juice increased significantly with water content as well as temperature and water content had larger impact on specific heat of lemon juice than temperature. The specific heat capacity of mango pulp increased significantly with moisture content and moisture content had significant effect on magnitude of heat capacity of mango pulp than temperature (Bon *et al.*, 2010). The specific heat of milk increased linearly with water content as well as temperature (Minim *et al.*, 2002). The specific heat of coconut milk decreased linearly with increase in fat content and marginal increase with temperature (Tansakul and Chaisawang, 2006). The specific heat of mango and papaya puree decreased linearly with increase in total soluble solid content whereas it increased linearly with temperature and total soluble solid content had significant marked effect than temperature (Gundurao

et al., 2011; Tansakul *et al.*, 2012). Several authors have reported linear Siebel's equation for relating to moisture content to specific heat of food products (Mohsenin, 1980; Alvarado, 1991; Souza *et al.*, 2010). The Siebel's equation which relates to water content and specific heat was applicable above 50% of moisture levels. This was due to increased free water content, whereas below 50% moisture content the bound water fraction would increase which lead to deviation from Siebel's equation and exponential model was suggested for wide range of moisture content of different pulps, juices and other foods (Alvarado, 1991). In the present study exponential relation was found better to describe the relation between specific heat and moisture content/water activity of enzyme clarified sapota juice. This may be due to the clarification process and nature of solids, solute-solvent interactions and state of hydration in sapota juice.

Thermal diffusivity

The thermal diffusivity of food depends on chemical composition, nature of food system, physical state and temperature. Thermal diffusivity (α) is described as the rate at which heat diffuses through food material, which could be obtained from Fourier's general law of conduction equation. The thermal diffusivity of enzyme clarified sapota juice increased marginally from 1.043×10^{-7} to $1.394 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$ with increase in moisture content and water activity as reported in Table 1. With the increase in water content of food system the propagation of heat or diffusion through the medium speeds up. Thermal diffusivity of food and their products depends on other thermophysical properties such as thermal conductivity, density and specific heat of the material. The thermal diffusivity of food was directly related to thermal conductivity whereas it is inversely related to density and specific heat. These properties are strongly influenced by the moisture content. With increase in water fraction in food systems, there is an increase in thermal diffusivity of the food product. This could be explained by higher magnitude of thermal diffusivity values of water than that of solid present in food system. The variation of solid mass fraction such as fat, protein, and carbohydrate had a small influence on thermal diffusivity than mass fraction of water (Azoubel *et al.*, 2005). The magnitude of thermal diffusivity values of enzyme clarified sapota juice was within the range of other fruit juices, pulps and other food products (Fontan *et al.*, 2009; Telis-Romero *et al.*, 1998; Rapusas and Driscoll, 1995; Muramatsu *et al.*, 2010; Assis *et al.*, 2006; Cabral *et al.*, 2007; Ikegwu and Ekwu, 2009;

Table 6. Parameters of the different models relating to thermal diffusivity (α) to moisture content/water activity levels of enzyme clarified sapota juice

Model	a (m ² s ⁻¹)	b (m ² s ⁻¹ brix ⁻¹)	c (m ² s ⁻¹ brix ⁻²)	r	rmse%
$\alpha = a + b X_w$	$0.7679 \times 10^{-7} \text{***} \pm 0.0161 \times 10^{-7}$	$0.0066 \times 10^{-7} \text{***} \pm 0.0002 \times 10^{-7}$	-	0.9582	1.063
$\alpha = a + b X_w + c X_w^2$	$1.1166 \times 10^{-7} \text{**} \pm 0.0277 \times 10^{-7}$	$-0.0051 \times 10^{-7} \text{ns} \pm 0.0006 \times 10^{-7}$	$0.000092 \times 10^{-7} \text{ns} \pm 0.000003 \times 10^{-7}$	0.9772	0.812
$\alpha = a (X_w)^b$	$0.2919 \times 10^{-7} \text{**} \pm 0.0160 \times 10^{-7}$	$0.3405 \text{**} \pm 0.0133$	-	0.9411	1.253
$\alpha = a \text{Exp}(b X_w)$	$0.8265 \times 10^{-7} \text{***} \pm 0.0116 \times 10^{-7}$	$0.0057 \text{***} \pm 0.0002$	-	0.9652	0.978
$\alpha = a + b a_w$	$-0.6124 \times 10^{-7} \text{ns} \pm 0.0728$	$1.920 \times 10^{-7} \text{*} \pm 0.077$	-	0.8470	1.88
$\alpha = a + b a_w + c a_w^2$	$13.131 \times 10^{-7} \text{ns} \pm 1.241 \times 10^{-7}$	$-28.14 \times 10^{-7} \text{ns} \pm 2.64 \times 10^{-7}$	$16.38 \times 10^{-7} \text{ns} \pm 1.40 \times 10^{-7}$	0.9021	1.53
$\alpha = a (a_w)^b$	$1.312 \times 10^{-7} \text{***} \pm 0.004 \times 10^{-7}$	$1.564 \text{*} \pm 0.064$	-	0.8508	1.86
$\alpha = a \text{Exp}(b a_w)$	$0.2371 \times 10^{-7} \text{ns} \pm 0.0153 \times 10^{-7}$	$1.7164 \text{*} \pm 0.0689$	-	0.8577	1.82

Mean \pm S D (n = 3), *** p \leq 0.001, ** p \leq 0.01, * p \leq 0.05, ns p > 0.05, (k is thermal conductivity in W m⁻¹K⁻¹, MC is moisture content in %, a_w is water activity dimensionless).

