International Food Research Journal 25(3): 1067-1073 (June 2018)
Journal homepage: *http://www.ifrj.upm.edu.my*

Composition and thermophysical properties of Malay Rose apple pulp

[1*]Fontan, R. C. I., [1]Sampaio, V. S., [1]Souza Jr, E. C., [2]Pereira, R. G., [1]Rodrigues, L. B., [1]Gonçalves, G. R. F., [1]Gandolfi, O. R. R. and [1]Bonomo, R. C. F.

[1]*Graduate Program in Food Engineering and Science. State University of Bahia Southwest, Itapetinga, Brazil*
[2]*State University of Campinas, Campinas, Brazil*

Article history

Received: 23 January 2017
Received in revised form: 7 March 2017
Accepted: 8 March 2017

Keywords

Density
Specific heat
Thermal diffusivity
Water content
Standardization
Syzygium malaccense

Abstract

The Malay Rose apple is a tropical fruit with potential for exploitation. Its composition and thermophysical properties were studied to explore its industrial processing potential. In natura fruit pulp presented high water and sugar content, similar to obtained around the world, indicating commercial potential because of its ease of standardization independent of local planting conditions. Density (ρ), specific heat (cp) and thermal diffusivity (α) were determined as functions of the water mass fraction between 0.90 and 0.99 and temperatures between 2°C and 82°C (density). Higher water content caused α and cp to increase, while ρ decreased when temperature and water content increased. Empirical models were obtained ($R^2 > 0.95$), which adequately explained the properties analyzed in the studied ranges. This study could provide information for improving equipment development for processing the Malay Rose apple.

Introduction

The Malay apple, or Malay Rose apple (*Syzygium malaccense* Merr. and Perry), is a tropical fruit from the Myrtaceae family. Originating from southeast Asia, it is an evergreen tree growing to a height of about 15 m. The fruits are pyriform, succulent and the soft flesh of the ripe fruit has a pleasant sweet flavor with the characteristic aroma of a rose. They present intense reddish color when ripe, weigh between 40 g and 60 g, with a transverse diameter of around 4.7 cm and longitudinal diameter of around 5.8 cm (Augusta *et al*., 2010; Nunes *et al*., 2016). The fruit is usually eaten fresh but can be preserved. This species has been propagated to other tropical and subtropical regions because of its ability to adapt to soil and climate (Pino *et al*., 2004).

In some countries, including Thailand, the *Syzygium* genus is commercially exploited (Vara-Ubol *et al*., 2006). In other countries however, such as Brazil and Malaysia, this genus is underutilized, with consumption basically limited to fresh fruit at harvest season (Augusta *et al*., 2010; Lim and Rabeta, 2013) and production limited to domestic orchards. Processing the fruit is an alternative for it to be consumed throughout the year.

Knowledge of thermophysical properties is a necessity for sizing food processing equipment. Because of the lack of information on the behavior of thermophysical properties with regard to composition and temperature, it is difficult to design and control equipment. Equipment is usually oversized, which leads to an incorrect design. This results in higher costs and inferior quality (Alcantara *et al*., 2012). Extensive studies on existing methods for measuring thermophysical properties of foods have been done by Mohsenin (1980), Choi and Okos (1986), Constenla *et al.* (1989) and others. A generalized correlation to predict the thermal characteristics of food systems has not been described in literature, probably because of the physical complexity of food matrixes. Since it is difficult to predict thermal properties based on a purely theoretical foundation, experimental measurements must be performed (Minim *et al*., 2002).

Studies of thermophysical properties have been reported for many foodstuffs (Cepeda and Villaran, 1999; Zainal *et al*., 2000; Azoubel *et al*., 2005; Zuritz *et al*., 2005; Magerramov *et al*., 2007; Shamsudin *et al*., 2007). The majority of available data on fruits however focus on those from sub-tropical regions, resulting in a lack of published information regarding the thermal properties of tropical fruits and their products, such as juices and pulps (Azoubel *et al*., 2005).

