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Drying Studies of Tropical Fruits Cultivated in Malaysia: A Review

C.L. Hii, S.P. Ong and C.L. Law
Department of Chemical and Environmental Engineering, University of Nottingham,
Malaysia Campus, 43500 Jalan Broga, Semenyih, Selangor Darul Ehsan, Malaysia

Abstract: This study aims to compile and review the drying studies that were carried out for tropical fruits cultivated in Malaysian. The total cultivated land area for fruits is recorded at 298,429 ha with production at 1,767,800 metric tonne per year in Malaysia. Per capita consumption of fruit in Malaysia is estimated at 48.82 kg for year 2010. Over production of fruits during harvesting season often leads to food spoilage and wastage. Therefore, by preserving these fruits in dried forms the range of products can be further diversified and its market share expanded. The potential of rare fruits should be further envisaged in future drying research. However, such fruits are not planted and consumed widely and remain low profile in Malaysia. These fruits contain unique medicinal value which is beneficial to human health.

Key words: Dehydration, dried product, health benefits, nutrients, quality

INTRODUCTION

Industry outlook: Malaysia (2°30' N, 112°30' E) is a tropical country where various fruits are cultivated. Some of these fruits are native to this country while others are introduced elsewhere due to its high commercial potential. Various fruits are cultivated in Malaysia as shown in Table 1. The cultivated area for local fruit planting is currently recorded at 298,429 ha with production at 1,767,800 metric tonne per year (http://www.moa.gov.my/web/guest/statistik-pertanian). The per capita consumption of fruit in Malaysia is estimated at 48.82 kg for year 2010 (Hassan, 2007).

Eleven local fruits namely the starfruit, dragon fruit, pineapple, rambutan, durian, pomelo, papaya, mango, mangosteen, jack fruit and guava have been identified as the new export earners for Malaysia to date. These fruits, which are known as the exotic fruits in the West, are fast gaining popularity worldwide with an estimated market worth of over USD10 billion annually (http://biz.thestar.com.my/ news/ story.asp?file=/ 2010/ 8/3/business/6781157). Europe is currently the main tropical fruit importer making up to almost 50% of the market share. The Food and Agriculture Organisation of the United Nations (FAO) has also categorized mango, pineapple, papaya and avocado as the fourth world major tropical fruits. Malaysia is already producing some of these major tropical fruits in this list. Figure 1 shows some examples of fruits currently cultivated in Malaysia.

Table 1: Typical tropical fruits planted in Malaysia

Fruit name	Planted area (Ha)	Production (metric tonne)	Value (RM'Million)
Star fruit	1,276	11,820	31.6
Papaya	3,403	49,760	68.4
Cempedak	11,158	56,631	130.2
Ciku	1,115	6,050	18.1
Dokong	16,130	32,420	97.3
Duku	5,775	27,680	65.0
Durian	104,655	300,470	1392
Guava	1,525	19,650	50.6
Langsat	6,925	25,660	69.3
Mango	9,760	25,510	83.5
Mangosteen	7,685	29,520	79.7
Jackfruit	3,962	27,459	63.2
Banana	29,790	294,530	476
Rambutan	25,460	82,740	171
Salak	1,190	4,530	15.8
Watermelon	11,750	238,050	309

*Source: Department of Agriculture, 2010 statistics

Fruit drying: In general, fruits can be preserved easily and drying is known as one of the oldest preservation techniques known to mankind. Tropical fruits generally have short shelf life of few days to a week depending on the maturity and storage conditions. During peak harvesting period spoilage of fruits occurs due to over fruiting which results in excessive production.

Fruits can normally be dehydrated by various methods and processed into various forms of products. Hot air drying is the most common method used but other methods such as freeze drying, heat pump drying, vacuum drying and microwave drying can be used as an alternative drying option. The finished products can be

Corresponding Author: Hii Ching Lik, Department of Chemical and Environmental Engineering, University of Nottingham, Malaysia Campus, 43500 Jalan Broga, Semenyih, Selangor Darul Ehsan, Malaysia
Tel: +6(03) 89248000 Fax: +6(03) 89248017

