Results of temperature effect on thermo-physical properties of guava fruit of Southeast Asia

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Abstract. The research presents the results of the effect of temperature on thermo-physical properties of guava fruit of Southeast Asia. Guava is an energetic fruit with high nutritional value and is considered a tropical fruit of South-east Asia. Fruit growers need to use cold storage facilities to extend the revenue period while maintaining produce quality and freshness. The storage life of fresh fruits can be extended by several days by cooling. The specific heat of foods can be used to calculate the refrigeration load calculation. Therefore, the specific heat of food plays an important role in the design of storage and transport systems. One of the most important thermo-physical properties in foods are specific heat. The authors of the article used differential scanning calorimetry (DSC 204 F1), by which the specific heat of guava fruit was determined in the temperature range from −25 to 25 °C. It was found that the specific heat of guava fruit is dependent on temperature.

1. Introduction

Tropical and Subtropical fruits are very popular among the many countries of the world. Southeast Asia, a typical tropical region, plays an important role in exporting a variety of fruits worldwide [1]. In Southeast Asia, there are tropical and subtropical fruits such as dragon fruit (pitaya or pitahaya), coconut, banana, rambutan, pomelo, mango, mangosteen, jackfruit, guava, longan, papaya, pineapple, watermelon, sapodilla, durian, avocado and carambola. Guavas (\textit{Psidium guajava L.}) are fruits of commercial and nutritional values. Guava fruit is generally ovoid or pear shaped and depending on cultivar, their sizes vary from 2.5 to 10 cm in diameter and weight 50 to 500 g. The flesh may be pink, white or yellow, either with seed or seedless [2]. Guava (\textit{Psidium guajava L.}) is often marketed as "super-fruits" which has a considerable nutritional importance in terms of vitamins A and C with seeds that are rich in omega-3, omega-6 poly-unsaturated fatty acids and especially dietary fiber, riboflavin, as well as in proteins, and mineral salts. The high content of vitamin C (ascorbic acid) in guava makes it a powerhouse in combating free radicals and oxidation that are key enemies that cause many degenerative diseases and that can be used to fortify children foods. The anti-oxidant virtue in guavas is believed to help reduce the risk of cancers of the stomach, esophagus, larynx, oral cavity and pancreas [3]. Guava can be consumed fresh or can be processed into juice, nectar, pulp, jam, jelly, and slices in syrup, fruit bar or dehydrated products, as well as being used as an additive to other fruit juices or pulps [4].

The export of tropical fruits has limitations such as a short shelf life and difficulty in maintaining the quality because of tropical climate conditions and undeveloped postharvest technologies in Southeast Asia [1]. An important objective for developing postharvest technologies is to extend the shelf life of fresh fruits without deterioration in fruit quality. The storage life of fresh fruits can be
extended by several days by cooling and by several weeks or months by freezing. Fruits and vegetables are perishable foods with extremely rapid deterioration; this means that their stability after harvesting and during subsequent storage is critical [14]. Cooling at the field before the product is shipped to the market or storage warehouse is referred to as precooling [7]. Precooling is the rapid removal of field heat from freshly harvested fruits and vegetables before shipping, storage, or processing. Prompt precooling inhibits growth of microorganisms that cause decay, reduces enzymatic and respiratory activity, and reduces moisture loss. Thus, proper precooling reduces spoilage and retards loss of postharvest freshness and quality [8]. The cooling method is requirements during the transportation, storage, or processing of fruits. Cooling is one of the main tools for extending postharvest life: slow product metabolism and the activity of microorganisms responsible for quality deterioration. As a result, reserves are maintained with a lower respiration rate, ripening is retarded and vapor pressure between products and ambient is minimized, reducing water loss. During cooling and precooling operation, we need to be able to calculate processing times and heat loads of the product.

The thermo-physical properties of foods play a great role in heat transfer calculations of food processing. Thermo-physical properties of foods are included specific heat, enthalpy, thermal conductivity, thermal diffusivity and density. One of the most important thermo-physical properties in food processing is specific heat. Specific heat is an essential part of the thermal analysis of food processing or of the equipment used in heating or cooling of foods [10]. Specific heat of food product is majority of the refrigeration load calculation. Specific heat is a measure of the energy required to change the temperature of unit mass of the food by one degree [8, 12, 13]. Specific heat of foods materials needed for analysis and design processes involving heat transfer. These processes include cooling, freezing, heating and drying as found in post-harvest handlings and product processing, storage and distribution. The accurate specific heat data will allow food scientists and engineers to calculate the heat transfer precisely leading to the effective food process design including equipment design and implementation. The specific heat depends on the nature of the process of heat addition in terms of either a constant pressure process or a constant volume process. However, because specific heats of solids and liquids do not depend on pressure much, except extremely high pressures, and because pressure changes in heat transfer problems of agricultural materials are usually small, the specific heat at constant pressure is considered [10, 13].

There are several methods of determining specific heat of food and agricultural materials: Empirical equations, Method of mixtures, Method of guarded-plate, Method of comparison calorimeter, Method of calculated specific heat, adiabatic calorimeter and Method of differential scanning calorimetry. Values of specific heat determination of many food materials, using DSC have been reported for various researchers. Among the published methods for specific heat measurement, differential scanning calorimetry (DSC) has so far been the most accurate and rapid method [9]. DSC method has found use in foods and pharmaceuticals [15].

