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Foam-mat drying of starfruit (*Averrhoa carambola L.*) purée. Stability and air drying characteristics

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Abstract

Foams were prepared from starfruit (*Averrhoa carambola L.*) purée by adding various concentrations of methocel. Overrun and density of the foams from various concentrations of methocel were compared. Relative stability of the foam was determined by comparing amounts of juice separated from foam at 70°C. Drying rates at two drying temperatures (70 and 90°C) were also compared. Quality of the dry and reconstituted powder was evaluated with simple sensory evaluation and Hunterlab instrument. Overrun and stability of foams increased with increasing methocel concentration until maximum value was obtained at a methocel concentration of 0.4% w/w. Falling rate was observed for foam dried at both temperatures. Drying time could be shortened by as much as 30 min when drying temperature was increased from 70 to 90°C. However, obvious colour and flavour changes were observed in the product dried at 90°C. This study has indicated that, under the experimental conditions employed, reasonably good powder characteristics can be obtained.

1. Introduction

The starfruit (*Averrhoa carambola L.*) is grown in large quantities in many parts of the tropics, including Malaysia. Several varieties of the fruits are grown for export and for local consumption. Some of the fruit is, however, wasted at the production points due to non-availability of sufficient storage, transportation and processing facilities. Starfruit utilization, whether in the producer country or for export to premium markets, has always been limited by the perishable nature of the fruit.

In view of the above problems, development of a simple and inexpensive process of fruit preservation is desirable. Canning of the fruit slices in syrup is an attractive option. Some workers have investigated the feasibility of using modified atmosphere packaging to extend the shelf-life of whole fruit for export purposes (Kenny and Hull, 1986; Campbell et al., 1987; Abdul Aziz, 1994). Keeping quality of starfruit juice has been studied by Rusul and Ang (1994). Another possible method is dehydration, which may provide an alternative low cost preservation process.

Air-drying is considered as the simplest and most economical process and is still widely used especially in developing countries. Major problems associated with air-dehydration, however, are the considerable shrinkage caused by cell collapse following the loss of water, the poor rehydration characteristics of the dried product, and the unfavourable changes in colour, texture, flavour and nutritive value caused by drying (Mazza, 1983). Hertzendorf and Moshy (1970) have reviewed the application of foam-mat drying to many heat-sensitive food materials, including fruit juices. Foam-mat drying is a process by which a liquid or semi-liquid is whipped to form a stable foam, and subsequently dehydrated by thermal means. The main advantages of foam-mat drying techniques, when compared to other drying methods such as spray-drying or drum-drying, are lower drying temperatures and shorter drying times. These advantages can be attributed to the larger surface area exposed to the drying air which accelerates the moisture removal process (Brygidyr et al., 1977).

The foam-mat drying process is a relatively simple and inexpensive process. One difficulty that has previously been experienced with this process, however, is the lack of stability of the foam during the heating cycle. If the foam does not remain stable, cellular breakdown occurs causing serious impairment of the

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drying operation. Variables affecting foam formation, density and stability have been reported (Hart et al., 1963) and these include chemical nature of the fruit, soluble solids, pulp fraction, type and concentration of foaming agent, and type and concentration of foam stabilizer. Foaming conditions of various tropical fruits such as pineapple, passion fruit, guava purée, banana fruit, papaya purée and mango purée have been reported (Bates, 1964). However, to the best of the authors's knowledge, no work has been reported on the foaming characteristics of starfruit purée and its drying behaviour. The present paper reports the evaluation of foam-mat drying characteristics: its stability during drying, the drying rate at two dry bulb temperatures and the physical characteristics of the dried products.

2. Materials and methods

Starfruits (*Averrhoa carambola* L., B10 clone) were acquired fresh from the local market or from the farm around Seberang Prai. The fruits selected were free from physical damage and bruises, and ranged from 8 to 10 cm in length. Total soluble solids of the juice was 7.0°Brix and pH was in the range of 3.80–3.95. The fruits were washed in excess water followed by soaking for 1 min in 1% HCl and rinsing with water to remove dirt and pesticide residues.

2.1. Preparation of the starfruit purée and foam

The starfruits were cut with a stainless steel knife to remove the edible portion (which constituted about 91.6% of the whole fruit) and chopped into small pieces. The fruits were then blended in a Moulinex 276 blender at maximum speed for 2 min to obtain a homogeneous purée. The purée was pasteurised at 87°C for 3 min to inhibit microbial and enzyme activity such as pectinase and polygalacturonase. Excess heating of the purée was avoided by cooling the purée immediately in the ice bath after the stipulated pasteurisation time.

