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Development of dried chewy longan arils

Wiwat Wangcharoen*

Faculty of Engineering and Agro-Industry, Maejo University, Chiang Mai 50290, Thailand

* E-mail: wiwat@mju.ac.th

Abstract: Dried chewy longan arils were developed by osmotic dehydration with sucrose and glucose syrup solution and hot air drying. The water sorption isotherm of dried longan arils was better fitted by Gugenheim-Anderson de Boer (GAB) model than Brunauer-Emmett-Teller (BET) model and it showed that the water activity and moisture content of dried longan arils were decreased by glucose syrup solution. The most acceptable product was longan aril soaked for 2 days in sucrose solution followed by 2 days in glucose syrup solution before drying. This product showed the antioxidant capacity of at least 0.53 ± 0.08 mg vitamin C equivalent per g dry sample and this antioxidant activity was stable for 12 months. Its shelf life was predicted at 20 months.

Keywords: longan, osmotic dehydration, water sorption isotherm, antioxidant capacity, shelf-life prediction

INTRODUCTION

Longan (*Dimocarpus longan* (Lour.) Steud) is among ten of the most economically important fruits of Thailand. The main region of longan cultivation is in the upper northern part of the country, namely in the provinces of Chiang Mai (31.4%), Lamphun (28.8%) and Chiang Rai (8.8%). 'E Dor', the most popular commercial cultivar, occupies the largest area or 75% followed by 'Haeo', 'Bieo Khieo' and 'Si Chompu', each covering 7% of the total cultivated area [1]. Thailand currently becomes the top exporter of longan, followed by Vietnam [1-2].

Nowadays, longan is available year round in Thailand but the peak period is June-August [3]. The mature longan fruit is small (ca. 1.5-2 cm in diameter), conical, heart-shaped or spherical in shape and light brown in colour. It has thin, leathery and indehiscent pericarp surrounding succulent, edible white aril developed around a relatively large dark brown seed. Longan is non-climacteric and therefore must be harvested when the skin becomes yellow-brown and the flesh reaches optimal maturity at 15.5-16°Brix [4]. In practice, however, the harvest maturity is usually assessed on the basis of colour and flavour [2].

Longan has a very short postharvest life of 3-4 days at ambient temperature [5-6]. The major factors that reduce its storage life and marketability are microbial decay and pericarp browning. Low temperature storage at 1-5°C is used to reduce pathological decay up to approximately 30 days, but the fruit becomes visually unacceptable from pericarp browning and deteriorates rapidly when removed from cold storage. Sulfur dioxide fumigation has been the most effective postharvest treatment for control of pericarp browning in longan, and is used extensively in commercial situations at present [2].

For commercial processing, canning, freezing and drying are widely used for longan [7]. Dried longan is an important product and more than 3,000 hot-air driers are currently in operation in Thailand for its production [8]. Longan drying by a hot-air drier at 45-85°C is an energy-intensive process [9-11]. Both peeled and unpeeled dried longans are available in the local market and for export, but they are only suitable for use as ingredients for cooking or further processing because most of them have tough or hard texture. Combinations between hot-air driers and other processes such as microwave [12], two-stage superheated steam [13] and far-infrared radiation [14], have been studied in order to improve the drying process and the products. Some commercialised crispy longan arils [15, 16] have been produced by higher drying technology such as freeze-drying. They are suitable for direct consuming as snack or serving with drinks, yogurt or salad. A high content of vitamin C is claimed [16].

This work presents another method for preserving longan and developing another a dried longan snack with chewy texture. Longan arils were osmotically dehydrated before they were dried by a hot-air drier. The type of sugar solution used in osmotic dehydration was studied. A water-sorption isotherm of dried longan arils was created and an acceptance test of selected dried chewy longan arils was performed. The water activity, water content and antioxidant capacity of the most acceptable samples were evaluated during 12 months of storage at room temperature, and the shelf life of the product was predicted.

