Optimization of osmotic dehydration of *Terung Asam* (*Solanum lasiocarpum* Dunal)

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Abstract This study was designed to determine the effect of osmotic dehydration (OD) process temperature (35–55 °C), sucrose concentration (40–60% w/w) and immersion time (90–210 min) on the water loss (WL), solid gain (SG), DPPH radical scavenging activity, ferric reducing antioxidant power (FRAP) and sensory quality of the dehydrated *Terung Asam* slices. Response Surface Methodology with Central Composite Design was applied to investigate the influence of these variables on the aforementioned responses. The increase in the levels of these processing parameters increased the WL and SG. The antioxidant activities also increased with sugar concentration, but reduced with immersion time and temperature elevation. About 36–80% of IC₅₀ and 47–72% of FRAP were depleted after osmotic process. The loss of antioxidants was predominantly due to leaching during osmotic treatment rather than hot air drying. Despite the losses of these compounds, osmotic pretreatment was able to improve the sensory quality of the product. The optimum OD process condition was predicted as process temperature 38.1 °C, sucrose concentration 55.6% and osmotic duration 126.3 min.

Keywords Water loss · Solid gain · DPPH radical scavenging activity · Ferric reducing · Antioxidant power · Sensory evaluation

Introduction

Human health is closely associated with food and many modern-day ailments such as heart disease, Type II diabetes and cancers can be prevented through good diet and healthy lifestyle. Nowadays, consumers are more aware about health issues and their preferences on food have shifted to natural, nutritious and health promoting food. Among the substantial varieties of foods, foods comprised of natural bioactive compounds have maintained their reputation as beneficial. These bioactive compounds exhibit antioxidative properties that can protect the body against oxidative stress and associated pathologies such as cancer, heart disease and inflammation (Tapiero et al. 2002). Fruits and vegetables, which contain the aforementioned beneficial nutrients, are therefore becoming an extensive field of research. *Terung Asam* or scientifically named as *Solanum lasiocarpum* Dunal is one of the popular native vegetables that exhibits great nutritional value and antioxidant properties. It contains bioactive compounds such as beta-carotene, tocopherol and ascorbic acid (AVRDC 2003). It also contains better mineral content as compared to its cultivated relatives (Voon and Kueh 1999). *Terung Asam* is originated in Sarawak, East Malaysia and it has been granted a Geographical Indication certificate, characterized by a consistent high quality and good reputation. This vegetable has a distinct sour taste which makes it as a favorite vegetable and flavoring among the locals (Shariah 2012). The explorations of native plant species not only bring about the discovery of new sources of functional nutrients, but also broaden the diversity of the human diet.

Concerning the substantial amount of beneficial nutrients in *T. Asam*, processing technique that can retain most of the nutritional compounds has become the first priority. Osmotic dehydration (OD) has been proposed as an

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effective pre-treatment due to several benefits, especially on product quality improvement and energy related advantages. Since two major counter-current flows will take place simultaneously during OD, hence it is considered a combination of dehydration and impregnation process. The water removal process commences when a moisture rich foodstuff is immersed in a hypertonic aqueous solution (Phisut 2012). Unlike most of the traditional drying methods which employ high drying temperature, OD can effectively remove moisture under low or ambient temperature. This reduces the total energy consumption during processing. In addition, the low temperature water removal process also minimizes thermal degradation of nutrients and improves the organoleptic properties of food (Lee and Lim 2011). The reduction of water content, on the other hand, extends the shelf life of products (Roopa et al. 2014) and minimizes packaging requirement and transport weight.

Enormous scientific papers have focused on the OD of fruits and vegetables, such as papaya (Jain et al. 2011), strawberry (Garcia-Noguera et al. 2014), apricot (Raj et al. 2015), mango and guava (Kumar and Sagar 2014), but to date, there has been no study on the OD of *T. Asam*, which can contribute to the development of new value-added product as a means to diversify the human diet. Hence, the present study aimed to develop a nutritious dehydrated snack from *T. Asam*. In this study, the effect of OD pre-treatment on the water loss, solid gain, antioxidant activities and sensory quality of the osmotic dehydrated *T. Asam* were investigated, followed by process optimization using Response Surface Methodology. This study is of relevance as it leads to insights into the possible changes in the antioxidant capacity and the sensory quality of the food during OD, which in turn leads to product improvement.

