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Thermal and Physical Properties of Some Tropical Fruits and Their Juices in Nigeria

O.J. Ikegwu and F.C. Ekwu
Department of Food Science and Technology, Ebonyi State University, Abakaliki, Nigeria

Abstract: The thermo-physical properties of processed fruits and their juices from some tropical fruits grown in Nigeria were determined. The properties evaluated were density, moisture content, thermal conductivity, specific heat capacity, thermal diffusivity, latent heat of fusion and the viscosity of the fruit juices. The results obtained showed that the thermal properties increased with increase in moisture contents for all the samples. Water melon juice having the highest moisture content (92.3%). The values of the specific heat capacity and latent heat of fusion of the fruits and their juices ranged between 3.45-4.05 and 23785 kJ kg^{-1} °C to 31825 kJ kg^{-1}, respectively. The viscosity measurement determined at 28+2°C and the total solids of the samples studied increased with decrease in moisture content of the fruits and their juices. The results translates that a lot of energy will be required to heat or cool these fruits and their juices and these mean they are poor conductors of heat.

Key words: Tropical fruits, thermal conductivity, specific heat capacity, density, juices, Nigeria

INTRODUCTION

Food crops including cereals and legumes, fruits and vegetables, roots and tubers are processed for different reasons. UNIFEM (1988), reported that fruits can be processed into various products, namely; fruit juices, fruit salads, wine etc. The most commonly manufactured product is fruit juice. Fruit juice could be defined in the most general sense as the extractable fluid from fruits. Fruits and their juices are good source of phytochemical, therefore, in addition to the nutritive value of juices and the additional health benefits from phytochemicals will increase the popularity of such products. Fruits and their juices are also good source of Vitamin C, which is needed by the body.

For some years now their have been widespread interest in the engineering or thermal and physical properties such as viscosities, specific heat capacities, solid densities etc. of fresh or processed food stuffs. The information is required by food researchers for the purpose of quality assessment and evaluation, process design, operation and control of food plants, equipment design, etc. (Nwanekezi and Ukagu, 1999). The understanding of these engineering properties of food stuff and their responses to process conditions is necessary not only because they affect physical treatment received during processing, but also they are the commonest indicators of other properties and qualities (Hallstom and Jowitt, 1990). The structure and properties of food as well as their biological and microbiological characteristics create the need for unique consideration of the thermal and physical properties of foods. These will help in determining the best processing principles that will be applied to them (Charm, 1998).

Fruits and vegetables at different levels of processing are subjected to thermal treatments in food industry understanding of their responses to these thermal processes requires good knowledge of their thermal and physical properties. Lack of mechanization of the processing of variety of fruits, which abound in the tropics presently could be traced to the fact that data in their engineering properties are lacking.

The objective of this research was to evaluate the thermal and physical properties of local fruits and vegetables and their juices. The data will enhance better control of both processes and product for the benefit of consumers, processors and producers.

MATERIALS AND METHODS

Sources of samples: The fresh matured and ripe fruits used in this research (Orange, Pineapple, Pawpaw, Mango, Lemon, Lime, Cashew, Guava Sour sop and Banana) were purchased from the main market in Abakaliki, Ebonyi State Nigeria.

Preparations of samples: Fully ripped fruits free of mould or discolouration were washed in clean portable water, manually peeled and cut into half with stainless knife. The peeled and cut fruits were pressed and sieved to extract

Corresponding Author: O.J. Ikegwu, Department of Food Science and Technology, Ebonyi State University, Abakaliki, Nigeria

the juices, using sony multipurpose electric blender. The Juices were filled in pre-sterilized plastic cans, sealed and pasteurized in water bath (Model: Ambassador) maintained at temperature of 100°C for 10 min, cooled to room temperature and stored in a cool place for analysis.