MATERIALS AND METHODS

Preparation of Dried Longan Arils

Longan arils (E Daw cultivar) purchased from a local fruit canning company were dipped in boiling water for 1 min. They were then soaked in 70°Brix sugar solution (longan arils: sugar solution = 1:1 (wt/wt) [17]) at room temperature (28±5°C) for 24 hr, and were transferred to a new 70°Brix sugar solution every 24 hr. This osmotic dehydration was carried out by separately soaking for: (I) 3 days in sucrose solution; (II) 2 days in sucrose solution followed by 2 days in glucose syrup solution; (III) 1 day in sucrose solution followed by 3 days in glucose syrup solution; and (IV) 4 days in glucose syrup solution. The average weight and total soluble solid of the aril samples were recorded at day 0, 1, 2, 3 and 4. The osmotically dehydrated arils were dipped in boiling water for 1 min. to wash out the stickiness before they were dried in a hot-air drier at   50±2°C for 24 hr. They were left in airtight plastic boxes for moisture equilibration for 48 hr before measurement of shear force, water activity and moisture content (% dry basis).

The average weight was obtained by an electronic precision balance (BP610: Sartorius AG, Germany). The total soluble solid was recorded by a set of portable refractometers (FG 103/113, FG 104/114 and FG 106/116: Beijing Zhongjin Tech Metallurgical Equipment Corp., China). The shear force was measured by a Warner Bratzler shear (Salter: G-R Elec. Mfg. Co., USA). The water

activity was measured by a water activity meter (AquaLab Series 3: Decagon Device Inc., USA), and the moisture content (% dry basis) was determined by AOAC method [18].

Water Sorption Isotherm

Dried longan arils were placed over various saturated salt solutions (LiCl, CH_3COOK, $MgCl_2$, K_2CO_3, $Mg(NO_3)_2$, NaCl, KCl, $BaCl_2$ and K_2SO_4) in airtight plastic boxes at room temperature (28±5°C) for moisture equilibration (3-10 days) before their water activity and moisture content were determined. The moisture content was then plotted against water activity to create a water sorption isotherm of dried longan arils, which was then fitted by models of Brunauer-Emmett-Teller (BET) and Gugenheim-Anderson de Boer (GAB) [19-21] as follows.

BET : $Aw/[(1-Aw)*m] = 1/(mo*c) + [(c-1)/(mo*c)]*Aw$

GAB : $Aw/m = (k/mo)*((1/c)-1)*Aw^2 + (c-2)/(mo*c)*Aw + 1/(mo*c*k)$

where Aw = water activity; m = moisture content (% dry basis); mo = monolayer moisture content; c = energy constant; and k = constant

Sensory Evaluation

An acceptance test of selected dried chewy longan arils was performed. One hundred and twenty consumers were requested to evaluate samples of the dried longan arils with respect to appearance, flavour, texture and overall preference by using a 9-point hedonic scale: 1 = extremely dislike, 5 = neither like nor dislike, 9 = extremely like [22].

Shelf-life Study and Antioxidant Capacity

The most accepted samples of the dried longan were packed in 190-ml polypropylene plastic boxes (100 g per box) and kept at room temperature (25.4±6°C) for 12 months. Their water activity, moisture content and antioxidant capacity during storage were determined. The antioxidant capacity was measured by 3 different methods, namely ferric reducing/antioxidative power (FRAP) assay [23], improved ABTS radical-cation decolourisation assay [24] and DPPH free radical scavenging activity [25] with some modification as previously described [26]. Vitamin C was used as a standard for all methods and results were reported as mg vitamin C equivalent/ g dry sample. The change of water activity and moisture content was used to predict the shelf life of the products by the following linear equation [27]:

$$\ln [(m_e - m_0)/(m_e - m_c) = [K / \alpha] t$$

where m_e = Equilibrium moisture content of product (% dry basis)
    m_0 = Initial moisture content of product (% dry basis)
    m_c = Moisture content of product at the end of acceptance point (% dry basis)
    K   = Moisture transmission rate (g water/ g solid.time)
    α = Slope of liner regression (g water/ g solid)
    t   = Shelf life of product (time)

Statistical Analysis

All experiment was done in triplicate. Completely randomised design was used for analysis of variance for almost all of the data except those for sensory evaluation, for which randomised complete block design was used. Tukey (a)'s w test was used for the Post Hoc test.