The thermophysical properties of some

*Corresponding author.
Email: *rafaelfontan@yahoo.com.br, rafaelfontan@uesb.edu.br*

foodstuffs have been reported in the literature, such as those of coconut water (Fontan *et al.*, 2009), genipap pulp (Silva *et al.*, 2010), umbu pulp (Souza *et al.*, 2010), jackfruit pulp (Souza *et al.*, 2011) and bovine milk (Alcântara *et al.*, 2012; Souza Jr *et al.*, 2012). The best sources of thermal property data are prediction equations based on chemical composition, temperature and physical composition, which are usually reliable for most estimates of thermal properties of foods (Sweat, 1995). Therefore, because most of the thermal property models are based on statistical curve fitting rather than on a theoretical derivation involving heat transfer analyses, many prediction model treatments can be found (Heldman and Singh, 1981; Miles *et al.*, 1983; Choi and Okos, 1986).

The objectives of this work were to determine the physicochemical characteristics of Malay Rose apple pulp, including proximate analysis, pH, titratable acidity and soluble solids content and to investigate the effects of temperature (2–82°C) and water mass fraction (0.90–0.99) on some thermophysical properties of Malay Rose apple pulp, providing experimental data on an unexplored tropical fruit pulp and proposing simple models to predict its properties.

Materials and Methods

Sample preparation and physicochemical analysis

Malay Rose apples were harvested from three domestic orchards in Ilhéus city, Bahia State, Brazil, at medium maturity. The fruits were washed under running water to remove impurities. The edible portion of the fruit (peel and pulp) was separated manually from the seeds using a stainless steel knife and triturated using a commercial mixer to obtain a homogeneous mass. Part of the pulp was stored at -14°C until use, while the rest was used for proximate analysis of the original pulp, according to the methodology of AOAC (1996). Water content, total fat, protein, ash, fiber, reducing sugar, titratable acidity and pH were analyzed with three repetitions in triplicate. To obtain different moisture levels in order to simulate processing conditions, distilled water was added to pulp, which was mixed again for homogenization or concentrated using a vacuum pump (Model 131, Prismatec®, São Paulo) at 60°C and absolute pressure of 50 kPa. Only the water content was varied in the Malay Rose apple pulp (0.90 to 0.99 mass fraction), with the other constituents kept in their original composition (ratio) in dry basis.

Thermophysical properties

Thermophysical properties were determined in a completely randomized design with three repetitions, where repetitions consisted of pulp produced from fruits of different locations. Density, specific heat and thermal diffusivity were determined experimentally as described below.

The pycnometric method (Coimbra *et al.*, 2006; Fontan *et al.*, 2009) was used to determine the density of Malay Rose apple pulp at temperatures between 2°C (refrigerated storage condition) and 82°C (thermal processing condition). The studied water mass fractions were 0.90, 0.95 and 0.99. Pycnometers (25 mL) were calibrated with distilled water at the temperatures studied. A thermostatic bath, accurate to ±0.01°C, (Model Q214S2, Quimis®, São Paulo, Brazil) was used for temperature control. Density was calculated according to Equation 1.

$$\rho = \rho_w \frac{(m_s - m_e)}{(m_w - m_e)} \qquad (1)$$

where ρ is sample density (kg m^{-3}), ρ_w is water density (kg m^{-3}) and me, ms and mw are mass of the empty pycnometer, pycnometer + sample and pycnometer + water (kg).

In order to determine the specific heat of Malay apple pulp at different water mass fractions, calorimetry by the method of mixtures was used in six replicates at each mass fraction repetition evaluated. Despite the existence of errors, this method is simple and has been used extensively to determine specific heat of foodstuffs (Muniz *et al.*, 2006; Fontan *et al.*, 2009; Alcântara *et al.*, 2012; Oliveira *et al.*, 2012; Akhijahani and Khodaei, 2013). The calorimeter (made at our own laboratory) consisted of a thermal double walls glass bottle (nominal volume of 1.0 L) isolated with an expanded polystyrene layer measuring 20 cm thick. The temperature was measured using a copper-constantan thermocouple (Model Penta, Full Gauge®, São Paulo State, Brazil, accuracy of ±0.1°C) inserted into the calorimeter. The calorimeter was previously calibrated to determine its heat capacity (Equation 2) by a mixture of known amounts of cold (~15°C) and hot water (~60 °C) into the calorimeter. A small polyethylene bag was loaded with approximately 45 g of the sample, equilibrated at 50°C in a thermostatic bath (Model Q214S2, Quimis®, São Paulo State, Brazil) and inserted into the calorimeter previously equilibrated with water (~20°C). When the new equilibrium was established, the temperature was registered. The specific heat of the samples was determined using Equation 3.

