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Moisture Sorption Isotherm and Glass Transition of Palm Sugar Cake as Affected by Storage Temperature

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Abstract. The aim of this study was to determine the effect of storage temperature (20°C and 30°C) on moisture sorption isotherm (MSI) characteristic, equilibrium moisture content (EMC) and glass transition temperature (Tg) of palm sugar cake that produced from palm sugar syrup with either using an open pan or a vacuum evaporator. It was found that MSI of all palm sugar cake samples that stored under both storage temperatures was shown Type-III isotherms. This type can be found in a crystalline product. However, storage temperature did not affect on EMC when a sample stored under 11-75% of RH ($P \geq 0.05$). The EMC of all samples that stored under 20°C was higher than those stored under 30°C and 85% of RH ($P < 0.05$). In addition, higher EMC was found in a sample that produced from palm sugar syrup with using an open pan when compared to samples that produced from palm sugar syrup with using a vacuum evaporator ($P < 0.05$). Storage temperature did not affect on the Tg of a samples. There was no significant differences in Tg of a sample that stored under 11-51% RH ($P \geq 0.05$). However, the Tg of a sample decreased with increasing RH in a range of 75-85%. Palm sugar cake that produced from palm sugar syrup with using a vacuum evaporator presented a higher Tg than that produced from palm sugar syrup with using an open pan ($P < 0.05$).

Keywords: Palm sugar cake, Temperature, Glass transition, Storage, Sorption isotherm

1. Introduction

Sugar cake is made from various materials, mainly plant sap. This form of sugar based product is easy to transport and store and also provides a good source of sugar which is used as an ingredient. In the southern part of Thailand, palm sugar cake was originally made from the sugary sap of the Palmyra palm (*Borassus flabellifer* Linn.) In general, palm sap is heated during palm sugar cake production in order to remove water from the sap until its concentrated (the total soluble solid is more than 80°Brix). After the temperature of this sample reaches approximately 120°C, it is removed from the heat and stirred. The stirring process is continued until the solution begins to crystallise and stiffen. At this stage, it can be poured into a mould. Normally, palm sugar cake deteriorates fast and become watery within one or two weeks due to it has hygroscopic nature. In addition, a production of invert sugar through microbial degradation further increases the hygroscopicity of the palm sugar cake [1]. For the ease of handling, packaging and storage, sugar cake in a solid form is becoming popular. However, palm sugar cake product becomes watery and deteriorates during storage by moulds and yeasts. Knowledge of moisture sorption isotherms in palm sugar cake product at different storage temperature could be used as a tool for its handling, storage and packaging system design. However, information on moisture sorption isotherm of palm sugar cake that produced from palmyra palm syrup is rarely investigated. Therefore, the quality of palm sugar cake product relating with glass transition temperature (Tg) are of interest since Tg is considered as a tool to understand many aspects of food processing and shelf life. Therefore, the aim of this work was to determine moisture sorption isotherm (MSI) and Tg of palm sugar cake. The changes in crystallinity and the browning development of palm sugar cake

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that produced from palm sugar syrup either using an open pan and a vacuum evaporator during storage under the range of 11-75% of RH were also monitored.

2. Material and Methods

2.1. Raw Material

Palm sap was collected from a contact farm in Songkhla province, Thailand. Palm sap was tapped and harvested after 12 h of collecting in an open container. During tapping, natural wood called Kiam (*Cotylelobium lanceotatum* craih) was added into the container since the beginning state of tapping. The sample was filtrated using cloth sheet. Then, palm sap was concentrated using two methods either using an open pan or a vacuum evaporator. Palm sap was concentrated by using an open pan (at approximately 110^{o}C) and a vacuum evaporator (at 80^{o}C) until the total soluble solids reached 70^{o}Brix to obtain palm sugar syrup. Then, palm sugar cake was prepared from palm sugar syrup which was concentrated by two methods. The mixture of palm sugar syrup sample, sucrose and glucose syrup was mixed in a ratio of 50:40:10. Then, the mixture was boiled using an open pan until the total soluble solid reached 80^{o}Brix. After that, the sample was poured in thin slabs and allowed to cool at ambient temperature.