RESULTS AND DISCUSSION

Sample Preparation

The average weight and total soluble solid of longan arils measured at day 0, 1, 2, 3 and 4 are shown in Figure 1. The average weight of longan arils decreased whilst the total soluble solid increased because there was a diffusion of water and some solutes from tissues of longan arils into the sugar solution and a simultaneous counter-diffusion of solutes from the sugar solution into the tissues of longan arils. The rate of diffusion depends on several factors including the size and geometry of material [28]. The glucose syrup in this study was the original glucose syrup (dextrose equivalent=42) which contained glucose, maltose and higher molecular-weight sugars [29]. Its solution could better absorb water (Figure 1a) but more slowly increase total soluble solid in longan arils than did sucrose solution (Figure 1b). This osmotic dehydration could be accelerated to reduce processing time by increasing the temperature of the sugar solution [17, 28].

Shear force, water activity and moisture content of the dried longan arils are shown in Table 1. The shear forces of longan arils soaked in sucrose and glucose syrup solutions were much lower than those of the arils soaked in sucrose or glucose syrup solution alone because the crystallisation of sucrose was retarded in the former case and sugars with higher molecular weights in the glucose syrup helped to give body and chewiness to the longan arils [30]. Higher-molecular-weight sugars also caused toughness of longan arils and this is why the shear force of longan arils soaked in sucrose or glucose syrup solution only was higher. Moreover, glucose syrup solution helped to decrease the water activity and moisture content of longan arils due to its humectant property [31]. Since only dried longan arils (II and III) which were soaked in sucrose and glucose syrup solutions had the chewy texture, they were selected for the sensory evaluation.

Table 1. Shear force, water activity and moisture content of dried longan arils

	Longan arils (I)	Longan arils (II)	Longan arils (III)	Longan arils (IV)
Shear force (kg)	9.48 ± 2.53 [a]	1.52 ± 0.33 [b]	2.30 ± 0.39 [c]	7.72 ± 2.21 [a]
Water activity	0.713 ± 0.012 [a]	0.658 ± 0.016 [b]	0.630 ± 0.022 [bc]	0.602 ± 0.021 [c]
Moisture content (% dry basis)	17.79 ± 2.05 [a]	13.12 ± 1.42 [b]	11.18 ± 1.56 [b]	9.37 ± 1.29 [b]

