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Specific heat (Cp) of tropical fruits: Cajá, Cashew Apple, Cocoa, Kiwi, Pitanga, Soursop fruit and Yellow melon

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Abstract: The tropical/exotic fruits are important sources of vitamins, fibres and other nutritional components such as anti-oxidants. In addition to its health claim, the pleasant flavour and sensory profile result in a increasing fruit demand worldwide. Therefore there is a need for better understanding its processing and properties. The thermal process is a needed unit operation for guarantee the fruit products safety. The specific heat (Cp) knowledge is essential for an efficient fruit pulp thermal processing. Although the exotic fruits Cp were studied for various authors, there is no work in the literature related to the pulps of cajá (*Spondias lutea)*, cashew apple (*Anacardium occidentale*), cocoa (*Theobroma cacao*), kiwi (*Actinidia chinensis*), pitanga (*Eugenia uniflora*), soursop fruit (*Annona muricata*) and yellow melon (*Cucumis melon*). The present work evaluated the specific heat (Cp) of this eight tropical fruits at thermal processing condition (30-90ºC). The fruits Cp values were close to the water Cp, and ranged from 3746.3 $J \cdot kg^{-1}K^{-1}$ for the cocoa pulp, to 4037.1 $J \cdot kg^{-1}K^{-1}$ for the cajá pulp. The results here obtained can be directly used for processing design. Moreover, it is potentially useful for future studies on food properties and process design.

Keywords: Specific heat, thermal process, tropical fruits

Introduction

The fruits and vegetables consumption is recognized as one of the basis of a healthy diet (Sant'Ana, 2011). The tropical fruits, also called exotic fruits, are important sources of vitamins, fibres and other nutritional components such as anti-oxidants. In addition to its health claim, the pleasant flavour and sensory profile increase the fruit demand worldwide. Therefore there is a need for better understanding its processing and properties.

The health benefits and potential technological applications of exotic fruits could be better exploited if more information on their chemistry, biochemistry, nutritional properties, and microbiological, sensory, toxicological, technological and engineering aspects are available (Sant'Ana, 2011). Moreover, Furtado *et al.* (2010) and Ceva-Antunes *et al.* (2006) observed that the native fruit commercialization plays an important role in the social perspectives of developing countries, like Brazil.

The thermal process is one of the most important food preservation techniques, particularly for fruit pulps and juices. The optimization of the fruit thermal processing is highly desirable, as it results in better nutritional and sensorial properties, and lower energy consumption.

The specific heat (Cp) knowledge is essential for an efficient fruit pulp thermal processing (Singh *et al.,* 2009). Although the exotic fruits Cp were studied for various authors, there is no work in the literature related to the pulps of cajá *(Spondias lutea)*, cashew apple *(Anacardium occidentale)*, cocoa *(Theobroma cacao)*, kiwi *(Actinidia chinensis)*, pitanga *(Eugenia uniflora),* soursop fruit *(Annona muricata)* and yellow melon *(Cucumis melon)*. The present work evaluated the specific heat (Cp) of this eight tropical fruits.

Materials and Methods

Fruit pulps

The eight tropical fruits pulps evaluated (Table 1) were selected as there is no work in the literature describing its specific heat (Cp) in the temperature range of pasteurization(30ºC-90ºC). Pasteurized frozen commercial pulps were used in order to guarantee the standardization and repeatability. After washing, the fruits are pulped, pasteurized, packaged in small plastic bags and then frozen, prior to commercialization.

Samples were thawed and carefully homogenized before evaluation. Its soluble solids content were determined by using a refractometer (digital refractometer r² mini, Reichert Analytical Inst.,

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Japan), after filtering the samples trough cotton. The pulps pHs were directly measured by using a pH meter (Tecnal, TEC-2, Brasil). Table 1 shows the soluble solid content and pH of the eight fruit pulps evaluated.

Table 1. The eight fruit pulps evaluated

Fruit pulp	pH	Soluble solids content (ºBrix)
Cajá (*Spondias lutea*)	2.89	8.6
Cashew apple (*Anacardium occidentale)*	4.23	10.3
Cocoa (*Theobroma cacao*)	3.68	12.1
Kiwi (*Actinidia chinensis*)	3.31	12.4
Pitanga (*Eugenia uniflora*)	3.18	5.9
Soursop fruit (*Annona muricata*)	3.46	10.4
Yellow melon (*Cucumis melon*)	5.74	5.9

Procedures

Several methods can be used for measuring the specific heat (Cp) of food products, as the method of mixtures, the comparison calorimeter method, the adiabatic methods, or using the Differential Scanning Calorimetry (DSC) (Singh *et al*., 2009). The method of mixtures is the most widely used technique for measuring the specific heat of food products due to its simplicity and accuracy (Singh *et al.*, 2009). It was used by several authors for fruits evaluation (Silva *et al*., 2002; Mata et al., 2003; Lima et al., 2003; Araújo *et al*., 2004; Gratão *et a*l., 2005; Phomkong *et al*., 2006; Muniz *et al*., 2006; Aghbashlo et al., 2008). Therefore, the method of mixtures was selected in order to determine the specific heat (Cp) of the eight evaluated fruit pulps.