Physical properties

Viscosity measurements: The viscosity of the samples was determined using digital display viscometer (Model: NDJ-8S). The temperature of the fruit juice samples were maintained at room temperature (28±2°C) using water bath (Model: Ambassordor). Measurements were made on juice samples at a constant shear rate (60 rpm). A 600 mL beaker was used for all measurements and 500 mL of sample, was added to bring sample level to the immersion groove on the spindle shaft. Triplicate samples were analyzed and the viscosity values were obtained by multiplying dial reading by appropriate factors (supplied by the Viscometer manufactured).

$$\text{Viscosity} = \text{Dial reading} \times \text{Factor (500)}$$

Density: The density of the fruit samples was determined using simple flotation principle: Equal mass (10 g) of each sample was weighed using an electronic weighing balance (Model: Mettler P1210). The mass so measured was put into 250 mL measuring cylinder containing 100 mL water (as flotation liquid) and the difference in volume noted. The difference is the volume occupied by the 10 g sample. Density therefore, becomes mass of sample divided by the volume occupied by the sample. While the density of the fruit juice samples was determined using specific gravity bottle method. AOAC (1990) was adopted for moisture content determination.

Thermal properties: The moisture contents of various fruit and their juices were used to calculate the thermal conductivity, specific heat capacity, thermal diffusivity and latent heat of fusion. Mathematical formula developed by Sweat (1974) for calculating the thermal conductivities of fruit and their juice samples was adopted provided their moisture contents were higher than 60%.

The mathematical formula connecting the various engineering properties with moisture content of the fruits and their juices are as follows:

Thermal conductivity (K):

$$K = 0.148 + 0.00493\,W \qquad (1)$$

where:

K = The thermal conductivity (J sm^{-1} °C)
W = The moisture content (%)

Specific heat Capacity (Cp): The method of Dickerson (1969) was used to evaluate the specific heat C3apacity (Cp).

$$Cp = 1.675 + 0.025W \qquad (2)$$

where:

Cp = The specific heat Capacity (KJ kg^{-1} °C)

Thermal diffusivity (α) and latent heat (λ): The method of Lewis (1987) and Lamb (1976) were adopted for thermal diffusivity and latent heat determination, respectively.

$$\alpha = K/\rho\ Cp \qquad (3)$$

where:

α = The thermal diffusivity ($x10^{-7}$ M^2/s)
K = The thermal conductivity (J sm^{-1} °C)
ρ = The density (kg m^{-3})
Cp = The specific heat (kJ kg^{-1} °C)

$$\lambda = 335\ W \qquad (4)$$

where:

λ = The latent heat of fusion (J kg^{-1})

RESULTS AND DISCUSSION

Viscosity of the fruit juices: The apparent viscosity of the fruit juices is shown in Table 1. The viscosity values for the juices ranged from 728.0-1236.0 cps. From Table 1, it was observed that Sour sop juice had the highest (1236.0 cps) apparent viscosity value followed by Guava juice (1212.2 cps), while water melon juice had the least apparent viscosity value (728 cps). The viscosity of the samples decreased with (Table 1) increase in moisture content.

The observed increase in viscosity could be attributed to solubility and the quantity of total solids in the sour sop juice. This result is supported by the findings of Snyder and Kwon (1987), who reported that the more material there is in solution the higher the viscosity.

Density and relative density of the fruits and their juices: The density of the fruits and their juices is presented in Table 2, the density values of the fruits ranged from 889-1071 kg m^{-3}, pawpaw fruit recording the lowest density 889 kg m^{-3}, while guava fruit had the highest (1071 kg m^{-3}) density. The relative density (Table 1) of the fruit juices ranged from 1.032-1.065, with sour sop juice and water melon juice having the highest (1.065) and lowest (1.032) relative density, respectively. From Table 1, it is observed that the relative density of the fruit juices had positive correlation with total solid of the juices examined, higher the percentage total solid, the higher the relative density.