Note: Longan arils (I) were soaked for 3 days in sucrose solution before drying.
    Longan arils (II) were soaked for 2 days in sucrose solution followed by 2 days in glucose syrup solution before drying.
    Longan arils (III) were soaked for 1 day in sucrose solution followed by 3 days in glucose syrup solution before drying.
    Longan arils (IV) were soaked for 4 days in glucose syrup solution before drying.
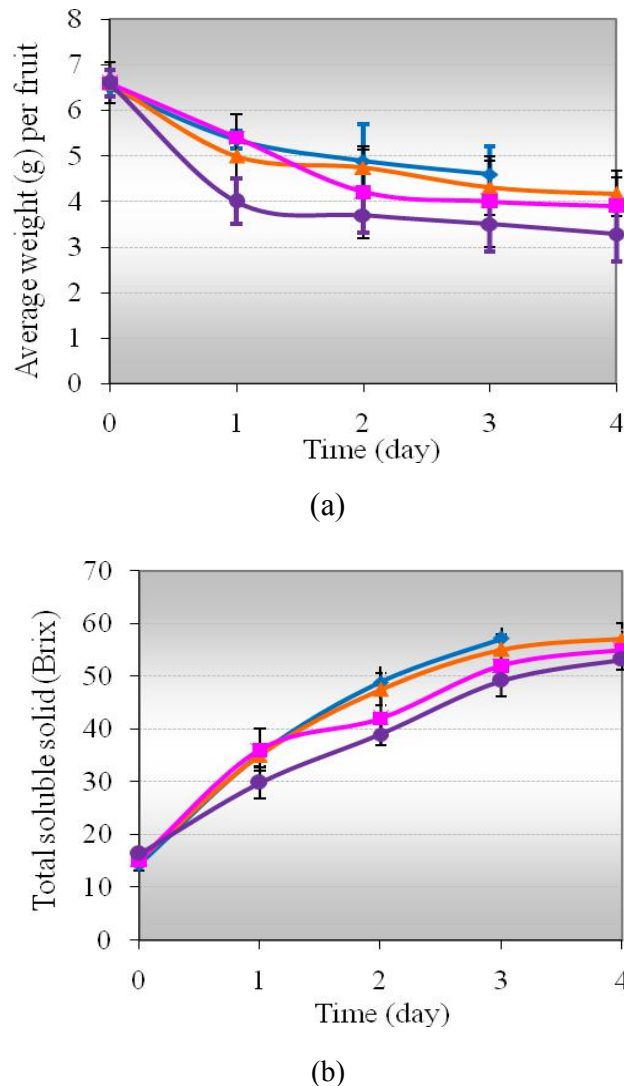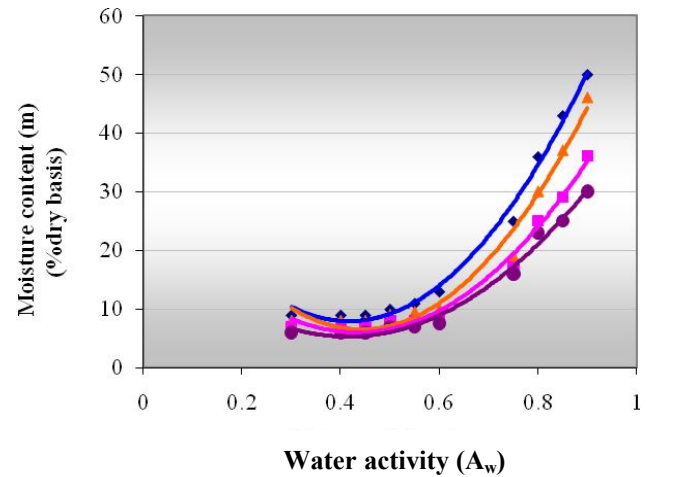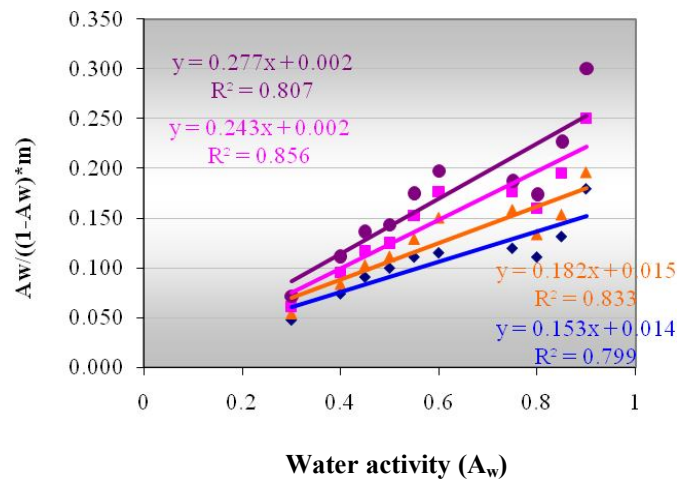   Means with different letters in the same row are significantly different (p<0.05).