Materials and methods

Raw material and sample preparation

Fully ripened fresh *T. Asams* (*S. lasiocarpum* Dunal) were purchased from Donggongon Street Market, Kota Kinabalu, Malaysia. Fruits with similar size (average height of 8 ± 1 cm, diameter 8 ± 1 cm and weight 280 ± 10 g) and without any physical damage were selected. The moisture content of the fresh *T. Asam* ranged between 90 and 95% (wet basis) and the soluble solid content determined by a hand-held refractometer ranged between 4° and 7° Brix. Before the *T. Asams* were subjected to OD process, they were cleaned and peeled, and cut into rectangular slabs of 30 mm length $\times$ 10 mm width $\times$ 5 mm thickness. The cut samples were blanched in hot water at 80 °C for a minute and subsequently cooled down by immersion in

cold water to inactivate enzymes that might generate off-flavor and off-color in the final product. Loss of bioactive compounds during blanching was normalized by standardizing the blanching time for each of the experimental run as to avoid the effect of this nuisance factor on the response.

Experimental design

A Central Composite Design (CCD) with three factors at three levels each was used as the experimental design. The three factors were process temperature (35, 45, 55 °C), sucrose concentration (40, 50, 60% w/w) and immersion time (90, 150, 210 min). The levels of the factor in coded form were -1 , 0 and $+1$. 20 experimental runs, with six replicated center runs were generated by CCD. The dried *T. Asam* slice (hot air-dried for 3 h at 50 °C) without OD treatment was served as a control sample in this study.

Osmotic solution preparation

Food grade sucrose (MSM Malaysia Holdings Berhad) was used as an osmotic agent in this study. The sucrose solution was prepared into specific concentration by dissolving the sucrose in distilled water on a weight-to-weight basis. The concentration of the solution was monitored by a hand-held refractometer. 1% citric acid was added to the osmotic medium to enhance the sensory acceptance and to lower the pH of the final product as a hurdle to extend the shelf life of the product.

Osmotic treatment

The *T. Asam* slices were placed in a 1 L glass beaker and were fully immersed in the sucrose solution. The sample to solution ratio was kept at 1:5 (w/w). The desired process temperature was achieved by holding the beakers in a temperature controlled shaking incubator. A constant agitation of 80 rpm was given throughout the OD process to ensure a uniform temperature distribution and to avoid localized dilution of the sucrose solution. After a specific OD period, the samples were removed from the solution and rinsed quickly with distilled water to remove the surplus sucrose solution on the sample surface before blotting with absorbent paper for 15 s. After that, the samples were dried in a food dehydrator at 50 °C until achieving the final water activity of 0.75 ± 0.01 .

Determination of water activity

The water activity of sample was measured at room temperature (25 ± 1 °C) using a water activity meter (HygroLab 3, Rotronic, Switzerland). Approximately 5 g of

samples was inserted into the sample cup and measurement was made immediately to avoid moisture transfer from the air to the samples.

Determination of water loss and solid gain

The WL and SG of the osmotic dehydrated samples were determined based on the following equations (Eren and Kaymak-Ertekin 2007):

$$WL (\%) = \frac{m_i z_i - m_f z_f}{m_i} \times 100$$

$$SG (\%) = \frac{m_f s_f - m_i s_i}{m_i} \times 100$$

where, m_i and m_f are the initial and final weight of *T. Asam* (g) respectively; z_i and z_f are the initial and final mass fraction of water (g) respectively; and s_i and s_f are the initial and final mass fraction of total solids (g) respectively.

Sample extraction for antioxidant activity assays

The osmotic dehydrated *T. Asam* slices were ground using an electric food grinder (KD-333, Dekka, Malaysia) prior to methanol extraction process. 10 g of the ground samples were immersed in 100 mL of methanol for 72 h at room temperature. After that, the extract was filtered by using Whatman filter paper no. 1. The solvent was then removed by using a rotary evaporator under vacuum at 40 °C until a viscous mass was obtained (Matanjan et al. 2008).