Methocel 65 HG (Fluka Biochemika 64670) was used as a foaming agent and contains 27–29% methodyl group. It has a solubility of 2% at 25°C and viscosity of 4000 cp. Methocel was prepared in the form of solution by dissolving an appropriate amount of the dry powder in 20 ml distilled water at 30°C and stirred slowly until a uniform solution was obtained. Methocel solutions were prepared to give a final concentration of 1, 2, 3, 4, and 5% w/w.

Twenty grams of Methocel solution of a certain concentration were mixed with 180 g of the starfruit purée to give a final concentration of Methocel in the mixture at 0.1, 0.2, 0.3, 0.4, and 0.5% w/w. Foaming of the Methocel-purée mixture was done by blending the mixture in a Kenwood Chef (KM 901D model) at maximum speed for 4 min at 30°C.

2.2. Determination of foam density

Foam density was determined using a method described by Labelle (1966). The density of Methocel-purée mixture was determined by weighing 100 ml of the mixture in a 100 ml measuring cylinder. For the foam, 200 ml of the foam was transferred into a 250 ml measuring cylinder and weighed. The foam transferring was carried out very carefully to avoid destroying the foam structure or trapping the air voids while filling the cylinder. The determinations were done in triplicate for each batch of preparation and the average values were reported.

The foam overrun was calculated based on AOAC 16.22D and 16.22 methods (AOAC, 1984) and modified for foam:

$$\text{Overrun} = \frac{\text{Foam density}}{\text{Density of methocel} - \text{puree mixture}} \times 100$$

2.3. Determination of foam stability

Foam syneresis or drainage method was adapated from a method described by Sauter and Montoure (1972). The foam was filled into a conical-shaped plastic wire mesh (10 mesh) which was supported by a thistle funnel and placed on a 250 ml graduated cylinder. The apparatus assembly was put in the mini kiln smoker (used for the drying experiment) at 70°C and air flow-rate of 0.12 ms^{-1}. The liquid juice which separated from the foam due to syneresis was collected in the measuring cylinder. The amount of juice collected after certain time intervals was recorded.

2.4. Evaluation of drying characteristics

The foam was spread on to the tray with a scraper to give a layer not exceeding 5.0 mm thick. A plastic wire mesh (10 mesh, 65×50 cm) was placed on the tray so that the foam was spread on the perforated mat. Based on observations from foam stability experiments (foam syneresis rate), one stabilizer concentration (0.4%) was chosen to study the drying behaviour of the foam. Drying was carried out with a mini kiln smoker at a dry bulb temperature of 70 and 90°C and air flow-rates of 0.12 ms^{-1}. For the measurement of foam temperature during drying, thermocouples were inserted into the foam and the temperature recorded with a temperature recorder (Ellab Copenhagen) at 10 min intervals for a period of 90 min. After a given time interval, the samples (around 5 g) were withdrawn from the drying

chamber and the moisture determined by drying the samples in a vacuum oven at 70°C (48.8 mm Hg for 24 h). The sampling was done in such a manner to minimize error due to position of the tray and variation in drying temperature. The drying experiments at each temperature were repeated four times, each time changing the location of the thermocouples.

2.5. Freeze-dried product

One litre of pasteurised starfruit purée was freeze-dried for comparison purposes in the quality assessment of the foam-mat product. The purée was frozen in a freezer (Rinox model A8MA) to −30°C for 3 h. The sample was then transferred into a freeze-dryer (Unitop) for 24 h at 20 mm Hg pressure. A powder was obtained by grinding the dried material in a Moulinex 276 blender for 3 min and kept in an air-tight bottle.

2.6. Product analyses

Product moisture contents were determined by drying to constant weight at 70°C under vacuum. Colour evaluation was performed on all dehydrated samples using a Hunterlab Model D25 Tristimulus Colorimeter, equipped with a D25 circumferential optical sensor. A white standard tile with reflectance values of $X = 82.51$, $Y = 84.53$, $Z = 101.23$ was used as a reference. A representative sample of the powder was placed in a 6 cm diameter Petri dish to a depth of 1.5 cm. The sample dish was covered to avoid stray light. The Hunter L, a, b scale gives measurement of colour in units of approximate visual uniformity throughout the solid. L measures lightness and varies from 100 for perfect white to zero for black; a measures redness when positive and greenness when negative, and b measures yellowness when positive and blueness when negative. Each value represented a mean value of triplicate determinations on four different samples.