In this method, a specific sample mass (m_{sample}) is set at a determined initial temperature (T_1) and then added in an adiabatic vessel (a calorimeter or Dewer flask) at a determined initial temperature (T_2), whose calorimetric capacity (Ccalorimeter) must be known. Then, it is mixed with a specific mass of a liquid with known properties (water, in general – m_{water}, Cp_{water}) at T_2. After thermal equilibrium (at T_3, where $T_2 < T_3 < T_1$), the sample specific heat (Cp_{sample}) is thus obtained by the energy balance using Equation 1.

$$Cp_{sample} = \frac{Cp_{water}(T_3 - T_2) + C_{calorimeter}(T_3 - T_2)}{m_{sample}(T_1 - T_3)} \quad \text{Equation 1}$$

A similar procedure must be previously carried out in order to determine the calorimeter calorimetric capacity ($C_{calorimeter}$). In this procedure, water is used as a material with known properties, and a specific mass of hot and cold water are mixed in the calorimeter. The calorimeter calorimetric capacity ($C_{calorimeter}$) is then obtained using Equation 2.

$$C_{calorimeter} = \frac{m_{hot\_water}Cp_{hot\_water}(T_3 - T_2) - m_{cold\_water}Cp_{cold\_water}(T_1 - T_3)}{(T_1 - T_3)}$$

Equation 2

The calorimeter used in the present work, was composed by a 1 L glass flask which of that surfaces were coated with a reflective layer, involved by a low density polyethylene case. An extra cotton layer (70 mm) was added in order to minimize the heat transfer with the environment. The flask was sealed with a silicon cork coupled to a type-T thermocouple (Digital Pocket Thermometer, USA). It was similar to those described by Mata and Duarte (2003).

The calorimeter calorimetric capacity (Ccalorimeter) was determined using 600 g of distilled water at 5ºC and 300 g of distilled water at 90ºC. The fruit pulps specific heat (Cp) were determined using 300 g of pulp at 90ºC and 600 g of distilled water at 5ºC. Before each experiment, the packaged water and samples were kept in water-baths in order to guarantee the initial desired temperature. Moreover, the calorimeter was maintained with distilled water at the desired initial temperature. The experiments were carried out in three replicates.

Results and Discussion

The calorimeter calorimetric capacity (Ccalorimeter) was 149.0±29.6 $J \cdot K^{-1}$. It is interesting to notice that this value is close to those reported by Mercali *et al.* (2011) for a similar equipment (124.5 $J \cdot K^{-1}$). The Ccalorimeter was then used in order to determine the pulps specific heat (Cp), as described in Equation 1.

Table 2 shows the specific heat (Cp) obtained values for the eight evaluated fruit pulps. These values are the correspondent mean values in the evaluated temperature range (30ºC to 90ºC), which was chosen in order to provide the necessary data for thermal

Table 2. The eight fruit pulps specific heat (Cp; 30ºC-90ºC). Mean of three replicates ± standard deviation. CV is the coefficient of variation in % (= [standard deviation / average]·100)

Fruit pulp	Cp (J·kg^{-1}K^{-1})	CV (%)
Cajá (*Spondias lutea*)	4037.1±60.4	1.5
Cashew apple (*Anacardium occidentale*)	4027.8±45.2	1.1
Cocoa (*Theobroma cacao*)	3746.3±158.0	4.2
Kiwi (*Actinidia chinensis*)	3893.2±63.8	1.6
Pitanga (*Eugenia uniflora*)	3967.6±61.6	1.6
Soursop fruit (*Annona muricata*)	3865.6±112.9	2.9
Yellow melon (*Cucumis melon*)	4030.2±104.2	2.6