1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity

The extract solution was prepared into different concentrations (containing 0.5–5.0 mg/mL of extract). 2 mL of sample solution was mixed thoroughly with 2 mL of 0.1 mM methanolic DPPH solution. The mixture was kept in dark for 30 min. The absorbance was measured using a spectrophotometer at $\lambda_{\max} = 517$ nm. The results were expressed as % DPPH scavenging activity relative to the control sample based on the following equation:

$$\% \text{DPPH scavenging activity} = \left[\frac{(A_{\text{control}} - A_{\text{sample}})}{A_{\text{control}}} \right] \times 100$$

The antioxidant activity of samples was then evaluated by IC_{50} . The IC_{50} values were estimated from the % DPPH scavenging activity versus concentration plot, using a non-linear regression algorithm (Blois 1958).

Ferric-reducing antioxidant power

FRAP reagent was prepared on the day of experiment and was warmed to 37 °C. It contained 300 mM acetate buffer (pH 3.6) (3.1 g $\text{C}_2\text{H}_3\text{NaO}_2 \cdot 3\text{H}_2\text{O}$ and 16 ml $\text{C}_2\text{H}_4\text{O}_2$ per liter of buffer solution), 10 mM TPTZ in 40 mM HCl and 20 mM $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ in the ratio of 10:1:1. 500 μL of sample solution at the concentration of 1 mg/mL was mixed with 3 mL of FRAP reagent. The absorbance was measured at $\lambda_{\max} = 593$ nm after 10 min. Trolox in the concentration of 0–200 μM was used as standard for calibration (standard equation $y = 7.8089x + 0.2604$, $R^2 = 0.9986$). The results were expressed as μM Trolox/g extract (Benzie and Strain 1999).

Sensory evaluation

Multisample Difference Test was employed to measure the differences between the treated and the untreated (control sample) *T. Asam* slices. Balanced Incomplete Block Design was applied (Cochran and Cox 1957) and a total of 35 panelists (18 females and 17 males, between the ages of 20 to 32 years old) were involved in the sensory test. Each sample was packed individually in a sealed plastic bag and labeled with a three-digit code. Each panelist would compare three samples to the control by referring to a 7-point scale. The attributes evaluated were colour, surface dryness, shrinkage, aroma, hardness, sweetness and overall acceptability. The denotations of the scores of the scale were as follows: 1 = very weak in comparison to the control, 2 = weaker than the control, 3 = slightly weaker than the control, 4 = no difference with the control, 5 = slightly stronger than the control, 6 = stronger than the control, 7 = very strong in comparison to the control (Lee and Lim 2011).

Statistical analysis

Response Surface Methodology was applied to estimate the effects of process variables on the responses, by using the statistical software package Design-Expert ver 6.0 (Stat-Ease Inc., Minneapolis, USA). This software was also used for the regression analysis and the generation of response surface plot. The experimental data were fitted to the second-order polynomial model as follow:

$$y = \beta_0 + \sum_{i=1}^k \beta_i x_i + \sum_{i=1}^k \beta_{ii} x_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^k \beta_{ij} x_i x_j$$

where y is the response variable, x_i and x_j are the independent variables, $\beta_0, \beta_i, \beta_{ii}, \beta_{ij}$ are the regression coefficients for intercept, linear, quadratic and interaction terms. Terms that were not statistically significant ($p < 0.05$) by

analysis of variance (ANOVA) were dropped to obtain a simplified model. The response surface plots were generated by holding the values of the third variable as constant.

Optimization of osmotic process condition was performed using the desirability function proposed by Derringer and Suich (1980). The desirability has a value from zero to one for any given response. The Design-Expert program would combine the individual desirability into a single number and the highest overall desirability was selected. The most desirable case is represented by a value of one, while zero denotes that one or more responses fall outside the desirable limits. The optimized set was verified by conducting experiments under that condition. The experimental values obtained were compared with the predicted values by performing T test.