2.7. Experimental design and data analysis

Completely randomized block design with four replications was adopted in this study. Statistical analysis of the data was carried out with MINITAB Release 8.0 (Minitab Inc) for Macintosh.

3. Results and discussion

3.1. Foam density and overrun

Analysis of variance showed that the source of starfruit had no significant effect on the foam overrun as compared to the effect of methocel (at 5% level of significance). Fig. 1 shows the effect of methocel on the foam overrun. As the concentration of methocel in the purée increased, the foam overrrun also increased significantly ($p < 0.05$). Higher overrun indicates that more air was trapped in the foam and this gave rise to lower foam density. This can be seen more clearly by examining the changes in the density which show that the foam density decreased with increasing methocel concentration.

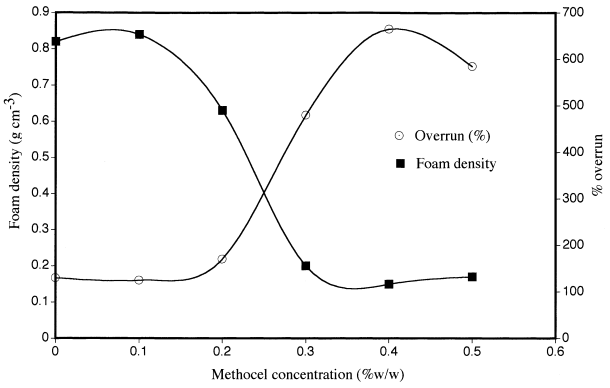

Fig. 1. Foam density and overrun as a function of methocel concentrations.

The foam overrun increased drastically at 0.3% w/w methocel concentration (Fig. 1). This indicates that at least 0.3% w/w of methocel was required to reduce the surface tension and interfacial tension to a level sufficiently low to form the interfacial film that exceeds the critical thickness. Methocel can reduce the surface tension and interfacial tension in an aqueous system in the range of 41–55 dyne cm^{-1} and 18–28 dyne cm^{-1}, respectively (Greminger and Krumel, 1980). In addition, methocel aids in the formation of strong film and stabilises the interfacial film. Apparently at lower concentration of methocel, the air bubbles were not stable because the critical thickness required for interfacial film could not be formed.

As the concentration of methocel was increased, the overrun also increased until a maximum value was obtained at a methocel concentration of 0.4% w/w. At this concentration, an overrun value of 653.2% and foam density of 0.153 g cm^{-3} was obtained. However, increasing the methocel concentration further beyond this point seems to produce the opposite effect; i.e. the overrun decreases. This phenomenon has not been reported before in foaming studies using methocel as the foaming agent. It has been suggested (Bikerman, 1973) that high viscosity liquid would prevent the trapping of air during whipping or mechanical mixing. Increasing methocel concentration above 0.4% w/w would also increase the viscosity of the mixture, possibly exceeding the limiting viscosity at which maximum volume of air can be incorporated; this results in reduction of the foam overrun.

3.2. Foam stability

Fig. 2 illustrates the relationship between the foam syneresis (expressed as volume of juice collected, ml) as a function of time and Fig. 3 shows the syneresis rate as a function of different concentrations of methocel. Syneresis rate in this context reflects the water holding capacity of the foam. It can be seen that there was a direct relationship between foam density and the extent of syneresis. In other words, foams with higher concentration of methocel (lower density) exhibited less syneresis as compared to higher density foams (lower concentration of methocel). This observation is in marked contrast to the finding of Brygidyr et al. (1977) for tomato purée and Labelle (1966) for orange juice; they reported that foams with more additives collapse faster. This conflicting observation may be attributed to the types of foaming agents or stabilizer used; Labelle (1966) used glyceryl monostearate as a foaming agent and methocel as a stabilizer and Brygidyr et al. (1977) used a mixture of mono- and diglyceride. In addition,

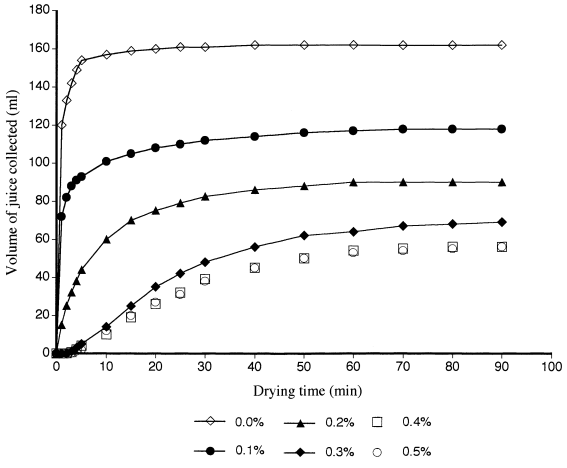

Fig. 2. Syneresis of starfruit foam at different methocel concentrations during drying at 70°C.

