Songklanakarin J. Sci. Technol.
33 (1), 33-41, Jan. - Feb. 2011

SONGKLANAKARIN JOURNAL OF SCIENCE AND TECHNOLOGY
http://www.sjst.psu.ac.th

Original Article

Production of tamarind powder by drum dryer using maltodextrin and Arabic gum as adjuncts

Weerachet Jittanit*, Maythawee Chantara-In, Tithiya Deying and Wantanee Ratanavong

Department of Food Science and Technology, Faculty of Agro-Industry, Kasetsart University, Chatuchak, Bangkok, 10900 Thailand.

Received 14 December 2009; Accepted 3 February 2011

Abstract

Tamarind powder specimens were produced by drum-drying of mixture between juice squeezed from tamarind pulp and drying aid. Two popular drying aids namely maltodextrin (MD) and Arabic gum (AG) were applied at the ratios of juice (20°Brix) and drying aids of 1:0.4, 1:0.8 and 1:1.4. A double drum dryer was employed in this work at the drying temperatures of 120 and 140°C, drum speed of 0.35 rpm, and the gap between drums of 0.4 mm. The results indicated that in order to obtain the tamarind powders, the ratio of tamarind juice and MD should be 1:0.8 if drying at 140°C or 1:1.4 if drying at 120-140°C. In case of using AG as a drying carrier the proportion should be 1:0.4 or 1:0.8 for drying temperatures between 120 and 140°C. Sensory evaluation indicated that the tamarind powders with MD were preferred in facet of appearance, color, and overall liking, while those with AG were favored in their aroma and taste. The energy costs of producing tamarind powders were between 7.27 and 21.00 Baht/kg$_{powder}$ whereas the drying aid costs were in the ranges of 208-228 Baht/kg$_{powder}$ and 640-768 Baht/kg$_{powder}$ if using MD and AG respectively.

Keywords: drum drying, drying aid, instant tamarind juice, tamarind, tamarind powder

1. Introduction

Tamarind is one of the most important fruits of Thailand with total production over 100,000 tons a year. It can be consumed fresh or processed before intake, like pickled tamarind. Moreover, tamarind juice is an essential ingredient that provides the inimitable sour taste in many kinds of Thai food; for example, Pad Thai noodle.

The tamarind powder is an interesting product because of its characteristics. The powder can be used as an ingredient for cooking food or as a flavoring agent in some products. Its advantages consist of (a) a long shelf life at ambient temperature due to low water activity, (b) low logistic expenditures due to little weight and volume, and (c) easy to use compared with squeezing juice from tamarind flesh. In addition, this product development would help reducing the tamarind loss caused by the microorganisms, chemical and enzymatic reactions during the peak of harvesting season.

To date, there have been a number of studies about the drying of fruit juices. Some researchers claimed that drying of fruit juice could produce the fruit powder that reconstituted rapidly to a fine product resembling the original juice (Gabas *et al.*, 2007). Nonetheless, there are some difficulties in drying the fruit juice with high sugar content due to their thermoplasticity and hygroscopicity at high temperatures and humidity levels causing their packaging and utilization in trouble (Bhandari *et al.*, 1997; Adhikari *et al.*, 2004; Cano-Chauca *et al.*, 2005). These characteristics are attributed to low molecular weight sugars such as fructose, glucose and sucrose and organic acids such as citric, malic and tartaric that are the major solids in fruit juices (Bhandari *et al.*, 1997; Cheuyglintase and Morison, 2009). The low glass transition temperature (T_g), high hydroscopy, low melting point, and high water solubility of these solids lead to a

* Corresponding author.
Email address: fagiwcj@ku.ac.th

highly sticky or rubbery product when dried (Adhikari *et al.*, 2003; Cheuyglintase and Morison 2009). Additionally, Roos and Karel (1991) stated that these materials are very hygroscopic in amorphous state and loose free flowing character at high moisture content.

The thermoplasticity and hygroscopicity troubles occurring in drying the fruit juice with high sugar content can be overcome by adding some drying carriers such as maltodextrin (MD) and Arabic gum (AG) (Bhandari *et al.*, 1993; Cano-Chauca *et al.*, 2005; Gabas *et al.*, 2007). These drying adjuncts are high molecular weight compounds that have high T_g, accordingly, they can raise the T_g value of feed and the subsequent powder (Shrestha *et al.*, 2007). According to Cano-Chauca *et al.* (2005) and Langrish *et al.* (2007), MD is the most popular in spray drying due to its physical properties such as high water solubility; while, AG is recommended for fruit juice drying due to its emulsification properties and ease of dissolution in water. Gabas *et al.* (2007) described that MD consists of b-D-glucose units linked mainly by glycosidic bonds and are typically classified by their dextrose equivalent (DE). Bhandari *et al.* (1993) and Silva *et al.* (2006) pointed out that MD could improve the stability of fruit powder with high sugar content because it reduced the stickiness and agglomeration problems during storage.