Results and discussion

Water loss and solid gain

The regression equation describing the effect of process variables on the water loss (WL) of *T. Asam* slices is shown in Table 1. Results obtained demonstrated that there is a good fit (high R^2 values) of experimental data to the equation obtained. WL was highly influenced by the changes of sucrose concentration, followed by immersion time and temperature, which was in accordance with the findings of Uddin et al. (2004) for the OD of carrot using sucrose solution. These variables exhibited a notable linear effect ($p < 0.05$) on the WL. Besides that, a significant

quadratic effect ($p < 0.05$) was also observed on solution concentration, but not on temperature and immersion time ($p > 0.05$). On the other hand, a significant interaction effect ($p < 0.05$) between process temperature and sucrose concentration was also detected in this study.

Increase of sucrose concentration and immersion time accelerated the WL. When the fresh *T. Asam* slices were immersed in the concentrated sucrose solution, the osmotic gradient between the hypertonic sucrose solution and the intracellular fluid of *T. Asam* slices promoted the water diffusion from the samples into the osmotic medium. Therefore, an accelerated water removal could achieve by increasing the solution concentration to create higher osmotic driving force. Similar observation was reported by Uddin et al. (2004) and Yadav et al. (2012) on the OD of carrot and peach respectively.

Osmotic duration is another important variable that possesses an inevitable influence on the mass transfer rate. It is noted that a prolonged immersion time improved the WL. This result was in agreement with Yadav et al. (2012), who observed a continuous increase in the WL of peach slices as the osmotic duration increased from 2 to 4 h. The continuous increase in WL with immersion time was due to the high osmotic pressure gradient between the hypertonic sucrose solution and the fresh *T. Asam* slices at the initial stage of the process. The rate of water removal would generally slow down at the later stage and eventually achieved equilibrium.

Similar to the previously reported findings on potato, pumpkin and peach (Eren and Kaymak-Ertekin 2007; Lee and Lim 2011; Yadav et al. 2012), temperature elevation

Table 1 Estimated regression coefficients of predicted models for the WL, SG, DPPH (IC₅₀) and FRAP of osmotic dehydrated *Terung Asam* (*Solanum lasiocarpum* Dunal)

Factor	WL	SG	DPPH (IC ₅₀)	FRAP
β_0 (intercept)	54.80	20.35	1.81	13.64
β_1 (temperature)	4.28***	2.42***	0.36***	−1.31***
β_2 (concentration)	7.82***	−0.97*	−0.15*	0.70**
β_3 (immersion time)	5.61***	2.29***	0.58***	−1.69***
β_{11}	1.45	−0.11	—	—
β_{22}	−1.95*	−2.21***	—	—
β_{33}	−0.52	−0.86*	—	—
β_{12}	2.99*	−0.37	—	—
β_{13}	−0.39	0.78	—	—
β_{23}	1.26	−0.51	—	—
R^2	0.9330	0.8936	0.9134	0.8869
Adjusted R^2	0.9091	0.8555	0.8971	0.8657
Predicted R^2	0.8599	0.7749	0.8496	0.8141
Lack of fit p value	0.1920	0.0565	0.0779	0.1210
CV	5.43	7.85	11.02	5.44

Lack of fit is not significant at p value > 0.05

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

would rise up the mass transfer of water and solute. A gradual increase of WL was detected when the temperature rose up from 35 to 55 °C. This could be due to the swelling effect of cell membranes under high temperature (Uddin et al. 2004), together with the release of trapped air from the tissue structure of *T. Asam* which resulted in a more efficient transfer of water from the sample into the surrounding hypertonic sucrose solution. Furthermore, a lower viscosity of the concentrated sucrose solution generated under high temperature also contributed to a better mass transfer characteristic on the product surface (Lazarides et al. 1995).

An interaction effect between solution concentration and temperature on the WL was detected in this study ($p < 0.05$). The maximum WL ($67.9 \pm 2.9\%$) was recorded at the highest sucrose concentration and temperature (Fig. 1a). This finding was in agreement with Eren and Kaymak-Ertekin (2007) on the osmotic treatment of potato. Chenlo et al. (2002) and Moreira et al. (2003) stated that increase of process temperature reduced the viscosity of the concentrated osmotic medium, hence improved the moisture diffusion rate on the product surface.