Table 7. Correlation between moisture content, water activity and thermophysical properties of enzyme clarified sapota juice

	Moisture content (MC)	Water activity (a _w)	Density (ρ)	Viscosity (η)	Thermal conductivity (k)	Specific heat (C _p)	Thermal diffusivity (α)
Moisture content (MC)	1.0000						
Water activity (a _w)	0.9392****	1.0000					
Density (ρ)	-0.9937****	-0.9463****	1.0000				
Viscosity (η)	-0.8272****	-0.9491****	0.8526***	1.0000			
Thermal conductivity (k)	0.9513****	0.8254***	-0.9551****	-0.7088*	1.0000		
Specific heat (C _p)	0.9822****	0.8836****	-0.9844****	-0.7807**	0.9857****	1.0000	
Thermal diffusivity (α)	0.9574****	0.8460****	-0.9633****	-0.7253*	0.9968****	0.9822****	1.0000

****p \leq 0.000001, *** p \leq 0.00001, ** p \leq 0.0001, * p \leq 0.001

Rahaman, 1995; Lewis, 1987; Gundurao *et al.*, 2011; Tansakul *et al.*, 2012).

Different empirical models were fitted, relating thermal diffusivity to water content/water activity of enzyme clarified sapota juice. The model parameters and correlation coefficient of the models were reported in Table 6. The exponential equation was found better to describe the relation between thermal diffusivity to moisture content, whereas power law type relation was suited with water activity of enzyme clarified sapota juice at different moisture content and water activity levels. The suggested model equations were

$$\alpha = 0.8265 \times 10^{-7} * \text{Exp}(0.0057 X_w)$$

(r = 0.9652, rmse% = 0.978, p < 0.001)

$$\alpha = 1.312 \times 10^{-7} * (a_w)^{1.564}$$

(r = 0.8508, rmse% = 1.86, p < 0.05)

where, α is thermal diffusivity in m² s⁻¹, X_w is moisture content in % wb and a_w is water activity. Thermal diffusivity was high at low fat content and higher temperature for coconut milk and linearly related with fat content as well as with temperature (Tansakul and Chaisawang, 2006). Several authors reported thermal diffusivity increased linearly with moisture content as well as temperature, water content had strong influence on thermal diffusivity than temperature for fruit juices such as orange, grape, pineapple, lemon, cashew, black berry, yellow mombin and other products (Telis-Romero *et al.*, 1998; Yang *et al.*, 2002; Azoubal *et al.*, 2005; Assis *et al.*, 2006; Cabral *et al.*, 2007; Minim *et al.*, 2009; Muramatsu *et al.*, 2010). Thermal diffusivity of

mango and papaya purees decreased with increase in total soluble solid content whereas it increased with temperature. The total soluble solid content had significant effect than temperature (Gundurao *et al.*, 2011; Tansakul *et al.*, 2012). The deviation in modelling may be due to clarification, nature of solute, solute-solvent interaction and state of hydration in sapota juice.

Intercorrelation between thermophysical properties

The intercorrelation between moisture content/water activity and thermophysical properties of enzyme clarified sapota juice was reported in Table 7. High correlation among thermophysical properties and moisture content/water activity ($0.7088 \leq |r| \leq 0.9968$, p \leq 0.001) was observed. A significant positive correlation ($0.8254 \leq r \leq 0.9822$, p < 0.00001) between moisture content/water activity of sapota juice with thermal properties were observed, whereas negative correlation ($-0.9937 \leq r \leq -0.8272$, p < 0.00001) with physical properties was observed. There is a significant negative correlation between thermal properties such as thermal conductivity, specific heat, thermal diffusivity and physical properties such as density, viscosity of sapota juice ($-0.9844 \leq r \leq -0.7088$, p \leq 0.001) and significant inter positive correlation among thermal properties of sapota juice ($0.9822 \leq r \leq 0.9968$, p \leq 0.000001) was observed. In general, there is a strong negative correlation between physical and thermal properties of enzyme clarified sapota juice at different moisture content and water activity. It was evident that thermophysical properties of enzyme clarified sapota juice were significantly dependent on moisture

content and water activity of sapota juice.

Conclusions

This investigation showed that density and Newtonian viscosity of enzyme clarified sapota juice decreased significantly ($p < 0.05$) from 1266.27 to 1042.24 kg m⁻³ and 39.553 to 5.221 mPa s with increase in moisture content (38.01 to 88.64% wet basis) as well as water activity levels (0.839 to 0.987), respectively. The thermal conductivity increased significantly ($p < 0.05$) from 0.3989 to 0.5703 W m⁻¹K⁻¹ with increase in moisture content and water activity. The specific heat and thermal diffusivity increased markedly with moisture content as well as water activity. Empirical mathematical models were established relating to thermophysical properties of enzyme clarified sapota juice with moisture content/water activity. Results indicated that a high significant ($p < 0.0001$) correlation between thermophysical properties with moisture content/water activity of enzyme clarified sapota juice was observed. A significant ($p < 0.0001$) positive correlation between thermal properties and moisture content/water activity was observed; whereas a significant negative ($p < 0.00001$) correlation was observed between physical properties and moisture content/water activity. In general the thermophysical properties were markedly affected by moisture content/water activity. This information could serve extremely useful in processing and design of equipment for development of novel sapota juice products in large scale commercial production.

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