$$C_{cal} = \frac{m_h c_{p,w}\left(T_h - T_{eq}\right) - m_c c_{p,w}\left(T_{eq} - T_c\right)}{\left(T_{eq} - T_c\right)} \qquad (2)$$

$$c_p = \frac{\left(m_h c_{p,w} + C_{cal}\right)\left(T_{eq} - T_c\right)}{m_s\left(T_s - T_{eq}\right)} \tag{3}$$

where C_{cal} is the heat capacity of the calorimeter (J K^{-1}), c_p is the sample specific heat and cp,w is the water specific heat (J kg^{-1} K^{-1}), T_h, T_c and T_{eq} are hot water, cold water + calorimeter and final equilibrium temperatures (°C). mh, mc and ms are the hot water, cold water and sample masses (kg).

Thermal diffusivity was determined at each studied water mass fraction using the method proposed by Dickerson Jr. (1965). The experimental apparatus consisted of a cylindrical cell made of stainless steel (38.0 mm external diameter, 28.0 mm internal diameter and 255.0 mm length) with two nylon covers on each end. Two copper-constantan thermocouples (Model Penta, Full Gauge®, São Paulo State, Brazil, accuracy of ±0.1°C) were fixed at the center and external surface of the cell. The cell was immersed in a well agitated thermostatic bath (Model Q214S2, Quimis®, São Paulo State, Brazil) heated at a constant rate from 5°C to 85°C. The temperature increases were monitored at the wall and the center of the cylindrical cell. Thermal diffusivity was then calculated according to Equation 4.

$$\alpha = \frac{AR^2}{4\left(T_e - T_i\right)} \tag{4}$$

where α is the sample thermal diffusivity (m^2 s^{-1}), A is the rate of temperature increase in the linear region of the time x temperature graph (°C s^{-1}), R is the internal capsule radius (m) and T_e, T_i are the external and internal capsule temperatures (°C).

Analysis of the results

Upon collecting the experimental data, physicochemical results were expressed as mean values with standard errors. For the thermophysical properties (TPP), a linear regression analysis was performed, using the determination coefficient (R^2, based on treatment squares sum), parameter significance ($P < 0.05$) and phenomena description to select the models. The single linear model (TPP versus water fraction) was fitted to thermal diffusivity and specific heat values, while a multiple linear model (TPP versus water fraction and temperature) was fitted to density data. All analyses were performed in the SAEG software, v.9.0 (Ribeiro Jr, 2001).

Results and Discussion

Physicochemical analysis

Physicochemical characterization results of Malay Rose apple pulp are presented in Table 1, compared with data published in the literature from other authors and other *Syzygium* species. Malay Rose apple pulp presents a high water content, near 90%, which is related to its succulence. Nunes *et al.* (2016) and Santos *et al.* (2016) found similar values for Malay Rose apples from different regions of Brazil. The carbohydrates (total or sugars) were the second major group of constituents at around 5% to 12%, as is usually found in tropical fruits (Nunes *et al.*, 2016). Lim and Rabeta (2013) found a total carbohydrate level of 12.68% for Malay Rose apple while Rosnah *et al.* (2012) found a value close to 9% for water apple, with both studies being conducted with Malaysian fruits. In Brazil, Nunes *et al.* (2016) found carbohydrate levels around 5% to 6.5% for Malay Rose apples from two different locations. The results for the other constituents (ash, protein and fat) were near to those found by other researchers that studied Malay Rose apple (Nunes *et al.*, 2016; Santos *et al.*, 2016, Lim and Rabeta, 2013; Dignan *et al.*, 2004 and Morton, 1987). It was observed that in all cases the sum of ash, fat and protein levels total less than 5% of the composition of Malay Rose apples, with low contribution in the processing conditions.