Table 1 reveals that the process temperature and immersion time affected the solid gain (SG) in a linear manner ($p < 0.05$), while sucrose concentration exerted a more marked quadratical change in SG ($p < 0.05$). It is also obvious that the quadratic effect of immersion time was significant at $p < 0.05$. Meanwhile, no interaction effect between the variables was detected ($p > 0.05$).

Similar to WL, SG was accelerated by temperature elevation and immersion time. The maximum SG ($24.3 \pm 1.43\%$) was recorded at temperature 55°C and immersion time 210 min (Fig. 1b). The membrane swelling and plasticizing effect not only promoted WL in *T. Asam* slices, but also improved the solute diffusion rate as well as the permeability of cell membrane towards sucrose molecules (Lazarides et al. 1997). On the other hand, longer immersion time allowed a better countercurrent flow until equilibrium was achieved. Meanwhile, the decline of SG at a high sucrose concentration was explained by Giraldo et al. (2003) as case-hardening effect, where the surface cells become hardened due to the rapid removal of water. Additionally, the high viscosity of the concentrated sucrose solution also restricted solute penetration into the sample.

Antioxidant activities

Differing from the WL and SG, the parameters only affected the antioxidant activities in a linear manner (Table 1). Based on the coefficients obtained, the processing parameters exhibited similar magnitude of influence on the two dependent variables. The magnitude of

influence of these parameters in descending order could be ranked as immersion time > process temperature > sucrose concentration. A notable reduction in the antioxidant activities were evident following the progression of immersion time and temperature elevation (Fig. 2). The highest antioxidant activities (IC_{50} 0.87 ± 0.20 mg/g 0.1 mM DPPH and FRAP 16.64 ± 0.74 μ M TE/g extract) were recorded at the shortest immersion time and lowest temperature. IC_{50} represents the concentration that causes a decrease in the initial amount of DPPH radicals by 50% (Huang et al. 2005), and it is known to be correlated to the antioxidant level. When the antioxidant level is high, the IC_{50} is low, due to the presence of high amount of antioxidant that can act as free radical scavengers. Conversely, when the antioxidant level is low, the IC_{50} is high. Besides, the antioxidant activity is reported to be dependent on the content of polyphenols (Singh et al. 2016). Significantly high correlation was found between IC_{50} and TPC ($r = 0.907$, $p < 0.05$), as well as between IC_{50} and TFC ($r = 0.847$, $p < 0.05$).

Although leaching was generally considered to be quantitatively negligible, but results obtained in this study showed that a considerable amount of antioxidant compounds in *T. Asam* slices was leached into the sucrose solution after a few hours of immersion. The large osmotic driving force together with an enhanced water flux under elevated temperature increased the loss of bioactive compounds, particularly the water soluble phenolics through leaching, which was in accordance with the findings by Devic et al. (2010). In fact, the sucrose solution became yellow-colored at the end of the osmotic process. A similar observation was reported by Blanda et al. (2009) during the osmotic treatment of strawberries, whereby the osmotic solution became pink-colored after processing due to lixiviation of phenolic compounds in osmotic media. On the other hand, the antioxidant activities of *T. Asam* were also found to reduce following temperature elevation, due to the low stability of bioactive compounds towards thermal process. The anthocyanin content of pomegranate seeds and blueberry was also reported to reduce significantly when the process temperature increased from 40 to 60 °C and 30 to 70 °C respectively (Bchir et al. 2012; Kucner et al. 2013).

Contrary to immersion time and temperature, sucrose concentration possessed a positive influence towards the retention of antioxidant activities in dried *T. Asam* slices (Table 1). The higher was the sucrose concentration, the better the retention of antioxidant activities. High sucrose concentration restricted the contact between *T. Asam* and oxygen, thus inhibited the activity of oxidant enzyme which led to the changes in antioxidants (Chottamom et al. 2012).