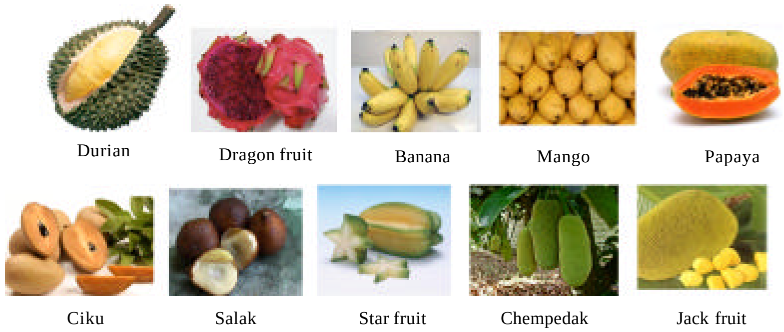

Fig. 1: Examples of tropical fruits cultivated in Malaysia

Table 2: Drying studies of Malaysian fruits

Type of fruit	References
Durian	Radziah *et al.* (2007a), Chin *et al.* (2010)
Ciku	Chong *et al.* (2009), Chong and Law (2011)
Chempedak	Chong *et al.* (2008a), Chong and Law (2008b)
Dragon fruit	Nordin *et al.* (2008), Taufiq (2009)
Jackfruit	Radziah *et al.* (2007b), Pua *et al.* (2010)
Salak	Ong and Law (2011)
Banana	Fernando *et al.* (2011), Fadhel *et al.* (2011)
Mango	Bachtiar and Sarmidi (1997)
Star fruit	Vignesvaran and Hii (2011)
Papaya	Zaki *et al.* (2007)

obtained in several forms such as chips, cubes, bars, powder, foam mat and leather. Fruits can also be pre-treated and subject to osmotic dehydration prior to thermal drying (Law and Mujumdar, 2008). During drying, nutrients degrade in fruits and careful selection of drying parameters is thus required to optimize the retention of these compounds. Texture, colour, flavour and microbiological attributes are equally important in the processing of fruit products (Hii *et al*., 2008).

Drying studies: Research and development works have been carried out by local research agencies and universities to improve planting, harvesting and processing of Malaysian fruits. Fruits can be consumed either in fresh or processed form i.e., dried, candied, canned, fried and pickled. This study aims to compile and review some selected drying studies that had been carried out by researchers for Malaysian fruits (Table 2) and to further explore the potential of drying other fruits that are planted locally.

DRYING OF MALAYSIAN FRUITS

Durian: Durian (Durio zibethinus) is the most popular and widely consumed fruit in Malaysia. This fruit is also widely planted in South East Asian countries and is known as the king of fruits. Typically, durian has a strong odour which could be unpleasant to some consumers

Table 3: Drying conditions used for durian

Studies	Drying methods	Analyses
Radziah *et al.* (2007a)	Air drying (35-90°C)	Drying kinetics and aesthetic quality
Chin *et al.* (2010)	Freeze drying (Stepwise for every 120 min: -20, -10, 0, 10, 20 and 30°C)	Volatile compounds

especially those not from Asian countries. The fruit has a thorn-covered husk and is usually consumed fresh. The fruit pulp is the only edible portion from the fruit. Traditionally, the fruit pulps can be processed into fermented durian (tempoyak) or durian cake (lempok). Drying studies have been carried out using heated air (Radziah *et al*., 2007a), spray and freeze drying (Man *et al*., 1999; Chin *et al*., 2010). Table 3 shows the drying conditions used in their studies.

Man *et al.* (1999) reported that freeze drying was better than spray drying and gave higher aroma scores, better colour (more yellowish, higher b value) and appearance. The better aroma score was due to better retention of the flavour volatiles during freeze drying. However, the bulk density was higher as compared to freeze drying due to the smaller particle size which contributed to tighter packing of the cell structures. Glucose syrup solid was found to be the most suitable encapsulating agent in spray drying.

Chin *et al.* (2010) reported the presence of 30 volatiles that were extracted from the fresh durian pulps. However, not all compounds remained present in the freeze and sprayed dried durian. Four ester volatiles (ethyl thioacetate, propyl butanoate, propyl 2-methylbutanoate and propyl 3-methylbutanoate) were not detected in the freeze dried sample while 10 more volatile compounds were not detected in sprayed dried samples. Eight new volatiles were even developed in the sprayed dried sample (5 aldehydes, 1 ketone, 1 furan and 1 pyrole). Freeze drying caused reduction of major aroma volatiles ranged from 70.5-97.2% as compared to spray drying at 98-99%.