Drum drying is the drying of a thin film of solution or suspension on a heated drum and subsequent removal of the film of dry solids by applying the doctor blade. It is a technique widely used in the food industry to produce food powder particularly for heat-sensitive products where short-time high-temperature drying is permissible (Nastaj, 2000). The drum drying parameters such as drying temperature, feed rate, rotation speed, feed concentration, and surrounding air condition are influential to the attributes of drum-dried food such as particle size, bulk density, moisture content, and solubility (Nastaj, 2000; Pua *et al.*, 2010).

Due to the lack of research in the area of tamarind powder production, this study was carried out with the following objectives; (1) to study the feasibility of producing the drum-dried tamarind powders, (2) to determine the optimal drying condition for drum drying of tamarind juice, and (3) to compare the drying cost and the product quality between using MD and AG as the drying carriers.

2. Materials and Methods

2.1 Raw materials

The sour tamarind (*Tamarindus indica* L.) flesh was obtained at the local market nearby Kasetsart University, Bangkok, Thailand. This sort of tamarind is normally used as an ingredient in some Thai food. The tamarind flesh was soaked and crushed. The juice was then squeezed out from the pulp by a pulper finisher. Then the soluble solid content of juice was standardized to 20°Brix by adding distilled water. The color and pH of the 20°Brix juice samples were measured by "Minolta" color meter model CM-3500d (manufactured by Konica Minolta Sensing, Inc. Osaka, Japan) and "JENCO" pH meter (produced by Jenco Instruments Co., Ltd. in Shanghai, China) respectively.

There were two kinds of drying adjuncts, namely MD and AG applied in this study. The MD had dextrose equivalent (DE) 10-12, pH 4.7, and moisture content 5.2%. It was manufactured by Zhucheng Dongxiao Biotechnology Co., Ltd. in Zhucheng city, Shandong, China. The AG used in this work was KB-120 (Food grade), which had a pH (25% Sol. in water) of 4.4 and a moisture content of 11.8%. It was supplied by Lab Valley Limited Partnership in Bangkok, Thailand. The feed material was prepared by adding the specified amount of drying carrier into the warmed tamarind juice 20 °Brix and then stirring. The ratios by weight of tamarind juice (20 °Brix) and drying carrier at 1:0.4, 1:0.8, and 1:1.4 were applied. These figures can be approximately converted to be the ratios of tamarind juice (based on total soluble solids) and drying aid (based on dry weight) at 35:65, 20:80 and 15:85 by weight respectively.

2.2 Drying experiment

The feed materials prepared by the procedure described in the previous section were dried in a local-made double drum dryer (drum diameter 22 cm and length 46 cm) with a 0.5 HP motor using a drum speed of 0.35 rpm and a gap between the drums of 0.4 mm. The drying experiments were carried out using the factorial completely randomized design of two drying aids (MD and AG), two drying temperatures (120 and 140°C), and three ratios of tamarind juice (20 °Brix) and drying aids (1:0.4, 1:0.8, and 1:1.4). During the drying experiments, the data of steam pressure at the inlet of drum dryer and inside the drum, the weight and the temperature of steam condensate at the dryer were recorded for the calculation of heat energy consumption. At the end of drying, the tamarind powders were collected, weighed, and kept in the sealed container for the quality determination.

2.3 Quality determination

The soluble solid content, color and pH of the fresh tamarind juice were measured by an "ATAGO" hand refractometer (manufactured by ATAGO Co., Ltd. in Tokyo, Japan), a "Minolta" color meter model CM-3500d, and a "JENCO" pH meter.

For the tamarind powders collected from the drying experiments, the bulk density, moisture content, water activity, and solubility were measured. Apart from that, the reconstituted samples from tamarind powder were subjected to the determination of color, pH, percentage of insoluble solid, and viscosity. Furthermore, the sensory evaluation was carried out for the juices reconstituted from the powders collected in two selected drying runs.

Figure 1 illustrates the throughout procedure from the raw material preparation until the solutions of tamarind powder were subjected to the quality determination.