Fig. 1 Response surface plot for the **a** water loss (hold at immersion time 150 min) and **b** solid gain (hold at 50% sucrose concentration) of *Terung Asam* slices during osmotic dehydration

This study found that the loss of antioxidant compounds was predominantly due to OD treatment rather than hot air drying (50 °C for 3 h). Even though some of the OD treatments managed to reduce the air drying time from 3 to 1 h, but the overall antioxidant lost was still higher than the control counterpart (Table 2). The IC_{50} and FRAP were 36–80% and 47–72% lower than the control respectively. The leach of these compounds during OD was facilitated by the large osmotic driving force. This finding was in corroboration with Bchir et al. (2012) who investigated the OD of pomegranate seeds. In spite of the notable losses during OD, the antioxidant activities of the OD treated samples were still considered high and comparable to fresh guava

($8.0 \pm 3.6 \mu\text{M TE/g}$), papaya ($3.9 \pm 0.4 \mu\text{M TE/g}$), banana ($4.2 \pm 1.6 \mu\text{M TE/g}$) and mangosteen ($6.5 \pm 1.9 \mu\text{M TE/g}$) (Patthamakanokporn et al. 2008). Hence, the osmo-dried *T. Asam* slices can serve as an alternative source of antioxidants other than these common fruits.

Sensory evaluation

Feedback of sensory panelists revealed that the colour of OD treated sample was affected quadratically by the three independent variables ($p < 0.05$) (Table 3). The colour of the dehydrated *T. Asam* slices became more attractive when the sucrose concentration and temperature increased up to

Fig. 2 Response surface plot for the **a** DPPH (IC_{50}) and **b** ferric reducing antioxidant power of the dried *Terung Asam* slices (hold at sucrose concentration 50%)

Table 2 The DPPH (IC_{50}) and FRAP of raw, control and osmotic dehydrated samples

Sample	DPPH (IC_{50}) (mg/ml)	FRAP (μ M TE/g extract)
Raw	0.50 ± 0.01	38.75 ± 0.18
Control ^a	0.61 ± 0.01	32.18 ± 0.34
OD treated	Varied from 0.95 ± 0.19 – 3.03 ± 0.19	Varied from 9.5 ± 0.74 – 17.03 ± 0.18

^a Hot air dried at 50 °C for 3 h

50% and 45 °C respectively (Fig. 3a). Generally, the colour of the osmo-dried sample was found more attractive (score >4) than the control due to sugar infusion which improved pigment stability during processing and inhibited browning reaction (Sagar and Kumar 2010). Meanwhile, only sucrose concentration and immersion time were found to affect ($p < 0.05$) the surface dryness and the shrinkage of the OD samples. Minimal dryness and shrinkage were achieved at a concentration around 50% and immersion time around 180 min (Fig. 3b, c), attributed to the high

Table 3 Estimated regression coefficients of predicted models for the colour, surface dryness, shrinkage, aroma, hardness, sweetness and overall acceptability of the osmotic dehydrated *Terung Asam* (*Solanum lasiocarpum* Dunal)

Factor	Colour	Dryness	Shrink-age	Aroma	Hardness	Sweetness	Overall acceptability
β_0 (intercept)	6.33	1.67	1.29	5.67	4.5	6.66	6.5
β_1 (temperature)	0.077	−0.14	−0.098	−0.050	0.088	0.13	0.067
β_2 (concentration)	0.021	−0.067	−0.056	−0.16	0.027	−0.073	6.257E−003
β_3 (time)	0.7030	−0.36**	−0.31**	0.30**	5.525E−003	0.25*	0.027
β_{11}	−0.87***	0.067	0.15	−0.31**	−0.62***	−0.42**	−0.61***
β_{22}	−0.92***	0.43**	0.44***	−0.29**	−0.64***	−0.50***	−0.64***
β_{33}	−0.54***	0.38**	0.36**	−0.037	−0.39**	−0.093	−0.38**
β_{12}	−1.325E−016	−0.019	1.250E−003	−0.019	0.017	0.035	0.054
β_{13}	−1.815E−016	−0.14**	−0.36**	−0.019	0.055	1.000	0.019
β_{23}	−0.035	0.019	1.250E−003	0.019	−0.018	0.072	−0.054
R^2	0.9443	0.8438	0.8529	0.7406	0.8819	0.8030	0.8758
Adjusted R^2	0.9185	0.7717	0.7851	0.6480	0.8274	0.7327	0.8184
Predicted R^2	0.9177	0.7828	0.7605	0.6539	0.8216	0.7095	0.8060
Lack of fit p value	1.000	0.9999	0.9595	1.000	1.000	0.9961	0.9999
CV	6.80	14.62	16.38	6.05	10.28	5.72	6.52

Lack of fit is not significant at p value >0.05

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

soluble solid intake. In addition to occupy the tissue volume as to avoid structural collapse, sugar also acts as a humectant that bind water molecules and control water activity, while retaining sufficient moisture. The entire OD treated samples were found less dry (score <3) and experienced less shrinkage (score <3) as compared to the control.