Results obtained were similar to those reported by other authors for Malay apple composition (see Table 1), where the differences were caused by geographic, genetic and environmental factors, in addition to production practices (Rosnah *et al.*, 2012; Nunes *et al.*, 2016). This similarity is very interesting, since the authors analyzed fruits from different places in the world, such as Hawaii, El Salvador and Ghana (Morton, 1987), the Pacific Islands (Dignan *et al.*, 2004; Lim and Rabeta, 2013) and Brazil (Cardoso, 2008; Nunes *et al.*, 2016; Santos *et al.*, 2016), suggesting a considerable standardization grade in the quality of Malay Rose apple fruits, which is desirable for processing and commercial relationships. Compared with other *Syzygium* species, the low pH values observed indicate the acidic character of this genus. This is interesting for processing these fruits as juices or jellies (Cardoso, 2008; Augusta *et al.*, 2010), thus increasing the potential uses of this fruit.

Thermophysical properties

Experimental density data was correlated with temperature (T) and water content (x_w) by multiple linear regression (Figure 1). The density of Malay Rose apple pulp decreased as temperature and water content increased. The model with a quadratic effect for temperature and linear effect for moisture content best explained density behavior of Malay Rose apple pulp at the studied conditions. The fitted equation is showed below (Equation 5).

Table 1. Physicochemical characterization of Malay Rose apple compared to those obtained by other authors, including other species of *Syzygium*

Variable	*S. malaccense*							*S. cumini*	*S. samaragens*
	present study [a]	Nunes *et al.* (2016) [a]	Santos *et al.* (2016) [a]	Lim and Rabeta (2013) [a]	Cardoso (2008) [a]	Dignan *et al.* (2004) [a]	Morton (1987) [a]	Lago *et al.* (2006) [a]	Rosnah *et al.* (2012) [b]
water content (%)	90.84 ± 0.17	91.18	90.91	83.28 ± 0.16	87.00	90.00	90.3 – 91.6	87.75	90.54 - 92.58
ash (%)	0.45 ± 0.04	0.31	n.e.	0.85 ± 0.06	n.e.	n.e.	0.26 – 0.39	0.34	2.84 – 3.41
fat (%)	0.76 ± 0.15	0.16	n.e.	0.30 ± 0.03	n.e.	0.20	0.10 – 0.20	0.30	0.07 – 0.12
protein (%)	0.29 ± 0.02	0.88	n.e.	1.21 ± 0.09	n.e.	0.70	0.50 – 0.70	0.67	4.11 – 5.61
reducing sugar (%)	4.91 ± 0.52	0.54	n.e.	n.e.	6.40	n.e.	n.e.	1.00	n.e.
fiber (%)	1.82 ± 0.06	1.72	n.e.	1.68 ± 0.03	n.e.	1.90	0.60 – 0.80	0.28	4.68 – 5.61
titratable acidity (%) [c]	0.73 ± 0.02	n.e.	0.68	n.e.	0.80	n.e.	n.e.	5.91	0.20 – 0.25
pH	3.53 ± 0.03	3.79	3.60	n.e.	3.38	n.e.	n.e.	3.90	3.84 – 4.12

[a] expressed in wet basis as mass % (except to pH).
[b] ash, fat, protein and fiber contents expressed in dry basis as mass %. Kristal Taiwan variety evaluated.
[c] titratable acidity expressed as citric acid.
n.e. – not evaluated.

$$\rho = 1487.470 - 484.770x_w - 0.024T - 0.009T^2 \quad ; \quad R^2 = 0.96 \quad (5)$$

where ρ is density (kg m^{-3}), x_w is water mass fraction (dimensionless) and T is temperature (°C).