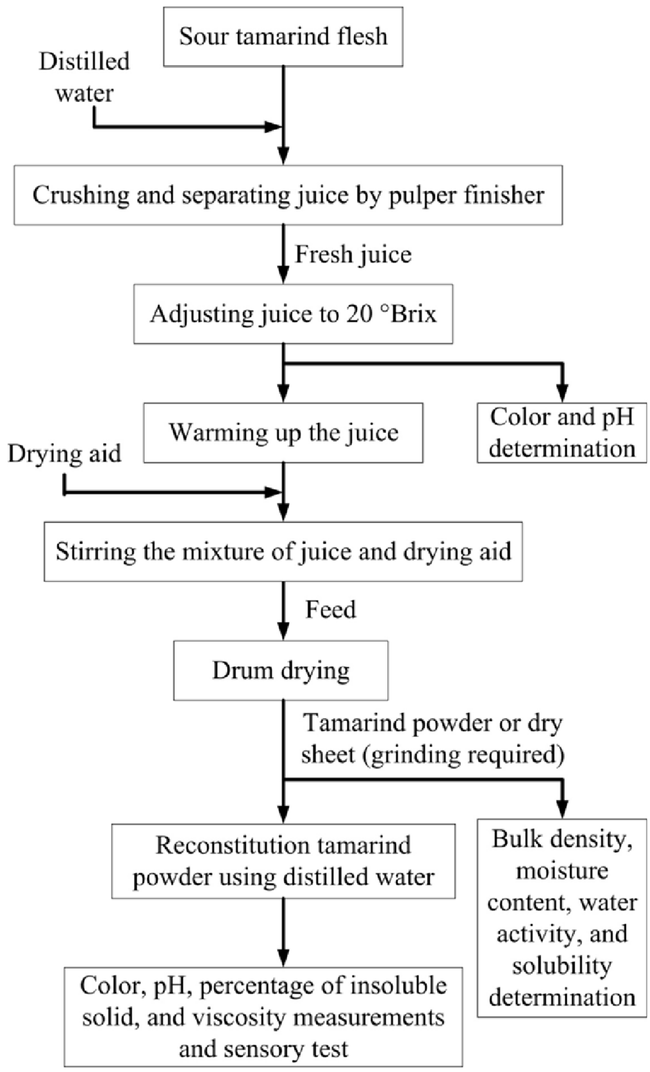

Figure 1. Schematic diagram of the experiments.

2.3.1 Bulk density

The procedure described by Al-Kahtani and Hassan (1990) was used. Twenty grams of powder were transferred to a 100 mL graduated cylinder which was mounted on a shaker compartment of the "STUART SCIENTIFIC" water bath model SBS 30 (produced by Bibby Scientific Ltd., Staffordshire ST15 OSA, UK). The shaker was set at position 100 rpm and operated for 5 minutes. The bulk density was calculated by dividing the weight of the powder by the volume occupied in the cylinder.

2.3.2 Water activity

The water activity of tamarind powders was measured by a "Novasina" water activity instrument, model TH2/RTD33 (made by Novasina AG, Lachen, Switzerland).

2.3.3 Moisture content

The moisture content was determined by the oven method using 2 g of powder and 105°C drying temperature for 2 hrs. Thereafter, the sample was cooled in a desiccator, weighed and re-dried for 2 hrs. The process was repeated until a change in weight between the successive dryings at 2 hr intervals was not more than 2 mg (Jittanit *et al.*, 2010). The weight loss after drying in the oven was used to calculate the moisture content of tamarind powder and was expressed on wet basis (WB).

2.3.4 Solubility

To determine the solubility, the methods of Al-Kahtani and Hassan (1990) and Sommanas (1997) were applied. The powder sample of 10 g and distilled water of 100 mL were combined into a 500 mL beaker. A magnetic bar was then dropped and the beaker was located on the "FISHER" stirrer model 210T (supplied by Fisher Scientific (M) Sdn Bhd (Part of Thermo Fisher Scientific) in Selangor Darul Ehsan, Malaysia) setting at speed level 5. The measurement was conducted in the room temperature at 25°C. The time the powder in the beaker was entirely dissolved was recorded in "second".

2.3.5 Color

The tamarind powders were dissolved into the distilled water to prepare the reconstituted samples. For the reconstitution procedure, the proportion of powder/distilled water for each batch of sample was calculated using the Equation 1 so that the samples would be similar to the feed materials. The colors of reconstituted specimens were measured and expressed as L*, a* and b* values in CIE system.

$$WDWR = \left(\frac{WFM - WDP}{WDP}\right) * WPR \qquad (1)$$

Where WDP is the weight of powder produced from the drying batch (kg), WDWR is the weight of distilled water for reconstitution (kg), WFM is the weight of feed mixture for the drying batch (kg) and WPR is the weight of powder for reconstitution (kg).

2.3.6 Percentage of insoluble solid

The percentage of insoluble solid was determined by applying the method of Vongsawasdi *et al.* (2002). The tamarind powder of 20 g was dissolved into the 200 mL of distilled water. Then the solution was filtered using the "Pyrex" 2 L suction flask with the buchner funnel diameter 18.5 cm and "WHATMAN" filter paper No 41. The suction flask was connected to the "ULVAC" vacuum pump model GLD-050 motor 200 W (manufactured by ULVAC Technologies, Inc., Methuen, MA 01844 USA). The solid that cannot pass through the filter paper was dried, weighed and calculated to obtain the value of the percentage of insoluble solid (100*mass of insoluble solid/mass of total solid).

2.3.7 Viscosity

An aliquot of the reconstituted samples prepared by the same method applied for color determination was used to measure the viscosity using a "Brookfield" digital viscometer with the spindle no 27 (produced by Brookfield Engineering Laboratories, Inc., Middleboro, MA 02346 USA).

2.3.8 Sensory evaluation

Apart from the quality determination as previously described, the reconstituted samples were subjected to the sensory test for appearance, color, aroma, taste and overall liking perceptions. The sensory was evaluated using a 5-point hedonic scale test by 30 panelists who were the undergraduate students in the faculty.

2.4 Calculation of energy and drying aid costs

In order to obtain the complete perspective of tamarind powder production, the costs of energy and drying aid for each drying batch were calculated. Although this information was acquired from the lab-scale drying process which is normally diverse to some extent from the industrial-scale drying, they should be able to be utilized by the industry or researcher as a guideline for the economic evaluation purpose.