2.2. Method

The moisture sorption isotherm (MSI) of palm sugar cake was monitored gravimetrically by exposing a sample to an atmosphere of known relative humidity at a constant temperature. A sample was stored in a desiccators over P_2O_5 for one week. After that, a sample was considered as anhydrous stage. Anhydrous sample was transferred into a hermetic plastic box that contained saturated salt solutions with different relative humidity. This sample was kept under two storage temperatures either 20^{o}C or 30^{o}C over seven saturated solutions of LiCl, CH_3COOK, $MgCl_2$, K_2CO_3, $Mg(NO_3)_2$, NaCl and KCl to get a specific RH. The sample weight was monitored everyday till it reached a constant value, where the equilibrium moisture content of the sample was assumed to be achieved. In each equilibrated stage, a sample was determined for moisture content, Tg, crystallinity, intermediate browning product (IBP) and browning intensity (BI).

2.3. Statistical Analysis

All analysis and measurements were performed in triplicates. The experimental design was a completely randomized design (CRD). Data was subjected to analysis of variance (ANOVA). Comparison of means was carried out by Duncan's multiple-range test. Analysis was performed using a SPSS package (SPSS for windows, SPSS Inc, Chicago, IL).

3. Results and Discussion

3.1. Natural of Moisture Sorption Isotherm

Fig. 1 shows MSI of the palm sugar cake that produced from palm sugar syrup either using an open pan or a vacuum evaporator and stored in both temperatures (20 ℃ and 30 ℃). All palm sugar cake samples demonstrated Type III isotherm characteristics that referred to a crystalline product as stated by Brunauer-Emmett-Teller (BET) classification [2]-[3]. A small increase in EMC of palm sugar cake that stored under 11-54% of RH was detected ($P<0.05$). However, a sharp increase in EMC of palm sugar cake that stored under 75-85% of RH was observed ($P<0.05$). The type III of sorption shows very little moisture gain until the RH goes above the point where water begins to dissolve a crystal surface (such as in 75% and 85% RH for sucrose). However, under low RH (11-54% RH), the interaction of water with the sugar molecules is not strong enough to break the interactive forces of individual sugar molecules in a crystal. However, as the RH increased, the increase of overall water-sugar interactions caused disruption of the sugar-sugar interactions. Thus, water begins to penetrate into a crystal, dissolving sugar molecules and exposing new surfaces. Under these range of RH (75-85% RH), the moisture rises dramatically. Then, solution is being created, dissolution of sugar occurs, and a crystalline sugar is converted to amorphous state, resulting higher absorption of moisture. Storage temperature did not affect on EMC ($P\geq0.05$) with a range of 11-75% of RH. However, under 85% of RH, EMC of a sample that stored under 20^{o}C was higher than those stored under 30^{o}C ($P<0.05$). This result is explained by high excitation state of water molecules at high temperature that caused a decreasing of an attractive force between water molecules and food components [4]. Water molecules are

activated to higher energy levels and break away from the water-binding sites of the food with increasing temperature. Thus, the decreasing in equilibrium moisture content is occurred. The EMC of palm sugar cake that produced from palm sugar syrup with using an open pan was higher than that produced from palm sugar syrup with using a vacuum evaporator at constant RH. This result might be explained by the different types of sugar containing in palm sugar cake product. Palm sugar cake that produced from palm sugar syrup with using an open pan contained high reducing sugar content. This due to high processing temperature and a long time during processing can promote high inversion reaction. Normally, monosaccharide such as invert sugar is hygroscopic. Hence, palm sugar cake that contained high amount of reducing sugar is rapidly absorbed water into the structure. In addition, crystallinity in the sample that produced from palm sugar syrup with using an open pan was lower than that produced from palm sugar syrup with using a vacuum evaporator. Thus, water molecules are easily penetrated into the structure, resulting in more water was absorbed.

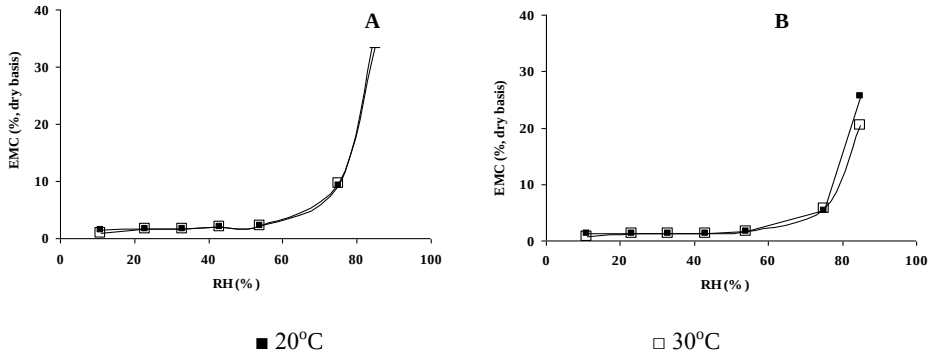

Fig. 1: MSI of palm sugar cake produced from palm sugar syrup with either using an open pan (A) or a vacuum evaporator (B)