Malay Rose apple pulp presented low fat content, with the total solids composed mainly of sugars, which have a density higher greater than that of pure water. Thus, increasing the water fraction should decrease pulp density, as observed. The addition of any solid, except fat, in the water increases the density (Lewis, 2006). This was verified in this paper, since density was reduced with increasing water content. A more complex behavior was observed when temperature was increased, due to thermal expansion of the different components of the pulp, as observed by Souza *et al*. (2011) who studied jackfruit pulp density. When temperature increased the intra and inter molecular interactions had more energy. Thus, atoms and molecules tend to be more distant to stabilize this effect, with a consequent decrease in density (McQuarrie and Simon, 1997).

Souza *et al.* (2011), studying density of jackfruit pulp with water concentration ranging from 65–95 mass % (wet basis), found experimental values near to those obtained in this work. Similar results were also obtained from other authors studying different fruits, such as genipap pulp (Silva *et al*., 2010) and umbu pulp (Souza *et al.*, 2010).

Experimental values obtained for specific heat varied from 4.07 ± 0.03 to 4.17 ± 0.02 kJ kg^{-1} K^{-1}, as water content increased, with this relationship being directly proportional. According to Lewis (2006), because of the unique characteristics of the hydrogen interactions, water presents a higher specific heat in comparison to other food constituents. Therefore, this property is significantly affected by the amount and physical state of water present in the food. Many authors have observed this fact, including Silva *et al.* (2010) working with genipap pulp, Mercali *et al.* (2011) for acerola and blueberry pulps, Souza *et al.* (2011) for jackfruit pulp, Oliveira *et al.* (2012) for

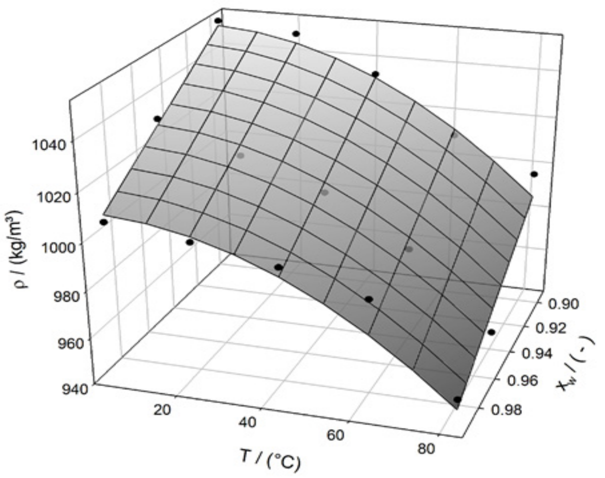

Figure 1. Effects of temperature and water content on density of Malay Rose apple pulp. (• - experimental data; surface - fitted model).

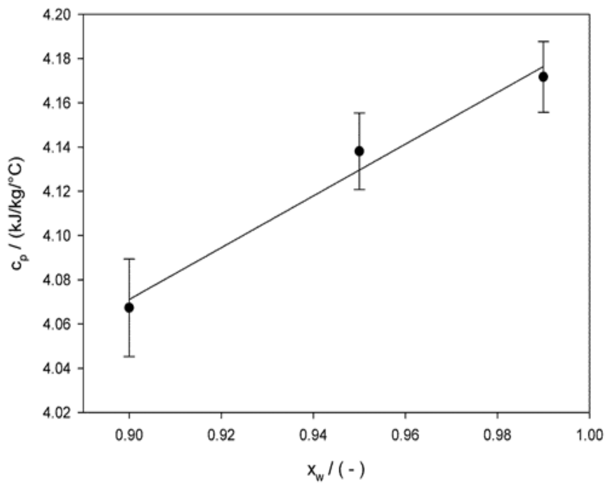

Figure 2. Effect of water content on specific heat of Malay Rose apple pulp (• - experimental data; line – fitted model).