The energy cost of drum drying could be divided into two parts comprising heat energy and electrical energy. It must be noted that the energy cost calculated in this study excluded the energy used for warming up the drying system. The heat energy was calculated from the data of steam pressure at the inlet of drum dryer and inside the drum and the amount and the temperature of steam condensate at the dryer. The data of steam pressure at the inlet of the drum dryer and inside the drum were conversed to be the steam temperature using the saturated steam table (Incropera *et al.*, 2007). Then heat energy was calculated from Equation 2. Due to the fact that the steam was produced by the combustion of Bio-diesel (B5) oil fuel that provides the approximate net heating values of 38,730 kJ/kg with a density of 0.875 kg/L (Canakci *et al.*, 2009; Qi *et al.*, 2009), the fuel consumption for heat energy was calculated using Equation 3. Consequently, the heat energy cost can be calculated by Equation 4 if the price of the B5 oil fuel is 27 Thai Baht/L (35 Thai Baht ≈ 1 USD).

$$E_{heat} = m_c h_{fg} + m_c c_{p,g}\left(T_i - T_d\right) + m_c c_{p,f}\left(T_d - T_c\right) \quad (2)$$

$$FC = \frac{E_{heat}}{38{,}730 * 0.875} \quad (3)$$

$$HEC = 27 * FC \quad (4)$$

During the drum drying process, the electricity energy was consumed mainly by the motor that drove the double drums. Hence, the electricity energy cost was calculated by Equation 5. The unit price of electricity was approximately 3 Thai Baht/kW × h (3 Thai Baht per 3.6 MJ of electrical energy).

$$EEC = P * t * UPE \quad (5)$$

The costs of drying aids were calculated based on the unit price of MD and AG of 260 and 960 Thai Baht/kg respectively.

2.5 Statistical analysis

All measured quality attributes of tamarind powders and the reconstituted samples were determined in three replications, except the percentage of insoluble solid that was measured without replication because it required a large amount of powder for measurement. The software package of Statistica 5.5 StatSoft™ (supplied by StatSoft, Inc. Tulsa, OK 74104 USA) was used for the analysis of variance (ANOVA) and a Duncan's multiple range test in the statistical analysis.

3. Results and Discussion

3.1 Fresh tamarind juice

The average soluble solid content of the fresh tamarind juice after squeezing by a pulper finisher was 38°Brix. After standardization of fresh juice to the soluble solid content of 20°Brix, the mean and standard deviation of their lightness (L*, +), redness (a*, +) and yellowness (b*, +) were 11.76±0.61, 8.36±0.69, and 13.43±0.84, respectively, while the pH was 2.69±0.086. It is apparent that the 20°Brix tamarind juice is a high acid food, with the high contents of organic acids such as citric and tartaric. Thus, if drying the tamarind juice without the drying adjuncts, the products would be sticky or rubbery due to the low glass transition temperature, high hydroscopy, low melting point, and high water solubility of these organic acids (Adhikari *et al.,* 2003; Cheuyglintase and Morison 2009). The color and pH values of the 20°Brix tamarind juice were used for comparison with those of the reconstituted juices in Section 3.3. As a consequence, the effects of drying process and adding the adjuncts would be elucidated.

3.2 Quality of tamarind powder

After conducting the drying experiments, it appeared that there were some drying conditions that could not provide the suitably dried products as detailed in Table 1. For instance, when applying the MD at the ratio of 1:0.4 the feed was not sticky enough to attach it on the drums; whereas, in the cases of using AG at the ratio of 1:1.4, the feed was too sticky and could not be simply removed from the drums. As

Table 1. Features of the drum-dried products under various conditions.

Drying temperature (°C)	Drying aid	Ratio of tamarind juice 20°Brix and drying aid (by weight)		
		1:0.4	1:0.8	1:1.4
120	MD	Feed mixture was not sticky enough to be attached on the drums.	Glassy and cannot be removed from the drums by doctor blades.	Powder feature and can be easily removed from the drums by doctor blades
	AG	Dry and thin film feature that can be easily removed from the drums by doctor blades. Dried flake must be ground to be powder.	Dry and thin film feature that can be easily removed from the drums by doctor blades. Dried flake must be ground to be powder.	Sticky and cannot be removed from the drums by doctor blades
140	MD	Feed mixture was not sticky enough to be attached on the drum.	Dry and thin film feature that can be easily removed from the drums by doctor blades. Dried flake must be ground to be powder.	Powder feature and can be easily removed from the drums by doctor blades
	AG	Dry and thin film feature that can be easily removed from the drums by doctor blades. Dried flake must be ground to be powder.	Dry and thin film feature that can be easily removed from the drums by doctor blades. Dried flake must be ground to be powder.	Sticky and cannot be removed from the drums by doctor blades

Table 2. Bulk density, moisture content, water activity, and solubility of tamarind powders.