One of the major adverse effects of hot air-drying is an increase of alcohols in the dried product that results in the fermented smell. However, these negative aroma compounds were very low in the OD treated samples (Bignardi et al. 2000). This study found that OD pretreatment well-preserved the aroma of *T. Asam* (score >4) especially at longer osmotic duration because high sugar infusion could enhance the retention of volatiles. In the meantime, all three process variables induced sample hardness in quadratic manner. With the sensory score <5, it suggested that most of the treated samples were softer than the control. Normally, a long period of heating would loosen the food texture, hence soften the product.

Meanwhile, the sweetness of the sample was found maximum at 50% concentration and 210 min of immersion (Fig. 3d). Generally, OD pretreated samples were sweeter (score >5) than the control, owing to sugar diffusion into sample during osmosis. This was desirable as to balance out the sourness of the *T. Asam* in order to make it a more sensory acceptable dehydrated snack. Results obtained signified that all the sensory attributes observed improved notably after the OD process, hence the overall acceptability of osmo-dried *T. Asam* was rated higher (score >5)

than the control. Different OD process conditions brought remarkable influence on the acceptability of the final product. Therefore, it is crucial to identify the right combination of process conditions in order to guarantee an acceptable product.

Process optimization

Desirability, a mathematical function was used to determine the optimum osmotic process condition. Since the aim of this study was to produce the most sensory acceptable dehydrated snack with the maximum retention of antioxidant activities, hence the constraint criteria selected for optimization were maximum possible WL, FRAP, colour and overall acceptability; minimum possible SG, IC₅₀ and shrinkage; surface dryness (1–4); aroma (5–6); hardness (3–4); sweetness (5–7). The optimum operating condition was predicted as process temperature 38.1 °C, sucrose concentration 55.6% and immersion time 126.3 min. Correspondingly, the value for WL was 52.2%; SG 16.4%; FRAP 16.21 ± 0.74 µM TE/g extract; IC₅₀ 1.01 ± 0.20 mg/g; colour 5; surface dryness 2; shrinkage 2; aroma 5; hardness 4; sweetness 6; overall acceptability 6. In the meantime, the overall desirability obtained was 0.751. On the other hand, experiments conducted on the optimized set condition revealed that the experimental values were not differ statistically ($p > 0.05$) from the predicted values, indicated that the models were able to predict the responses with satisfactory values.

Fig. 3 Response surface plot for the **a** colour, **b** surface dryness **c** shrinkage and **d** sweetness of the dried *Terung Asam* slices

Conclusion

In conclusion, the three independent variables used in OD treatment would affect the WL, SG, antioxidant activities and sensory quality of the dehydrated *T. Asam* slices. An increased sucrose concentration was more likely to improve the process as it led to a higher WL and better

retention of antioxidant activities. Prolonged immersion time and elevated process temperature also showed a promising effect on enhancing the WL, but these were unfavorable for the retention of antioxidants. In this study, OD treatment did not improve the retention of antioxidant activities of the dehydrated samples due to the high leaching rate of these compounds. Nonetheless, feedback

Fig. 3 continued

of sensory panelists indicated that the OD pretreatment could significantly improve the sensory quality of the products. In spite of the high losses of bioactive compounds after osmotic treatment, the antioxidant levels of the OD treated sample were still considered high and comparable to some of the common fresh fruits. In the meantime, results of process optimization showed that the

optimum operating condition for maximum WL and retention of antioxidant activities and sensory quality was at process temperature 38.1 °C, sucrose concentration 55.6% and immersion time 126.3 min.

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