3.2. Glass Transition Temperature

Fig. 2 shows the Tg of palm sugar cake that produced from palm sugar syrup either using an open pan or a vacuum evaporator, respectively. There are no significant differences in Tg of palm sugar cake that stored under 11-51% RH ($P \geq 0.05$). Tg decreased with increasing RH in a range of 75-85% RH ($P < 0.05$). However, temperature seems to be not affected the Tg of palm sugar cake ($P \geq 0.05$). Tg decreased with increasing RH due to the plasticizing effect of water. Tg of palm sugar cake that produced from palm sugar syrup with using a vacuum evaporator was higher than those that produced from palm sugar syrup with using an open pan. This probably was due to low reducing sugar content in a sample. Tg of palm sugar cake was depended on type and ratio of sugars. Low molecular weight sugars (glucose and fructose) had been shown to plasticize more easily than high molecular weight sugars such as sucrose [5]-[6]. Thus, high invert sugar (fructose and glucose) content in a sample that produced from palm sugar syrup with using an open pan also caused a higher decrease in Tg when compared to a sample that produced from palm sugar syrup with using a vacuum evaporator.

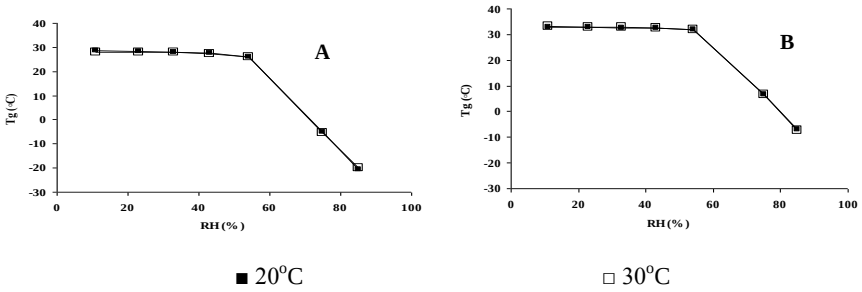

Fig. 2: Tg as a function of RH of palm sugar cake produced from palm sugar syrup with either using an open pan (A) or a vacuum evaporator (B)

3.3. Changes in Crystallinity of Palm Sugar Cake During Storage

Crystallinity of palm sugar cake during storage under different relative humidity (RH) was shown in Fig. 3. Crystallinity of all samples tended to decrease with increasing RH and storage time ($P < 0.05$). Similar

trend of crystallinity was found in palm sugar cake that stored under low RH including 11-51%. Initial crystallinity of palm sugar cake that produced from palm sugar syrup either using an open pan or a vacuum evaporator was 78.54% and 84.53%, respectively. Crystallinity of all samples that stored under low RH including 11-51% slightly decreased from their initial values within the first two days during storage. Thereafter, no change in crystallinity was found in all samples until the fourteen days of storage. Continuous decrease in crystallinity was found in a sample that stored under high RH including 75-83% until the twelve days of storage ($P<0.05$). Thereafter, no change in crystallinity was found until the fourteen day of storage. The reduction of crystallinity of palm sugar cake during storage was due to the increase in moisture content in a product. Under high RH, water content of a sample was sharply increased, resulting in the decrease in crystallinity and a sample became watery and partial liquefied.

3.4. Changes in Intermediate Browning Product and Browning Intensity During Storage

The Maillard reaction caused colour change in the palm sugar cake during storage. The accumulation of intermediate browning product (IBP) and browning intensity (BI) was monitored in a sample that stored under 30°C as shown in Fig. 4. RH in a range of 11-51% did not affect on IBP and BI. However, the IBP and BI increased with increasing RH in a range of 75-85%. No changes in IBP and BI were found in palm sugar cake that stored under low RH including 11-51% during storage time ($P\geq0.05$). However, continuous increase in IBP and BI was found in a sample that stored under high RH (75-85% RH) during storage time ($P\geq0.05$). Under low RH, a sample absorbed less water from an environment, and thus reactant mobility was restricted. While a sample gains a lot of water form an environment when it stored under high RH, resulting in a sufficient water to promote Maillard reaction [7].