Drying condition				Bulk density (g/ml)	Moisture content (%wb)	Water activity	Solubility (second)
No.	Drying aid	Drying temperature (°C)	Ratio of tamarind juice and drying aid				
1	MD	120	1:1.4	$0.816^{a} \pm 0.066$	$3.46^{a} \pm 0.03$	$0.260^{a} \pm 0.003$	$83^{a,b} \pm 2$
2	MD	140	1:0.8	$0.781^{a} \pm 0.045$	$3.38^{b} \pm 0.03$	$0.326^{b} \pm 0.006$	$98^{a} \pm 18$
3	MD	140	1:1.4	$0.478^{b} \pm 0.063$	$3.11^{c} \pm 0.04$	$0.342^{c} \pm 0.001$	$8^{c} \pm 1$
4	AG	120	1:0.4	$0.731^{a,c} \pm 0.038$	$3.20^{d} \pm 0.04$	$0.306^{d} \pm 0.007$	$79^{a,b} \pm 18$
5	AG	120	1:0.8	$0.790^{a} \pm 0.037$	$3.62^{e} \pm 0.04$	$0.265^{a,e} \pm 0.006$	$73^{b} \pm 8$
6	AG	140	1:0.4	$0.648^{c} \pm 0.032$	$3.09^{c} \pm 0.02$	$0.276^{e} \pm 0.002$	$140^{d} \pm 8$
7	AG	140	1:0.8	$0.783^{a} \pm 0.094$	$3.41^{a,b} \pm 0.03$	$0.263^{a} \pm 0.012$	$16^{c} \pm 2$

Note: Bulk density, color, moisture content, water activity and solubility values are mean ± standard deviation (n = 3). Means with the same superscript within same column are insignificant different (P > 0.05).

a consequence, only the dried samples from seven drying conditions were used to determine the bulk density, moisture content, water activity, and solubility.

The results in Table 2 indicate that all drying conditions except conditions no. 3 and 6 provided the tamarind powders that had insignificant differences in their bulk density values. The bulk density is an important characteristic for the packaging design and the calculation of transportation volume. The bulk density of tamarind powder was in agreement with those of orange powder produced by Chegini and Ghobadian (2005) ranging from 0.34 to 0.95 g/ml. The tamarind powder that had the lowest bulk density was from the drying condition no.3 while that from the drying condition no.6 was significantly higher than that from the drying condition no.3 but lower than the rest of the drying conditions. The drying temperature and the formula of feed are deemed as the causes of this occurrence. At the same formula of feed, the higher drying temperature resulted in the lower bulk density (Chegini and Ghobadian, 2005). The higher drying temperature led to a higher rate of moisture evaporation from the feed resulting in a higher porosity and lower bulk density of the dried powder. Furthermore, at the same drying temperature, the higher proportion of MD would lower the bulk density. On the other hand, the higher proportion of AG would raise the bulk density of powder. Referring to the specification data, the bulk densities of MD and AG were 0.45 and 0.64 g/ml, respectively; therefore, this might be the explanation for the prior statements.

Regarding the moisture contents of tamarind powders, all specimens had moisture contents below 4%wb. They are close to the moisture contents of dried tea powders with the range of 3-5% (Sinija *et al.*, 2007). It is clear that at the same formula of feed, the higher drying temperature resulted in the lower moisture content of dried product. Heat and moisture transfer rates were usually boosted if the drying temperature was elevated (Nastaj, 2000; Vongsawasdi *et al.*, 2002). However, there was no relationship between the moisture content and water activity. It was plausibly due to the dissimilar compositions of dried powders from different drying conditions. The water activities of samples ranged between 0.260 and 0.342 which is low enough for long storage purpose.

The results in Table 2 indicate that the solubility values of samples fell in the range between 8 and 140 seconds. It means that the tamarind powder could be dissolved in water at room temperature without difficulty. Accordingly, it is convenient for the user to utilize it. The reason for these solubility values is that the majority of the tamarind powder was the drying carrier (approximately 65, 80, and 85% for the ratios of tamarind juice/drying carrier at 1:0.4, 1:0.8, and 1:1.4 respectively). The drying carriers, MD and AG, are easily dissolved in water (Cano-Chauca *et al.*, 2005); thus, they enhanced the dissolution ability of the tamarind powders. Pua *et al.* (2010) pointed out that the solubility of drum-dried powder was primarily influenced by the type and concentration of drying carriers. Also, the drying temperature had a positive effect on the solubility because the higher drying temperature resulted in more porosity of the powders. The higher porosity led to the more specific surface area of powder, resulting in the larger contact surface area between powder and water. However, if comparing between drying conditions no. 4 and 6, it appears that the tamarind powder dried at 140°C required a longer time period for dissolving in water than that dried at 120°C. This phenomenon can be attributed to the low proportion of drying carrier in these drying runs. If the lower proportion of drying carrier is applied, the layer of drying carrier on the tamarind powder surface will be subsequently thinner. As a consequence, the solids from tamarind juice will contact to heat more directly, leading to the changes of some compositions such as sugar, protein and vitamins especially at high drying temperatures. This resulted in the decrease in their dissolution abilities.

3.3 Quality of reconstituted tamarind juice

The reconstituted samples were determined for their color, pH, percentage of insoluble solid, and viscosity. These quality attributes of reconstituted specimens are compared with those of the fresh juice (20°Brix) as shown in Table 3.