Table 3. Fruit pulps specific heat (Cp) values*

Fruit pulp	Cp (kJ·kg^{-1}K^{-1})	Temperature range (ºC)	Pulp concentration (ºBrix; % solids)	Reference
Acerola	4.172	8 – 72	8	Mercali *et al.* (2011)
Bacuri	2.986 - 3.616	NS	5 – 20	Muniz *et al.* (2006)
Berberis	1.97 – 3.28	50 - 70	25.7 - 80.7	Aghbashlo *et al.* (2008)
Blueberry	3.720 – 4.040	8 – 72	14.2 – 16.0	Mercali *et al.* (2011)
Cajá	1.516 – 3.688	(-196) – (-18)	9 – 60	Mata *et al.* (2003)
Cajá	1.646 – 3.677	(-196) – (-18)	9 – 60	Mata *et al.* (2005)
Cajá	3.51	5 – 15	14.7	Silva *et al.* (2002)
Cupuaçu	3.24 - 3.71	NS	12 - 9	Araujo *et al.* (2004)
Nectarine	3.0 – 4.0	25 – 50	29.9 – 83.1	Phomkong *et al.* (2006)
Papaya	3.02	20	9.5	Espinoza-Guevara *et al.* (2010)
Passion fruit	2.5 – 4.0	0.4 – 68.8	10 – 50	Gratão *et al.* (2005)
Peach	3.6 – 4.0	25 – 50	23.7 – 86.0	Phomkong *et al.* (2006)
Plum	2.25 – 3.00	25 – 50	16.4 – 67.5	Phomkong *et al.* (2006)
Tomato	2.75 - 4.25	20 – 150	4.8 – 80.0	Choi and Okos (1983)
Umbu	3.21 – 3.67	NS	10 – 30	Lima *et al.* (2003)

** NS = not specified*

processes design. As described by Singh *et al.* (2009), the effect of temperature is negligible on unfrozen food products Cp, which allows its evaluation by the average value in the desired temperature range.

Table 2 also shows the coefficient of variation (CV), that was always lower than 5%. It indicates a good reproducibility, and also the values reliability. The Cp values ranged from 3746.3 J·kg^{-1}K^{-1} for the cocoa pulp, to 4037.1 J·kg^{-1}K^{-1} for the cajá pulp. Thus, the samples Cp were closed to the water (4180 J·kg^{-1}K^{-1}), which is expected due to the water-suspension nature of fruit pulps. The obtained Cp values are closed to those described for other fruit products, as acerola, beriberis, bacuri, blueberry, cupuaçu, nectarine, papaya, passion fruit, peach, plum, tomato and umbu pulps (Table 3).

Considering the evaluated fruit pulps, only cajá pulp Cp was previously evaluated. Moreover, Araujo *et al.* (2004) studied the cupuaçu pulp (9ºBrix), a fruit that is in the same family of cocoa (Theobroma). The cupuaçu Cp was 3.71 kJ·kg^{-1}K^{-1}, a value very close to those here obtained for the cocoa pulp (3.75 kJ·kg^{-1}K^{-1}). Mata and Duarte (2003) and Mata *et al.* (2005) evaluated the cajá pulp (9ºBrix) Cp at low temperatures (from -18ºC to -196ºC), whose values ranged from 1.52 kJ·kg^{-1}K^{-1} to 2.56 kJ·kg^{-1}K^{-1}. Silva *et al.* (2002) studied the cajá pulp at 14.7ºBrix and temperatures from 5ºC to 15ºC. The Cp value was 3.51 kJ·kg^{-1}K^{-1}.

The Cp value obtained in the present work is 4.04 kJ·kg^{-1}K^{-1}. It is higher than the values described by Mata and Duarte (2003) and Mata *et al.* (2005) and Silva *et al.* (2002), which is due to the temperature and concentration range evaluation (-196ºC to 15ºC). In Mata and Duarte (2003) and Mata *et al.* (2005) and Silva *et al.* (2002) works, the main objective was to obtain the cajá Cp value at refrigeration and frozen conditions. In the present work, the objective was to obtain the same property, but at thermal processing conditions (30-90ºC).

Thus, the need to obtain exotic and tropical fruits specific heat (Cp) at thermal processing conditions is highlighted, in order to guarantee optimized and safety products. The obtained results can be directly used for processing design. Moreover, they are potentially useful for future studies on food properties and process design.

Conclusions

The present work evaluated the specific heat (Cp) of eight tropical pulp fruits (cajá, cashew apple, cocoa, kiwi, pitanga, soursop fruit and yellow melon) in the temperature range of 30-90ºC by using the method of mixtures. The Cp values were close to the water, and ranged from 3746.3 J·kg^{-1}K^{-1} for the cocoa pulp, to 4037.1 J·kg^{-1}K^{-1} for the cajá pulp. Although the specific heat (Cp) of exotic fruits is being studied for various authors, there is no work in literature related to the eight pulps here evaluated. The obtained results can be directly used for processing design, being potentially useful for future studies on food properties and process design.

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