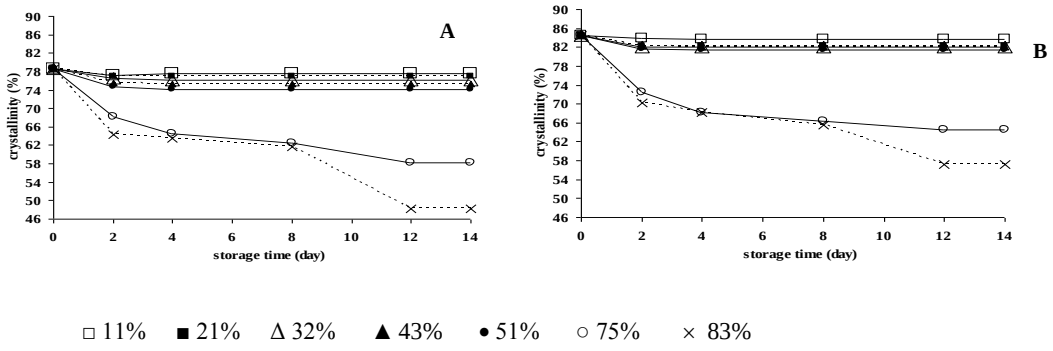

Fig. 3: Changes in crystallinity of palm sugar cake produced from palm sugar syrup with either using an open pan (A) or a vacuum evaporator (B) during storage in different relative humidities under 30°C

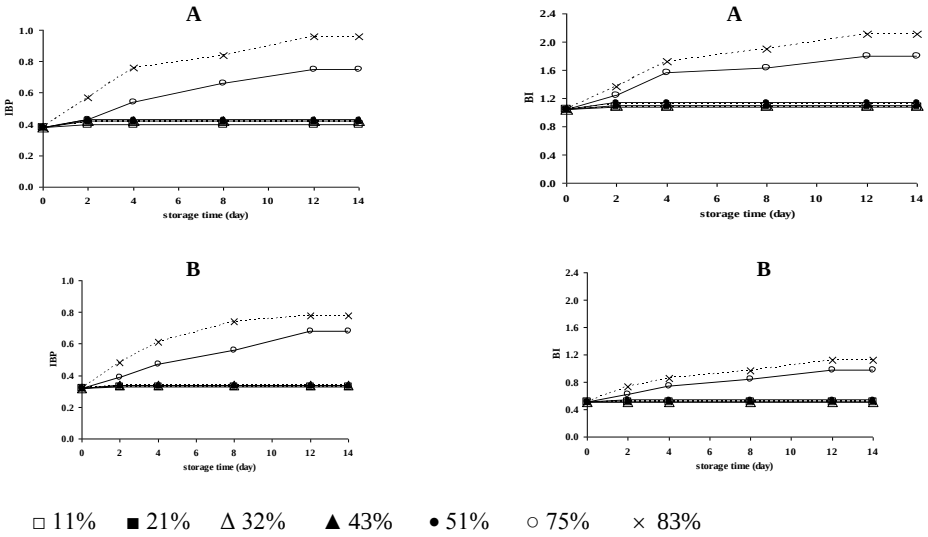

Fig. 4: Changes in IBP and BI of palm sugar cake produced from palm sugar syrup with either using an open pan (A) or a vacuum evaporator (B) during storage in different relative humidity under 30°C

4. Conclusion

The MSI for palm sugar cake are Type-III isotherms. Storage temperature did not affect in MSI characteristics, EMC and Tg of palm sugar cake. Under low RH (11-51% RH), palm sugar cake absorbed less water while high amount of moisture content was absorbed in a sample that stored under high RH (75-85% RH). Low RH (11-51% RH) did not affect on Tg, crystallinity, IBP and BI of palm sugar cake. On the other hand, high RH (75-85% RH) influenced a decrease in Tg, crystallinity and an increase in IBP and BI. Thus, high RH (75-85% RH) is not suitable to store palm sugar cake due to it decreased in Tg and crystallinity and increased in brown colour.

5. Acknowledgements

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