The results in Table 3 show that the lightness (L*) of most reconstituted samples was lower than that of the fresh juice except the drying condition no.3. It should be due to the much higher solid content from the addition of drying aids in the reconstituted samples comparing with the fresh juice. Vongsawasdi *et al.* (2002) and Pua *et al.* (2010) claimed that the lightness of the fresh fruit and vegetable juice was higher than that of the reconstituted juice due to the non-enzymatic browning such as Maillard reaction and caramelization occurring during the drying process. The redness (a*) of reconstituted samples was in the range between 6.62 and 8.97 that were close to that of the fresh juice (8.36). The deviations might be caused by the whiteness of added drying

Table 3. Quality attributes of the solutions of tamarind powders and the fresh tamarind juice.

Drying condition				Color			pH	Percentage of insoluble solid	Viscosity (cP)
No.	Drying aid	Drying temperature (°C)	Ratio of tamarind juice and drying aid	L*	a*	b*			
1	MD	120	1:1.4	$7.57^{a}\pm0.22$	$7.78^{c}\pm0.04$	$9^{d}\pm0.24$	$2.58^{a}\pm0.015$	6.3	$16{,}158^{a}\pm1{,}955.8$
2	MD	140	1:0.8	$4.97^{b}\pm0.12$	$6.62^{a}\pm0.36$	$6.69^{a}\pm0.35$	$2.65^{a,b}\pm0.006$	6.8	$2{,}523^{b,c}\pm187.7$
3	MD	140	1:1.4	$11.89^{c}\pm0.31$	$7.84^{c}\pm0.06$	$14.61^{b}\pm0.42$	$2.70^{b}\pm0.020$	5.6	$4{,}297^{c,d}\pm485.0$
4	AG	120	1:0.4	$3.97^{d}\pm0.13$	$6.76^{a}\pm0.13$	$5.78^{c}\pm0.16$	$2.80^{c}\pm0.026$	12.0	$5{,}738^{d}\pm239.5$
5	AG	120	1:0.8	$11.04^{e}\pm0.14$	$8.07^{c,d}\pm0.37$	$13.74^{e}\pm0.59$	$3.18^{d}\pm0.070$	7.1	$19{,}818^{e}\pm2{,}342.3$
6	AG	140	1:0.4	$5.82^{f}\pm0.29$	$8.65^{b,d}\pm0.14$	$8.47^{d}\pm0.71$	$2.79^{c}\pm0.051$	31.7	$23{,}639^{f}\pm1{,}311.5$
7	AG	140	1:0.8	$9.60^{g}\pm0.60$	$8.97^{b}\pm0.36$	$13.38^{e}\pm0.15$	$3.05^{e}\pm0.025$	11.5	$17{,}406^{a,e}\pm3{,}928.6$
Fresh tamarind juice				$11.46^{c,e}\pm0.61$	$8.36^{c,d}\pm0.69$	$13.43^{e}\pm0.84$	$2.69^{b}\pm0.086$	-	$467^{b}\pm28.0$

Note: L* = lightness; a* = redness; b* = yellowness; L*, a*, b*, pH and viscosity values are mean ± standard deviation (n = 3). Means with the same superscript within same column are insignificant different (P>0.05).

aid and the browning reaction occurring during drying. The yellowness (b*) of reconstituted samples was between 5.78 and 14.61, while that of the fresh juice was 13.43. Most samples excluding those of drying condition no. 3 had lower or insignificantly different yellowness (b*) from the fresh juice. The addition of carrier and high temperature treatment should be the causes of this effect. Vongsawasdi *et al.* (2002) stated that the decrease of yellowness was owing to the oxidation of some free radicals in the fruit and vegetable juice during drying. The color differences between the fresh and reconstituted juices must be concerned especially if the tamarind powder was consumed as the instant beverage powder.

The pH of reconstituted samples using MD as a drying aid fell between 2.58 and 2.70 that were very close to that of the fresh juice that was 2.69. Therefore, the tamarind powder can be used as the sour agent for cooking food. On the other hand, all of the samples using AG as a drying aid had pH significantly higher than the fresh juice especially when the ratio of juice and AG was 1:0.8. The pH of MD was 4.7, while that of AG (25% Sol. in water) was 4.4; so, the addition of AG should lessen the pH of sample more than MD. Thus, these phenomena required further study for better understanding.

The percentages of insoluble solid showed that the reconstituted samples using MD as a drying aid had lower percentages of insoluble solid than those of using AG. This result should be explained by the higher dissolution ability of MD than those of AG (Cano-Chauca *et al.*, 2005).

Regarding the viscosity of reconstituted samples, it was apparent that all samples had much higher viscosity than that of the fresh juice. This should be due to the fact that (1) the reconstituted samples had much higher solid contents than the fresh and (2) the drying adjuncts especially AG raised the stickiness of the samples due to its functional properties. The increase in viscosity would affect the application of tamarind powder as an instant juice powder but it should be still suitable if using them as a sour ingredient for cooking food.