Table 1: Engineering properties of fruit juices produced from some tropical fruits

Fruit juices	MC (%)	Physical properties: Specific gravity	Total solids (%)	Viscosity (Cps)	Thermal properties: Thermal conductivity (J S m^{-1} °C)	Thermal diffusivity (×10^{7} m^{2} s^{-1})	Specific heat capacity (kJ kg^{-1} °C)	Latent heat of fusion (kJ kg^{-1})
Orange juice	89.6	1.041	10.4	1078.67	0.590	1.448	3.915	30016
Pineapple juice	87.9	1.050	12.1	1135.20	0.581	1.429	3.873	29447
Lemon juice	91.0	1.040	9.0	862.67	0.597	1.450	3.950	30485
Water melon	95.3	1.032	4.7	728.00	0.618	1.469	4.058	31926
Mango juice	85.2	1.056	14.8	936.00	0.568	1.414	3.805	28542
Orange/pineapple	88.6	1.048	11.4	1132.50	0.585	1.435	3.890	29681
Pineapple/Water melon juice	89.1	1.042	10.9	1110.70	0.587	1.443	3.903	29849
Pineapple/Mango juice	87.4	1.051	12.6	1162.70	0.579	1.431	3.860	29279
Sour sop juice	83.7	1.065	16.3	1236.00	0.561	1.398	3.768	28040
Guava juice	84.2	1.053	15.8	1212.20	0.563	1.414	3.780	28207

Table 2: Engineering properties of some tropical fruits in Ebonyi State, Nigeria

Fruits	MC (%)	Physical properties: Specific gravity	Total solids (%)	Solid density (kg m^{-3})	Thermal properties: Thermal conductivity (J S m^{-1} °C)	Thermal diffusivity (×10^{7} m^{2} s^{-1})	Specific heat capacity (kJ kg^{-1} °C)	Latent heat of fusion (kJ kg^{-1})
Orange	89.2	1.040	10.8	1040	0.588	1.45	3.91	29882
Pineapple	85.0	0.983	15.0	983	0.567	1.52	3.80	28475
Lemon	90.0	1.032	10.0	1032	0.592	1.46	3.93	30150
Water melon	95.0	1.030	5.0	1030	0.616	1.48	4.05	31825
Pawpaw	88.0	0.889	12.0	889	0.582	1.69	3.88	29480
Mango	84.0	1.068	16.0	1068	0.562	1.39	3.78	28140
Guava	81.0	1.071	19.0	1071	0.547	1.38	3.70	27135
Sour sop	83.0	0.960	17.0	960	0.557	1.55	3.75	27805
Banana	71.0	0.964	29.0	964	0.498	1.50	3.45	23785
Cashew	88.0	0.930	12.0	930	0.582	1.61	3.88	29480
Lime	90.7	1.030	9.3	1030	0.595	1.47	3.94	30385

The quality of a particular fruit can be determined by its density. The hollowness and soluble solid contents of intact fruits is related to their specific and solid densities. The variation in the density and relative density of the fruits and their juices might have been influenced by the structure of starch polymers which will result in low density. This imply that the lower the density, the higher the flotation of the fruit samples on top of water and as a result may not be of a high quality and may in turn be rejected by consumers. Nwanekezi and Ukagu (1999) found that density as an engineering property is used for quality assessment especially during separation of intact quality fruits and vegetables (damaged or rotten ones). Kato (1996) reported that the quality of Water melon is related to its relative and solid densities.

Moisture content: The solid content of food products are related to their food values. The greater the solid content (lower moisture content) of the fruits, the greater is its nutritional value. The moisture content of foods besides influencing engineering properties of fruits and vegetables is also of profound importance in determination of shelf-life of unprocessed and processed fruit and vegetables since it affects physico-chemical properties, microbiological spoilage and enzymatic change. Table 1 and 2 revealed that the moisture contents of the fruits and the juices examined were all higher than 60%, making the mathematical model connecting the various engineering properties with moisture contents of fruits and their juices valid. Furthermore, the high moisture and nutritional contents of the fruits and their juices make them suitable for spoilage organisms and agents to grow and multiply. Therefore, all the fruits and their juices are classified as highly perishable and cannot be preserved or stored at ambient conditions. In order to preserve these fruits and their juices, their moisture contents have to be reduced to the level that will make moisture unavailable for microbial growths. The ways, which these fruits can be preserved include refrigerating or freezing, which require transfer of heat to achieve them.