Table 4: Drying conditions used for ciku

Studies	Drying methods	Analyses
Chong *et al*. (2009)	Sun drying (T = 24-32°C and RH = 56-87%)	Drying kinetics, texture, colour and total polyphenols
Chong and Law (2011)	Intermittent drying (High: T = 52-54°C, RH = 7-11%, Low: T = 9-11°C, RH = 65-74%, Air velocity 1.4 m sec^{-1})	Drying kinetics and texture

The unusual high loss of volatiles in freeze drying could have happened during sample preparation prior to drying. Radziah *et al*. (2007a) reported drying at temperatures lower than 50°C produced dried product with better aesthetic quality. Drying at higher temperatures (80-90°C) markedly decolourised and shrivelled the sample.

Ciku: Ciku (*Manilkara zapota*) or commonly known as sapodilla is not native to Asian countries but is believed to be originated from Mexico, Central America and the Caribbean. The fruit is quite similar to a smooth skin potato and inside its fresh looks pale yellow to brown colour. This fruit is consumed among Malaysian but not as popular as other fruits such as banana, mango and durian. Drying conditions used for ciku are presented in Table 4.

Leong and Shui (2002) reported that ciku has the highest antioxidant capacity among tropical fruits. Chong *et al*. (2009) and Chong and Law (2011) reported drying studies of ciku using sun and intermittent drying, respectively.

Three drying periods (initial transient, constant and falling rate periods) were observed during sun drying. In terms of product quality, browning caused a decrease in L* and b* values but an increase in a* value which resulted in great colour change. This could be due to the prolong drying period which resulted in longer exposure time. For the same reason, retention of polyphenols was quite low (28%) as compared to fresh fruit. Texture analyses showed significant difference between the hardness and chewiness of dried ciku. Springiness of ciku was slightly lower and about 85% increase in cohesiveness was observed.

Studies using intermittent and dehumidified air drying were found able to reduce the hardness and chewiness of dried ciku. Critical moisture content that contribute to case hardening was identified at 0.15 g moisture/g dry matter. Drying profile that used 5 h cold air-19 h hot air intermittently was found optimum for ciku drying (Chong and Law, 2011).

Chempedak: Chempedak (*Artocarpus integer*) is native to South East Asia and quite resemble to the appearance of jackfruit (Fig. 2). The fruit is oblong in shape and contains

Table 5: Drying conditions used for chempedak

Studies	Drying methods	Analyses
Chong *et al*. (2008a)	Sun drying (T = 29-32°C and RH = 57-65%)	Drying kinetics, texture and colour
Chong *et al*. (2008b)	Hot air drying (T = 50-70°C, RH = 4-13%, V = 0.03 m sec^{-1})	Drying kinetics, texture and colour

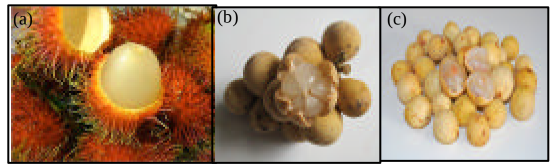

Fig. 2(a-c): (a) Rambutan, (b) dokong and (c) langsat

pulp coated seed which is edible. The pulp is usually consumed fresh while the seed need to be boiled or cooked in order to be consumable. The drying kinetics and product quality of chempedak fruit were reported by Chong *et al*. (2008a, b). Table 5 shows the experimental conditions used in their studies.

Fluctuating drying rates were reported during the sun drying process. However, both initial transient and falling periods were clearly observed during drying. Texture analyses showed that both hardness and chewiness were significantly higher than the fresh sample. The increase in hardness could be due to depolymerisation of cell wall constituents such as pectin, after exposure to heat during drying. The sun dried chempedak was observed darker due to enzymatic browning and this resulted in significant total colour change. Similar sample was subject to hot air drying and results showed occurrence of the initial transient and mostly falling rate period throughout drying. The logarithmic model was found able to predict the moisture reduction process. Similar observations were reported in sun drying in terms of colour and texture.

Dragon fruit: Dragon fruit or pitaya is a non-seasoning fruit native to Mexico, Central and South America. The fruit has red-skinned with white flesh, which is the type consumed widely but it can also be red-skinned with red flesh or yellow-skinned with white flesh. The flesh can be processed into juice and wine. This fruit has recently become popular among Malaysian and even to tourists.