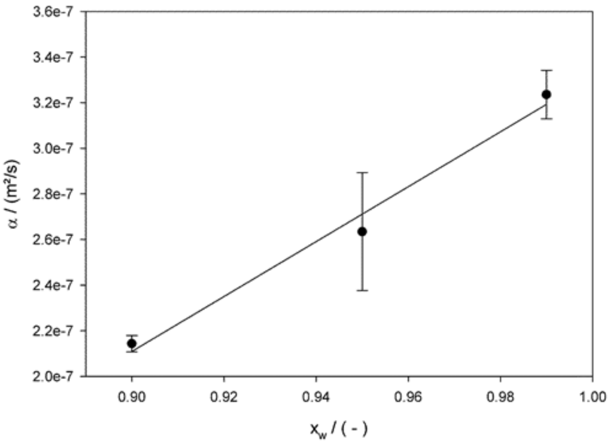

Figure 3. Effect of water content on thermal diffusivity of Malay Rose apple pulp (• - experimental data; line – fitted model).

tropical fruits and Akhijahani and Khodaei (2013) for Rasa grapes.

Figure 2 presents experimental values as well as the fitted model. A linear behavior was observed, where the specific heat increased with water content elevation. The fitted model is presented in Equation 6:

$$c_p = 1.17x_w + 3.02 \quad ; \quad R^2 = 0.98 \qquad (6)$$

where c_p is the specific heat (kJ kg^{-1} K^{-1}) and x_w is the water mass fraction (dimensionless).

Experimental results of thermal diffusivity (α) are shown (Figure 3). The fitted model by linear regression showing the relationship between thermal diffusivity and water content is presented below.

$$\alpha = 1.20\times10^{-6}x_w - 8.73\times10^{-7} \quad ; \quad R^2 = 0.99 \qquad (7)$$

where α is the thermal diffusivity (m² s^{-1}) and x_w is the water mass fraction (dimensionless).

An increase in thermal diffusivity was observed with increasing water content of the pulp. This means that the pulp's ability to conduct heat energy increases proportionally compared to storage when the water content is increased, which increases the velocity of heat propagation through the product (Souza *et al.*, 2010). Experimental values were in the range obtained by many authors studying other foodstuffs such as cashew, bacuri, genipap, umbu and jackfruit (Azoubel *et al.*, 2005; Muniz *et al.*, 2006; Silva *et al.*, 2010; Souza *et al.*, 2010; Souza *et al.*, 2011). These authors also reported that thermal diffusivity increases with water content. Thus, the ability of the pulp to conduct thermal energy compared to the ability to store it improved at the studied conditions.

Conclusion

Malay Rose apple pulp is rich in water and carbohydrates. It presents similar composition around the world, which facilitates the standardization of processing at different locations. This is essential for improving its consumption, especially far from production centers. Water content in the studied ranges significantly affected the thermophysical properties studied. Thermal diffusivity and specific heat were positively affected by an increase in water content. Density was also affected by temperature and decreased as temperature and moisture content increased. Simple models were fitted, properly explaining the studied properties.

References

Akhijahani, H.S. and Khodaei, J. 2013. Investigation of specific heat and thermal conductivity of Rasa grape (*Vitis vinifera* L.) as a function of moisture content. World Applied Sciences Journal 22(7): 939-947.

Alcântara, L.A.P., Fontan, R.C.I., Bonomo, R.C.F., Souza Jr., E.C., Sampaio, V.S. and Pereira, R.G. 2012. Density and dynamic viscosity of bovine milk affect by temperature and composition. International Journal of Food Engineering 8(1). DOI: 10.1515/1556-3758.1860.

AOAC 1996. Official Methods of Analysis, 16th ed., Gaithersburg: AOAC International.

Augusta, I.M., Resende, J.M., Borges, S.V., Maia, M.C.A. and Couto, M.P.G. 2010. Physical and chemical characterization of malay red-apple (*Syzygium malaccensis,* (L.) Merryl and Perry) skin and pulp. Food Science and Technology (Campinas) 30(4): 928-932.

Azoubel, P.M., Cipriani, D.C., El-Aouar, Â.A., Antonio, G.C. and Murr, F.E.X. 2005. Effect of concentration on the physical properties of cashew juice. Journal of Food Engineering 66(4): 413-417.

Cardoso, R.L. 2008. Stability of the color of mountain apple jelly (*Eugenia malaccensis,* L.) without rind stored at 25°C and 35°C in the presence and absence of light. Ciência e Agrotecnologia 32(5): 1563-1567.