(a)

(b)

Figure 1. Average weight (a) and total soluble solid (b) of longan arils soaked for: (I) 3 days in sucrose solution (♦); (II) 2 days in sucrose solution followed by 2 days in glucose syrup solution (▲); (III) 1 day in sucrose solution followed by 3 days in glucose syrup solution (■); and (IV) 4 days in glucose syrup solution (●)
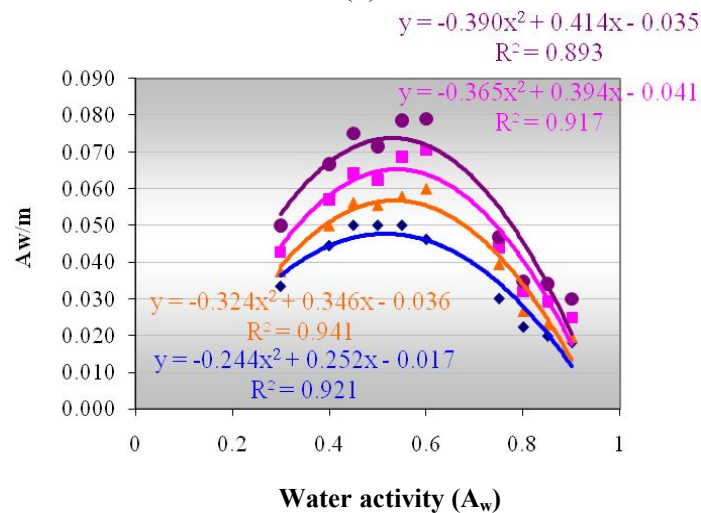
Water Sorption Isotherm

To create a water sorption isotherm of dried longan arils, the equilibrium moisture content and the water activity of longan arils placed over saturated salt solutions were plotted as shown in Figure 2a. It is a Flory-Huggins (type III) isotherm because sugars in dried longan arils have a fairly low adsorption of water until the water activity becomes sufficient for solubilisation when adsorption increases [32-33]. This type-III isotherm was also reported in a previous study with fresh and osmotically dehydrated apples, which showed that at a constant water activity the equilibrium moisture content decreased with increasing sugar content of the products [34]. The equilibrium moisture content of dried and osmotically dehydrated longan arils at each water activity value in this study was also lower than that of dried longan arils without osmotic dehydration reported by Janjai *et al.* [8].

(a)

(b)

(c)

Figure 2. Water sorption isotherms (a), BET model (b), and GAB model (c) of longan arils soaked for: (I) 3 days in sucrose solution (♦); (II) 2 days in sucrose solution followed by 2 days in glucose syrup solution (▲); (III) 1 day in sucrose solution followed by 3 days in glucose syrup solution (■); and (IV) 4 days in glucose syrup solution (●), before drying

When the water sorption isotherms of dried longan arils were fitted by models of BET and GAB, they were found to be better fitted to the GAB model (R^2 = 0.893 – 0.941) than the BET model (R^2 = 0.799-0.856) (Figures 2b and 2c). These findings agree with previous work [34-35]. The GAB model has become very popular because the activity range covered by this model is much wider (A_w = 0.05-0.80 or 0.90) than that by the BET model (A_w = 0.05-0.30), and it has been recommended by the European Project Group COST 90 on Physical Properties of Food as the fundamental equation of water sorption by food materials [36].

Since water adsorption is one of the main factors that affect the physical state and stability of products [32], its prediction can be useful for estimating the shelf life of the products. In this present work, fungal growth could be observed when the moisture content of dried longan arils was higher than 20% and this value was used as the end of acceptance point of product in the shelf-life study.

Sensory Evaluation

Dried longan arils (II and III) soaked in sucrose and glucose syrup solution which had the chewy texture were selected for sensory evaluation. Longan type II was preferred to type III by 120 consumers as shown in Table 2. This result may be correlated with sweet taste, less sticky texture and appearance of longan type II, as apparent from the comparative values of total soluble solid and shear force (Figure 1 and Table 1). This product was therefore used for the shelf-life study.