Drying studies were carried out to dry dragon fruit using microwave (Nordin *et al*., 2008) and spray drying (Taufik, 2009). Table 6 shows the drying conditions used in these studies. Nordin *et al*. (2008) reported that power density of 19.02 W g^{-1} is not suitable as the sample would char at this power level. Tang and

Table 6: Drying conditions used for dragon fruit

Studies	Drying methods	Analyses
Nordin *et al.* (2008)	Microwave drying (power density 19.02, 12.12, 10.86, 9.37 and 7.69 W g^{-1})	Drying kinetics, colour, shrinkage, hardness and structure
Dailami (2009)	Spray drying (T = 150-190°C, maltodextrin 5-25% for every 200 mL juice)	Solubility, moisture content, dissolubility rate and Vitamin C

Cenkowski model was found able to fit the kinetics data during drying. The time taken for significant colour changes to occur was found proportional to the power output. The colour change also followed closely to the beginning of the falling rate period. In terms of shrinkage, the samples shrank by more than 70% with increasing power density. However, there was no increase in hardness observed. The internal structure of the sample collapsed completely at the end of drying.

Taufik (2009) reported optimum condition of 180°C by using 20% maltodextrin for the production of dragon fruit powder. At this drying condition the retention of vitamin C was the highest among all drying conditions. Solubility was determined at 90% in all the samples while sample that was obtained at 180°C showed dissolubility rate of less than 40 sec.

Jackfruit: Jackfruit (*Artocarpus heterophyllus*) is native to South East Asia and is commonly known as nangka locally. It is also the national fruit of Bangladesh. The fruit can grow to as big as 90 cm long and weighs almost 36 kg. The edible part of the fruit is the golden yellowish flesh and it can be also eaten unripe by cooking both the flesh and the seeds. Drying studies have been reported by Radziah *et al.* (2007b) and Pua *et al.* (2010) by using heated air and drum drying, respectively.

Radziah *et al.* (2007b) reported limited degree of shrinkage and browning at drying temperature of 35°C. Drying at 40-45°C showed pronounced shrinkage and decolouration. The lower temperature also produced dried jackfruit with higher degree of redness. Studies by Pua *et al.* (2010) indicated that optimum drum condition for producing the jackfruit powder was at 336 kPa steam and 1.2 rpm rotational speed. This led to desirable quality attributes with the smaller colour change, lower moisture and water activity and higher scores in sensory evaluation. Response surface analyses indicated that both the drum speed and steam pressure affected the drum temperature significantly during drying.

Banana: Banana, or locally known as pisang, is widely planted and consumed in Malaysia. It is also one of the main traded fruits globally. The fruit is native to many south East Asian countries and it can be eaten fresh, fried, cooked and in some countries the banana heart (flower) is also consumed either in raw or cooked form. Drying conditions used for banana are presented in Table 8.

Table 7: Drying conditions used for jackfruit

Studies	Drying methods	Analyses
Radziah *et al.* (2007b)	Air drying (T = 35-90°C)	Drying kinetics and aesthetic quality
Pua *et al.* (2010)	Drum drying (Speed = 1-3 rpm, steam pressure = 300-440 kPa)	Colour, water activity, solubility index and sensory evaluation

Table 8: Drying conditions used for banana

Studies	Drying methods	Analyses
Fernando *et al.* (2011)	Infrared drying (Infrared power 0-100 W, T = 85-95°C, V = 2 m sec^{-1})	Drying kinetics
Fadhel *et al.* (2011)	Indirect solar drying	Drying kinetics

Drying studies (Table 7) were carried out by Fadhel *et al.* (2011) and Fernando *et al.* (2011) by using solar drying and infrared drying, respectively. Both studies reported fitting of various empirical models to predict the drying process. The effective diffusivity values were found increase with temperature and infrared power due to greater adsorption of energy on the product surface. Diffusivity values were reported ranging from 1.85×10-9 to 7.02×10-9 m^2 sec^{-1}.

Fadhel *et al.* (2011) developed an indirect solar dryer which consisted of a heat collector and a drying cabinet. The drying cabinet consisted of three trays and it was observed that the top tray dried faster as compared to the rest since this section was exposed to the heated air initially. The Wang and Sing model was found able to predict the experimental moisture reduction process.

Salak: Salak (*Salacca glabrescens*) is a native palm fruit in Indonesia and Malaysia. This fruit is commonly known as snake fruit by the locals as the fruit skin resembles the reptile skin. The fruit consists of three cloves in off white colour with a thin layer of transculent cuticular membrane on the surface.