The reconstituted samples using the tamarind powder from the drying condition no. 3 and 4 were subjected to the sensory evaluation. The powder from the drying condition no. 3 was selected. Among the drying conditions no. 1 to 3 using MD as a drying carrier, the powder from this condition required the shortest time to dissolve and its reconstituted juice had the most similar color to the fresh juice. For the drying conditions that applied the AG as a drying adjunct, the powder from drying condition no. 4 was chosen since this condition used the lowest amount of AG (AG is a rather expensive adjunct) and required shorter time to dissolve than that of drying condition no. 6. Furthermore, its reconstituted juice had the most resembling viscosity to the fresh juice. The sensory evaluation results are depicted in Figure 2.

The Figure 2 shows that the solutions of tamarind powders from drying condition no. 3 that used MD as a drying carrier achieved the higher score than those from drying condition no. 4 that used AG in the aspects of appearance, color, and overall liking. It might be due to the sticky appearance and darkness (lower L*) of the solutions of tamarind powders using AG as a drying aid. Nonetheless, the solutions of tamarind powders from drying condition no. 4 were preferred in the aspects of aroma and taste. It was noted that drying condition no. 3 applied the ratio of tamarind juice and drying aid at 1: 1.4, while the drying condition no. 4 used only 1: 0.4. So, the powder dried under drying condition no. 4 had more tamarind fraction than those from drying condition no. 3 that had MD around 85% by weight.

3.4 The cost of energy and drying aids

The calculated energy and drying aid costs are summarized in Table 4. It appears that the heat energy cost is the main proportion of the energy cost of drying tamarind juice. The specific energy costs of producing tamarind powder range between 7.27 and 21.00 Baht/kg_{powder}. The specific energy cost of drying condition no. 6 was exceptionally high because of its low weight of dried product due to low total solids in the feed. Also, the 140°C drying temperature was used in this drying run. However, the energy cost is only a minor cost in the tamarind powder production if comparing it with the drying aid costs that are in the range of 208-228 Baht/kg_{powder} and 640-768 Baht/kg_{powder} if using

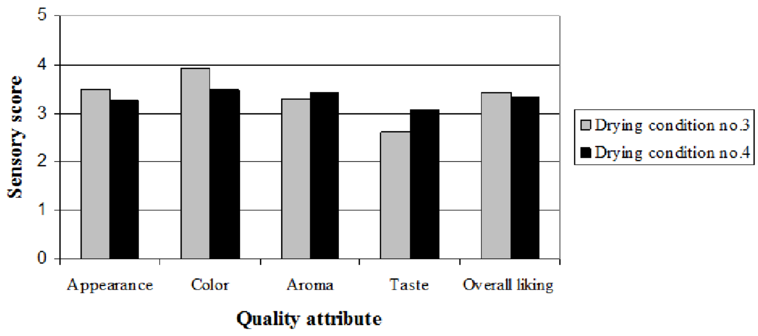

Figure 2. Sensory properties of the solutions of tamarind powders.

Table 4. Description of energy and drying aid costs for the production of tamarind powder

Energy consumption for drying				Dried product weight (kg)	SPEC ($kJ/kg_{product}$)	Energy cost for drying			Cost of drying aids (Thai Baht/ $kg_{product}$)
Drying condition no.	Heat energy (kJ)	Electrical energy (kJ)	Total primary energy (kJ)			Heat energy cost (Thai Baht)	Electrical energy cost (Thai Baht)	Specific energy cost (Thai Baht/ $kg_{product}$)	
1	2,421	675	4,177	0.320	13,052	1.93	0.56	7.79	227.50
2	2,027	524	3,390	0.200	16,951	1.62	0.44	10.26	208.00
3	4,354	565	5,823	0.320	18,195	3.47	0.47	12.31	227.50
4	1,342	278	2,066	0.120	17,218	1.07	0.23	10.85	640.00
5	2,354	299	3,132	0.200	15,659	1.88	0.25	10.62	768.00
6	2,928	225	3,512	0.120	29,267	2.33	0.19	21.00	640.00
7	1,464	345	2,361	0.200	11,805	1.17	0.29	7.27	768.00

Note: Total primary energy = Heat energy + [2.6*Electrical energy]. SPEC = specific primary energy consumption = Total primary energy/ Dried product weight. Specific energy cost = (Heat energy cost + Electrical energy cost)/ Dried product weight

MD and AG respectively. Owing to the high drying aid costs, the market price of tamarind powder must be relatively expensive; as a result, the target of this product should be carefully considered.

4. Conclusions

The results indicated that it is feasible to produce the tamarind powder as a sour agent or flavoring additive for food. In order to obtain the tamarind powder, the ratio of tamarind juice and MD should be 1:0.8 if drying at 140°C or 1:1.4 if drying at 120-140°C. In case of using AG as a drying aid the proportion should be 1:0.4 or 1:0.8 for drying temperatures between 120 and 140°C. The tamarind powders with MD were preferred in term of appearance, color, and overall liking, while those with AG were favored in their aroma and taste. The energy costs of producing tamarind powder were ranged between 7.27 and 21.00 Baht/kg_{powder}, whereas the drying aid costs were much higher. The production cost of tamarind powder was considered costly; therefore, a marketing study should be seriously conducted before launching this product.