This study proposes the result of study on specific heat of guava fruit using differential scanning calorimeter (DSC). Differential scanning calorimeter (DSC), which reports heat flow as a function of temperature is an excellent tool for the measurement of temperature-dependent specific heat and phase transitions [13]. Differential scanning calorimetry means the measurement of the change of difference in the heat flow rate to the sample and to a reference sample while they are subjected to a controlled temperature program [11]. Differential scanning calorimetry determines transition temperatures and enthalpy changes in solids and liquids under controlled temperature change. DSC is a convenient, rapid technique and easy to use method of obtaining a wealth of information about a material [15, 17]. For small sample sizes (5–50 mg) the DSC gives reliable results rapidly [17]. DSC is the most frequently used method in the field of Thermal Analysis [6, 17]. Rapid analysis, high significance for research and quality control tasks, and easy handling of the measuring instrument contribute to its versatility [6, 18].

This paper presents results of the effect of temperature on specific heat of guava fruit of Southeast Asia using differential scanning calorimetry DSC 204 F1.
2. Materials and Methods

Differential scanning calorimetry DSC 204 F1 phoenix (NETZSCH Germany) was used to determine the specific heat of guava fruit of Southeast Asia. The mass of the samples was measured using an analytical balance AND HR-200, accuracy class. The mass of the crucible is 38 mg, the mass of the lid is 25 mg. The samples were kept in refrigerator at about 5°C until experiments performed. About 28-42 mg of samples is used in the experiments. The samples were cut into small pieces by a snap off blade to obtain 6 mm-diameter and thickness 1-2 mm. Samples were hermetically sealed in aluminum crucibles. The mass of the samples was determined with an accuracy of ± 0.1 mg. The measurements were carried out in the temperature range of -25 to 25 °C in an atmosphere of gaseous nitrogen. The heating rate was 2 K/min. As a thermally inert substance (reference), sapphire weighing 50.1 mg was used. The tests were carried out in triplicate, following a similar experimental procedure described by DSC method for specific heat determination.

The method for determining the specific heat of the oils under study included four steps:

1. Setting the temperature program. In accordance with the specified temperature range from -25 to 25 °C, a temperature program was drawn up for studying the specific heat of guava fruit. The heating/cooling rate is 2 K/min, the stationary section time is 15 min, the initial stage lasted 15 min. Nitrogen gas with a flow rate of 20 ml/min and 50 ml/min, respectively, was used as the purge and protective gases.

2. Correction. On both cells are placed empty crucibles. The difference of heat fluxes through two empty crucibles (DSC = DSC_base) and the temperature of the right crucible are measured. This signals (DSC = DSC_base) were dependent on time and temperature.

3. Calibration. Crucible cell comparison remains empty. A substance is placed in the sample crucible with a known specific heat \(c_p\) standard and mass \(m_{standard}\). The difference between the heat fluxes through the empty crucible and the crucible with the reference standard DSC standard, and the temperature of the crucible with the reference is measured. The signals (DSC = DSC standard — DSC base) were dependent on time and temperature.

4. Measurement. The crucible of the reference cell remains empty. In the crucible for the sample is placed the test sample mass \(m_{sample}\). The difference between the heat fluxes through the empty crucible and the crucible with the sample DSC sample is measured, and the temperature of the crucible with the sample. The signals (DSC = DSC sample — DSC base) were dependent on time and temperature.

The specific heat \(c_p\) was measured by DSC. The measurement was conducted using DSC method according to following equation [5, 16]:

\[
\frac{DSC_{sample}-DSC_{base}}{DSC_{standard}-DSC_{base}} = \frac{c_p_{sample} \times m_{sample}}{c_p_{standard} \times m_{standard}}
\]

(1) \[
c_p_{sample} = \frac{m_{standard}}{m_{sample}} \times \frac{DSC_{sample}-DSC_{base}}{DSC_{standard}-DSC_{base}} \times \frac{c_p_{standard}}{c_p_{sample}}
\]

(2) DSC sample, DSC base, DSC standard are the ordinate of the DSC curves corresponding to the sample, blank specimen, and standard specimen, respectively. \(c_p\) sample and \(c_p\) standard are the specific heat of the sample and standard specimen, respectively. \(m_{sample}\) and \(m_{standard}\) are the mass of the sample and sapphire, respectively [5, 16].

3. Results and discussion

The following results on specific heat of guava fruit were obtained in the experiment carried out in the thermo-physical measurements and devices laboratory (ITMO University), Saint Petersburg. The specific heat of guava fruit was determined using differential scanning calorimetry (DSC 204 F1). NETZSCH Software Proteus® 6.1.0 was installed in system for evaluating the data. This study guava fruits samples (11-13 and 21-23) were used 41.1, 28.1, 30.5, 31.5, 30.7 and 36.0 mg obtained from Myanmar and Thailand. The changes in the specific heat of guava fruit at different temperature ranges
are presented in Figs 1-2, respectively. From these figures, it can be seen that the specific heat for the all samples of guava fruit increased with increased temperature, then dramatically decreased with increased temperature and slightly decreased with increased temperature, respectively.

Figure 1. Effect of temperature on specific heat for the all samples of guava fruit.

Figure 2. Approximating the arithmetic mean of specific heat of guava fruit.

The similar trend was described in the specific heat of food [8]. As in the study, the specific heat of guava is dependent on the on the temperature. Thermal properties of foods also change with time and temperature [7].

4. Conclusion
In designing food processes and processing equipment, we need numerical values for the specific heat of the food and materials to be used. Several experimental studies on determination of specific heat of foods and agricultural materials were reported in literature. However, the data depend on origin (variety, cultivar) and composition, processing conditions, and structure of the foods. The specific heat for the all samples of guava fruit increased with increased temperature, then dramatically decreased with increased temperature and slightly decreased with increased temperature, respectively. The linear
decrease of specific heat for the all samples of guava fruit at temperature rises from -9°C to 19°C. It was found that the specific heat of guava fruit is dependent on temperature. Specific heat of unfrozen foods slightly lower as the temperature rises from 0°C to 20°C [8]. In literatures [10,12,13] specific heats of food depend on their composition, structure and temperature.

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