Hot air and heat pump drying of salak fruit was carried out by Ong and Law (2011) at 40-90 and 26- 37°C, respectively. Studies showed that reduction of total ascorbic acid was due to combination of thermal and enzymatic degradation. Degradation of phenolic compounds was mostly due to thermal effects. Drying at temperature below 37°C produced final products with higher phenolic content than hot air drying (T>40°C). It was suggested to implement intermittent drying according to the different stage of drying to improve product quality.

Mango: Mango (*Mangifera indica*) is planted widely in many tropical countries and has a long history of cultivation i.e., it has been cultivated in India for over

4000 years. This fruit is very popular among Malaysians and mango tree can be seen planted in the garden of many Malaysian houses.

Mango puree was encapsulated with gum Arabic and dried using a spray dryer (Bachtiar and Sarmidi, 1997). Drying was carried out using inlet temperatures of 160-220°C and outlet temperatures of 79-110°C, respectively. Optimum condition was found at flowrate of 900 mL h^{-1} with inlet and outlet temperature at 200 and 134°C, respectively. The powder was able to retain its nutritional value, colour and aroma at this setting. However, in a pilot scale dryer different optimum condition was determined at 1200 mL h^{-1}, inlet temperature of 160°C and outlet temperature of 96°C. This could be due to several scale-up factors i.e., heat transfer that were not considered during the execution of the laboratory works.

Starfruit: Starfruit (*Averrhoa carambola*) is believed to be originated from Indochina, Malaysia and Indonesia. Malaysia is one of the biggest exporters of start fruit in the world (Mokji and Abu Bakar, 2007). The fruit when cut across the flesh resembles the shape of the star with five edges. The whole fruit is edible including the waxy skin and it is also a very good source of antioxidants (Shui and Leong, 2004).

Solar dryer was developed and tested with thermal heat storage by Vignesvaran and Hii (2011). The thermal heat storage system was constructed from river stone such that heat can be absorbed and released by the stone during day and night time, respectively. The thermal storage system was able to prolong drying for extra 10 h even during night time. Elasticity was found decreased with moisture content due to hardening. Colour change due to browning was observed typically caused by enzymatic browning.

Papaya: Papaya (*Carica papaya*) is one of the major fruits planted and produced in Malaysia. It is usually consumed fresh but pickled and dried papayas are also commonly found in the local market. Drying studies was carried out by Zaki *et al.* (2007) using microwave-vacuum dryer. Papaya samples were treated at various power levels (110-750 W) and pressure (200-700 mmHg). However, product quality of the dried papaya was not reported. Drying rates were found increased with microwave power intensity but system pressure played no significant effect in moisture reduction. Only falling rate period was observed throughout drying.

POTENTIAL OF OTHER FRUITS AND FUTURE WORKS

Based on the list in Table 1, there are still plenty of fruits that can be processed into dried fruit with high commercial potential. Fruits such as langsat, dokong and rambutan are often over produced during the harvesting season (Fig. 2). Farmers are not benefited from the over production due to the excessive supply which causes a sharp drop in the prices of these fruits. The flesh from these fruits has almost the same texture as longan, which is currently available in the market in dried form and is selling at a much higher price.

Besides commercial fruits, some rare fruits can also be found in Malaysia and reported to have unique medicinal value i.e., high antioxidant activity. These fruits are not planted widely due to lack of interest from estates and plantation. It is usually grown in wild or planted in family owned orchard. Examples of these fruits are such as cerapu, terap, cermai, pulasan, beruas, ceri, jentik-jentik and durian nyekak. It was found that cerapu and jentik-Jentik had the highest antioxidant capacity and the highest ß-carotene content, respectively, among the rare fruits tested (Khoo, 2009). Preservation of these fruits in dried form would enable these fruits to reach a wider segment of the consumers especially those from the urban areas. The dried fruits can also be branded with its high nutritional and antioxidant values which are well accepted by consumers from the Americas and Europe.

CONCLUSION

Various studies have been carried out in the past to process Malaysia fruits into dried form and to increase its market value. Research and development works are constantly carried out by local research agencies and universities to develop new product and to improve the quality of the existing one. The potential of other local fruits should be further envisaged as overproduction would not benefit the farmers in the long run. Rare fruits are another area with great commercial potential as these fruits are known to have medicinal value, such as antioxidant, which is beneficial to human health.

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