Table 2. Sensory evaluation of dried chewy longan arils by 120 consumers with 9 point-hedonic scales

	Longan arils (II)	Longan arils (III)
Appearance	6.23±1.08 [a]	5.83±1.44 [b]
Flavour	6.68±1.28 [a]	5.84±1.45 [b]
Texture	6.59±1.44 [a]	5.45±1.62 [b]
Overall preference	6.71±1.19 [a]	5.86±1.38 [b]

Note: Means with different letters in the same row are significantly different (p<0.05).

Shelf-life Study and Antioxidant Capacity

The water activity, moisture content and antioxidant capacity of longan type II were determined during 12 months of storage (Table 3). The fluctuation of water activity and moisture content was found to be due to the change of relative humidity of air [37]. The product adsorbed or desorbed moisture when the relative humidity of air was higher or lower than the water activity of the product. When the values of water activity and moisture content were plotted on the water sorption isotherm, a linear regression, y = 91.64x – 45.57, from the minimum moisture content during storage to moisture content at maximum relative humidity of air during storage (A_w = 0.800) was created as shown in Figure 3. The slope of linear regression in Figure 3 was used as the value of 'α' in the equation for predicting shelf life. To predict the shelf life of product, the transmission rate, K, during storage was first calculated from the equation for predicting shelf life and then its value was used for determining the product's shelf life from the same equation as elaborated below.

From equation ln [(m_e - m_0)/(m_e - m_c) = [K / α] t , when m_e = 30% (equilibrium moisture content at highest relative humidity of air during storage, A_w = 0.800), m_0 = 9.36% (minimum moisture content during storage), m_c = 16.61% (maximum moisture content during storage), α = 91.64 g water/ g solid (slope of linear regression, y = 91.64x - 45.57, in Figure 3), and t = 12

(months of storage), a moisture transmission rate (K) of 3.305 g water/ g solid.month was obtained. This K value, with the end of acceptance point of product observed from water sorption isotherm section (20% moisture content), m_e = 30%, m_0 = 9.36% and α = 91.64, was used to predict the shelf life of product (t), which turns out to be about 20 months.

Table 3. Water activity, moisture content and antioxidant capacity of dried chewy longan arils (type II)

Storage time (month)	Relative humidity* (%)	Water activity	Moisture content (% dry basis)	Antioxidant capacity (mg vitamin C equivalent/ g dry sample)		
				FRAP [ns]	ABTS [ns]	DPPH [ns]
0		0.658 ± 0.016 [ab]	13.12 ± 1.42 [cd]	0.86 ± 0.12	0.62 ± 0.05	0.97 ± 0.10
1	70	0.666 ± 0.026 [ab]	16.61 ± 1.76 [b]	0.76 ± 0.10	0.59 ± 0.03	0.92 ± 0.08
2	64	0.657 ± 0.033 [ab]	15.92 ± 1.07 [bc]	0.72 ± 0.07	0.53 ± 0.08	0.83 ± 0.14
3	47	0.589 ± 0.071 [b]	12.62 ± 1.99 [cd]	0.77 ± 0.09	0.56 ± 0.12	0.88 ± 0.21
4	47	0.617 ± 0.062 [ab]	12.46 ± 1.43 [cd]	0.83 ± 0.06	0.58 ± 0.05	0.74 ± 0.08
5	39	0.618 ± 0.044 [ab]	10.52 ± 0.90 [de]	0.79 ± 0.09	0.62 ± 0.01	0.65 ± 0.21
6	53	0.591 ± 0.034 [b]	9.36 ± 1.01 [e]	0.81 ± 0.11	0.56 ± 0.04	0.74 ± 0.16
7	63	0.620 ± 0.026 [ab]	10.06 ± 0.89 [de]	0.84 ± 0.12	0.61 ± 0.06	0.92 ± 0.08
8	70	0.649 ± 0.019 [ab]	10.88 ± 1.16 [de]	0.72 ± 0.01	0.58 ± 0.02	0.90 ± 0.10
9	80	0.692 ± 0.012 [a]	13.36 ± 1.96 [a]	0.80 ± 0.14	0.61 ± 0.02	1.06 ± 0.21
10	75	0.689 ± 0.009 [a]	13.04 ± 1.32 [b]	0.70 ± 0.01	0.61 ± 0.06	0.97 ± 0.02
11	74	0.668 ± 0.010 [ab]	12.47 ± 1.31 [cd]	0.82 ± 0.01	0.54 ± 0.12	0.76 ± 0.29
12	68	0.654 ± 0.017 [ab]	11.09 ± 1.47 [de]	0.64 ± 0.12	0.55 ± 0.02	1.04 ± 0.10