Cepeda, E. and Villaran, M.C. 1999. Density and viscosity of Malus floribunda juice as a function of concentration and temperature. Journal of Food Engineering 41(2): 103-107.

Choi, Y.O. and Okos, M.R. 1986. Effects of temperature and composition on the thermal properties of foods. In Maguer, M. and Jelen, P. (Eds) Food Engineering and Process Applications, p. 93-101. London: Science Publisher.

Coimbra, J.S.R., Gabas, A.L., Minim, L.A., Rojas, E.E.G., Telis, V.R.N. and Telis-Romero, J. 2006. Density, heat capacity and thermal conductivity of liquid egg products. Journal of Food Engineering 74(2): 186-190.

Constenla, D.T., Lozano, J.E. and Crapiste, G.H. 1989. Thermophysical properties of clarified apple juice as a function of concentration and temperature. Journal of Food Science 54(3): 663-668.

Dickerson Jr, R.W. 1965. An apparatus for the measurement of thermal diffusivity of foods. Food Technology 19(5): 198-204.

Dignan, C., Burlingame, B., Kumar, S. and Aalbersberg, W. 2004. The Pacific Islands food composition tables. Rome: Food and Agriculture Organization of the United Nation (FAO).

Fontan, R.C.I., Santos, L.S., Bonomo, R.C.F., Lemos, A.R., Ribeiro, R.P. and Veloso, C.M. 2009. Thermophysical properties of coconut water affected by temperature. Journal of Food Process Engineering 32(3): 382-397.

Heldman, D.R. and Singh, R.P. 1981. Food Process Engineering. 2nd edition. Westport: AVI Publishing Company, Inc.

Lago, E.S., Gomes, E. and Silva, R. 2006. Production of jambolan (*Syzygium cumini* Lamarck) jelly: processing, physical-chemical properties and sensory evaluation. Food Science and Technology (Campinas) 26(4): 847-852.

Lewis, M.J. 2006. Physical properties of foods and food processing systems. 4th reprint. Cambridge: Woodhead Publishing Limited.

Lim, A.S.L. and Rabeta, M.S. 2013. Proximate analysis, mineral content and antioxidant capacity of milk apple, malay apple and water apple. International Food Research Journal 20(2): 673-679.

Magerramov, M.A., Abdulagatov, A.I., Azizov, N.D. and Abdulagatov, I.M. 2007. Effect of temperature, concentration, and pressure on the viscosity of pomegranate and pear juice concentrates. Journal of Food Engineering 80(2): 476-489.

McQuarrie, D.A. and Simon, J.D. 1997. Physical Chemistry: A Molecular Approach. Sausalito: University Science Books.

Mercali, G.D., Sarkis, J.R., Jaeschke, D.P., Tessaro, I.C. and Marczak, L.D.F. 2011. Physical properties of acerola and blueberry pulps. Journal of Food Engineering 106(4): 283-289.

Miles, C.A., Van Beek, G. and Veerkamp, C.H. 1983. Calculation of thermophysical properties of foods. In: Jowitt, R., Escher, F., Hallstron, B., Meffert, H., Spiess, W. and Vos, G. (Eds) Physical Properties of Foods, p. 269-312. London: Science Publishers.

Minim, L.A., Coimbra, J.S.R. and Minim, V.P.R. 2002. Influence of temperature and water and fat contents on the thermophysical properties of milk. Journal of Chemical and Engineering Data 47(6): 1488-1491.

Mohsenin, N.N. 1980. Thermal properties of food and agricultural materials. New York: Gordon and Breach.

Morton, J. 1987. Malay Apple. In Morton, J.F. (Eds) Fruits of warm climates, p. 378-381. Miami: Florida Flair Books.

Muniz, M.B., Queiroz, A.J.M., Figueiredo, R.M.F. and Duarte, M.E.M. 2006. Thermophysical characterization of bacuri pulp. Food Science and Technology (Campinas) 26(2): 360-368.