References

Adhikari, B., Howes, T., Bhandari, B.R. and Troung, V. 2003. Characterization of the surface stickiness of fructose-maltodextrin solutions during drying. Drying Technology. 21, 17-34.

Adhikari, B., Howes, T., Bhandari, B.R. and Troung, V. 2004. Effect of addition of maltodextrin on drying kinetics and stickiness of sugar and acid-rich foods during convective drying experiments and modeling. Journal of Food Engineering. 62, 53-68.

Al-Kahtani, H.A. and Hassan, B.H. 1990. Spray drying of Roselle (*Hibiscus sabdariffa L.*) extract. Journal of Food Science, 55(4), 1073-1076.

Bhandari, B.R., Snoussi, A., Dumoulin, E.D. and Lebert, A. 1993. Spray drying of concentrated fruit juices. Drying Technology. 11(5), 1081-1092.

Bhandari, B.R., Dutta, N. and Howes, T. 1997. Problems associated with spray drying of sugar-rich food. Drying Technology. 15(2), 671-684.

Canakci, M., Ozsezen, A.N., Arcaklioglu, E. and Erdil, A. 2009. Prediction of performance and exhaust emissions of a diesel engine fueled with biodiesel produced from waste frying palm oil. Expert Systems with Applications. 36, 9268-9280.

Cano-Chauca, M., Stringheta, P.C., Ramos, A.M. and Cal-Vidal, J. 2005. Effect of the carriers on the microstructure of mango powder obtained by spray drying and its functional characterization. Innovative Food Science and Emerging Technologies. 6, 420-428.

Chegini, G.R. and Ghobadian, B. 2005. Effect of spray-drying conditions on physical properties of orange juice powder. Drying Technology. 23, 657-668.

Cheuyglintase, K. and Morison, K.R. 2009. Crystal induction by dietary fiber in spray drying of fruit juice. Proceedings of the 6th Asia-Pacific Drying Conference (ADC 2009), Bangkok, Thailand, October 19-21, 2009, 606-613.

Gabas, A.L., Telis, V.R.N., Sobral, P.J.A. and Telis-Romero, J. 2007. Effect of maltodextrin and Arabic gum in water vapor sorption thermodynamic properties of vacuum dried pineapple pulp powder. Journal of Food Engineering. 82, 246-252.

Incropera, F.P., Dewitt, D.P., Bergman, T.L. and Lavine, A.S. 2007. Fundamentals of Heat and Mass Transfer, 6th ed., John Wiley & Sons (Asia), pp. A23-A24.

Jittanit, W., Niti-Att, S. and Techanuntachaikul Sinija, O. 2010. Study of spray drying of pineapple juice using maltodextrin as an adjunct. Chiang Mai Journal of Science. 37(3), 498-506.

Langrish, T.A.G., Chan, W.C. and Kota, K. 2007. Comparison of maltodextrin and skim milk wall deposition rates in a pilot-scale spray dryer. Powder Technology. 179, 84-89.

Nastaj, J.F. 2000. Numerical model of vacuum drying of suspensions on continuous drum dryer at two-region conductive-convective heating. International Communications in Heat and Mass Transfer. 27(7), 925-936.

Pua, C.K., Hamid, N.S.A., Tan, C.P., Mirhosseini, H., Rahman, R.B.A. and Rusul, G. 2010. Optimization of drum drying processing parameters for production of jackfruit (*Artocarpus heterophyllus*) powder using response surface methodology. LWT-Food Science and Technology. 43, 343-349.

Qi, D.H., Geng, L.M., Chen, H., Bian, Y.ZH., Liu, J. and Ren, X.CH. 2009. Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil. Renewable Energy. 34, 2706-2713.

Roos, Y. and Karel, M. 1991. Water and molecular weight effects on glass transitions on amorphous carbohydrates and carbohydrate solutions. Journal of Food Science. 56, 1676-1681.

Shrestha, A.K., Ua-Arak, T., Adhikari, B.P., Howes, T. and Bhandari, B.R. 2007. Glass transition behavior of spray dried orange juice powder measured by Differential Scanning Calorimetry (DSC) and Thermal Mechanical Compression Test (TMCT), International Journal of Food Properties. 10, 661-673.

Silva, M.A., Sobral, P.J.A. and Kieckbusch, T.G. 2006. State diagrams of freeze-dried Camu-Camu (myrciaria dubia (hbk) mc vaugh) pulp with and without maltodextrin addition. Journal of Food Engineering. 77(3), 426-432.

Sinija, V.R., Mishra, H.N. and Bal, S. 2007. Process technology for production of soluble tea powder. Journal of Food Engineering. 82, 276-283.

Sommanas, K. 1997. Production of Banana Powder by Foam Mat Drying and Spray Drying, MSc Thesis, Kasetsart University, Thailand, pp. 121.

Vongsawasdi, P., Nopharatana, M., Tangbumrungpong, D. and Apinunjarupong, S. 2002. Production of instant fruit and vegetable juice by spray dryer and microwave-vacuum dryer, KMUTT Research and Development Journal. 25(3), 257-277.