Note: Means with different letters in the same column are significantly different (p<0.05).
[ns] Means in the same column are not significantly different (p>0.05).
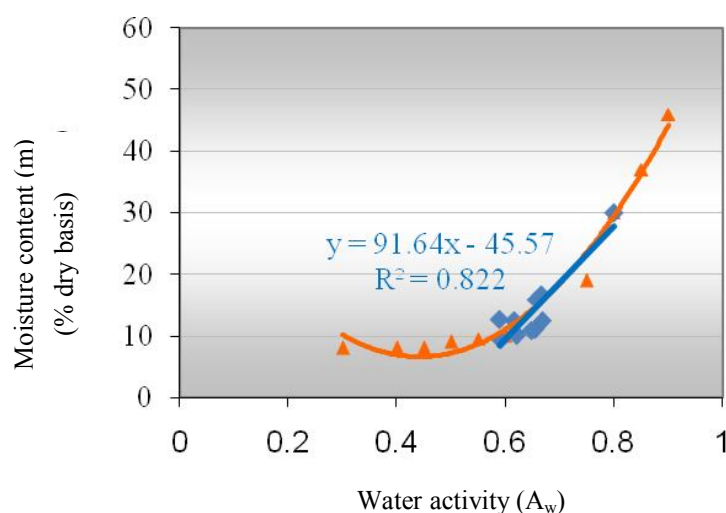* Data from Titi Tudorancea Bulletin [37]

Figure 3. Water sorption isotherm (▲) and linear regression of water activity and moisture content during storage of dried chewy longan arils type II (♦)

As seen in Table 3, the antioxidant capacity did not significantly change (p>0.05) during 12 months of storage. This antioxidant capacity has been shown to be the result of compounds present

in longan fruits such as phenolic/flavonoid glycosides and ellagitannins [38], vitamin C [39] and browning pigments formed during heat treatment [26, 40-41]. In addeition, antioxidant compounds in fresh longan may decompose during drying and storage whilst browning pigments are formed. From Table 3, FRAP and DPPH values, which have been found highly correlated with browning pigment formation, are obviously higher than ABTS values, which are highly correlated with phenolic compounds in our previous work [26]. Browning pigment formation, therefore, was likely to be the main factor which made for a more or less constant antioxidant capacity in this study.

From Table 3, the minimum value of antioxidant capacity of dried chewy longan arils is 0.53 ± 0.08 mg vitamin C equivalent/ g dry sample. Recommended intake or daily value of vitamin C for adults or children from four years of age, based on a caloric intake of 2,000 calories, is 60 mg [42], and a product which contains at least 20% of the daily value of vitamin C can be claimed as 'high in antioxidant vitamin C', although this claim can be used only for antioxidant vitamins in products which include vitamin C, vitamin E and beta-carotene [43]. However, an analysis of antioxidant capacity as mg of vitamin C equivalent can be used to show the antioxidant potential of these dried chewy longan arils.

CONCLUSIONS

Longan preservation by osmotic dehydration and hot air drying, resulting in longan arils with a chewy texture suitable for snacks or similar products, seems to be an alternative method which may be useful for local manufacturers when longan is readily available and low-priced in the peak season.

ACKNOWLEDGEMENTS

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