Nunes, P.C., Aquino, J.S., Rockenbach, I.I. and Stamford, T.L.M. 2016. Physico-chemical characterization, bioactive compounds and antioxidant activity of Malay apple [Syzygium malaccense (L.) Merr. and L.M. Perry]. PLoS ONE 11(6): e0158134. DOI 10.1371/journal.pone.0158134.

Oliveira, J.M., Lessio, B.C., Morgante, C.M., Santos, M.M. and Augusto, P.E.D. 2012. Specific heat (Cp) of tropical fruits: cajá, cashew apple, cocoa, kiwi, pitanga, soursop fruit and yellow melon. International Food Research Journal 19 (3): 811-814.

Pino, J.A., Marbot, R., Rosado, A. and Vázquez, C. 2004. Volatile constituents of Malay Rose apple [*Syzygium malaccense* (L.) Merr. and Perry]. Flavour and Fragrance Journal 19(1) :32-35.

Ribeiro Jr J.I. 2001. Statistycal analysis on SAEG. Viçosa: Editora UFV.

Rosnah, S., Wong, W.K., Noraziah, M. and Osman, H. 2012. Chemical composition changes of two water apple *(Syzygium samaragense)*. International Food Research Journal 19(1): 167-174.

Santos, P.H., Silva, L.H.M., Rodrigues, A.M.C. and Souza, J.A.R. 2016. Influence of temperature, concentration and shear rate on the rheological behavior of Malay apple *(Syzygium malaccense)* juice. Brazilian Journal of Food Technology 19: e2015009. DOI 10.1590/1981-6723.0915.

Shamsudin, R., Daud, W.R.W., Takriff, M.S. and Hassan, O. 2007. Physicochemical properties of the Josapine variety of pineapple fruit. International Journal of Food Engineering 3(5). DOI 10.2202/1556-3758.1115.

Silva, N.M.C., Bonomo, R.C.F., Rodrigues, L.B., Chaves, M.A., Fontan, R.C.I., Bonomo, P., Landim, L.B. and Sampaio, V.S. 2010. Thermophysical characterization of genipap pulp. International Journal of Food Engineering 6(3). DOI 10.2202/1556-3758.1701.

Souza Jr, E.C., Fontan, R.C.I., Verissimo, L.A.A., Sampaio, V.S., Silva, W.S., Bonomo, R.C.F. and Veloso, C.M. 2012. Thermal diffusivity and specific heat of bovine milk affected by temperature and composition. International Journal of Food Engineering 8(3). DOI 10.1515/1556-3758.2307.

Souza, M.A., Bonomo, R.C.F., Fontan, R.C.I. Minim, L.A., Coimbra, J.S.R. and Bonomo, P. 2010. Thermophysical properties of umbu pulp. Brazilian Journal of Food Technology 13(3): 219-225.

Souza, M.A., Bonomo, R.C.F., Fontan, R.C.I. Minim, L.A. and Coimbra, J.S.R. 2011. Thermophysical properties of jackfruit pulp affected by changes in moisture content and temperature. Journal of Food Process Engineering 34(3): 580-592.

Sweat, V.E. 1995. Thermal properties of foods. In Rao M.A. and Rizvi S.S.H. (Eds) Engineering Properties of Food, p. 99-138. New York: Marcel Dekker.

Vara-Ubol, S., Chambers, E., Kongpensook, V., Oupadissakoon, C., Yenket, R. and Retiveau, A. 2006. Determination of the sensory characteristics of Rose Apples cultivated in Thailand. Journal of Food Science 71(7): S547-S552.

Zainal, B.S., Abdul Rahman, R., Ariff, A.B., Saari, B.N.

and Asbi, B.A. 2000. Effects of temperature on the physical properties of pink guava juice at two different concentrations. Journal of Food Engineering 43(1): 55-59.

Zuritz, C.A., Puntes, E.M., Mathey, H.H., Pérez, E.H., Gascón, A., Rubio, L.A., Carullo, C.A., Chernikoff, R.E. and Cabeza, M.S. 2005. Density, viscosity and coefficient of thermal expansion of clear grape juice at different soluble solid concentrations and temperatures. Journal of Food Engineering 71(2): 143-149.