Specific heat capacity: Specific heat capacity is defined as the quantity of heat gained or lost by a unit mass of fruits and their juices to accomplish unit change in temperature. The specific heat capacity ranged from 3.45-4.05 kJ kg^{-1} °C for fruits and 3.768-4.058 kJ kg^{-1} °C for the juice Table 1 and 2, respectively. Form Table 1 and 2, it was observed that the specific heat capacities of fruits and their juices, examined were found to be high running into thousands of joules per kilogram for a unit change in temperature. This translates that lot of energy will be required to heat or cool these fruit and their juices and once heated or cooled, they retain their temperatures for long time. This is as a result of large moisture contents of these fruits and their juices. Lamb (1976) reported, that water retains its temperature for long-time because of its high specific heat capacity value. Based on this water melon juice will retain its temperature for a longer time, than other fruits and their juices. Besides water, specific heat capacity also is influenced by the composition of fruits and vegetables such as protein and fat (Wang and Brennar, 1993).

Thermal conductivity and diffusivity: The thermal conductivities of the fruits and their juices ranged from 0.498-0.616 J ms^{-1} °C for fruits and 0.561-0.618 J ms^{-1} °C for the juices Table 1 and 2, respectively. It was observed that the values of thermal conductivities and diffusivities (Table 1 and 2) of the fruits and their juices were low compared to pure water. This may be due to the total solids in the fruits and the juices. This implies that they are poor conductors of heat, also the heat energy diffusion or transfer through these fruits and their juices during drying, refrigeration, freezing, evaporation etc. are likely to be very slow. Generally, the thermal conductivity of the juice was higher than the fruit in each sample. This may be due to higher moisture content of the juices compared with the fruits. Water is a good conductor of heat. This may explain why the juice with high moisture content has higher thermal conductivity. Nwanekezi and Ukagu (1999) reported that good conductors like metals have high thermal conductivities and low specific heat capacity values.

The low thermal diffusivities for these fruits may probably explain their low conductivities. The thermal diffusivity of the fruits ranged $1.38\text{-}1.69\times10^{-7}$ m^2 s^{-1} and their juices ranged $1.398\text{-}1.469\times10^{-7}$ m^2 s^{-1} (Table 1 and 2). Therefore, movement or diffusion of heat energy from one point to another in these foods would generally be very low during thermal processing.

Latent heat of fusion: The latent heat of fusion for these fruit and their juices were very (Table 1 and 2) high just like those of specific heat capacities. The values ranged from 23.782-31.926 (kJ kg^{-1}) with water melon juice having the highest value (31926 J kg^{-1}), while banana fruit showed the least mean value (23782 J kg^{-1}). This mean that the amount of energy required for these foods to be frozen in a freezer would be high.

CONCLUSION

The investigation indicated that the viscosities of all the fruit juices decreased with increased moisture content compositions of the samples. The moisture content of the fruits and their juices were found to be high ranging between 71.0 and 95.3%. Therefore, in order to preserve these foods, their moisture contents have to be reduced to the level that will make moisture unavailable for microbial growth. These can be achieved through refrigerating, freezing or drying. All these processes require transfer of heat. The results revealed that the values of thermal conductivities and diffusivities of the fruits and their juices were low compared to pure water. This implies that they are poor conductors of heat, also the heat energy diffusion or transfer through these fruits and their juices during drying, refrigeration, freezing, evaporation etc. are likely to be very slow. Generally, the thermal conductivity of the juice was higher than the fruit in each sample. This may be due to higher moisture content of the juices compared with the fruits. The study showed that the relative density of the fruit juices had positive correlation with total solid of the juices examined, higher the percentage total solid, the higher the relative density.

The study also revealed that a lot of energy will be required to process (heat or cool) these fruits and their juices, because they are poor conductors of heat.

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