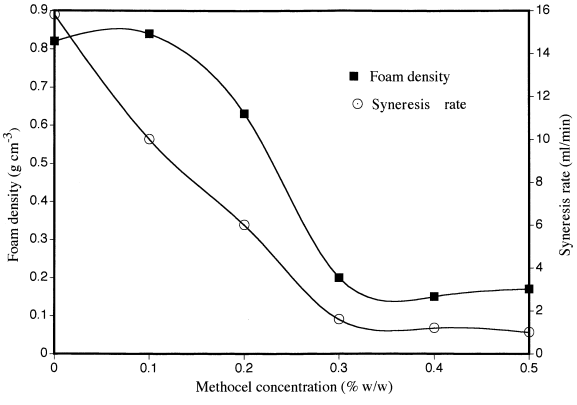

Fig. 3. Foam density and foam syneresis rate as a function of methocel concentrations.

the nature of the raw material (i.e. chemical compositions) may affect the stability of the foam. Cooke et al. (1976) reported that, for mango purée, increasing the additive concentration resulted in reduced foam density and gave a lower loading of foam per surface area of tray, which agrees with our observation. It should be noted that foam syneresis is undesirable in foam-mat drying since accumulation of the liquid at the conveying surface leads to more difficult removal of the dried product from the tray of the belt (Labelle, 1966).

In foam-mat drying, foam stability is very critical because the foam should be able to retain its open structure throughout the drying process in order to increase the total surface area and capillary effect during drying (Hart et al., 1963). In addition, the foam should be 'stiff' enough to prevent it from flowing through the wire mesh support during drying. The open foam structure is desirable for rapid drying and ease of removing the dried material from the tray. If foams break or drain excessively, drying time is increased, reducing product quality. On the other hand, excessively stable foams retain too many gas inclusions in the dry state. Upon resconstitution, these produce suds and opacity, and reduce apparent colour intensity (Hart et al., 1963).

All foams, however, would eventually collapse (Bikerman, 1973). According to DeVries (1958), foam stability is influenced by the thickness of the interface, foam size distribution, interface permeability and surface tension. During drying, foam syneresis and/or foam collapse may occur. Syneresis would result in the separation of the juice (liquid phase) from the interface layer, and result in thinning of the interface which eventually leads to foam collapsing. Foam collapsing during aging is also due to gravity acting on the foam and the increase in foam size because small foams combine or merge together (DeVries, 1958; Labelle, 1966).

In Fig. 2, it can be seen that foam syneresis occurred at all concentrations of methocel but to different extents and at different rates. The rate of syneresis was rapid at the beginning of the drying period (the first 10 min) and declined or reached a plateau when drying was extended further. Evidently, foam without methocel addition exhibited the highest degree of juice separation; as the concentration of methocel increased the rate of foam syneresis decreased. This observation suggests that, at low concentration of methocel, the interface layer is very thin and can collapse easily. The effect caused by increasing the concentration of methocel was perhaps by increasing the viscosity of the foam. In this context, DeVries (1958) and Prin (1988) reported that foam is more stable at high viscosity and this would protect the interfacial wall from breaking easily. There is, however, a limiting value of viscosity which can be used in this application. According to Bikerman (1973), a high viscosity liquid would prevent the trapping of air during whipping or mechanical mixing. Thus, as seen is Fig. 1,

the foam overrun reached a maximum at approximately 0.4% methocel concentration.

As mentioned earlier, methocel aids in the formation of a strong film and stabilises the interfacial film. In addition, the stabilisation effect of methocel may also be attributed to the reversible thermogelation properties of methocel. Starting from room temperature (30°C), the viscosity of methocel solution will decrease when heated. When the temperature reaches 50°C, the viscosity increases drastically (Greminger and Krumel, 1980; Grover, 1986). This phenomenon perhaps explains how methocel plays its role in stabilizing the foam during drying. For the same reason, thermogelation properties of methocel are being used to advantage in extruded food products such as seafood and potatoes to reduce oil pick-up during deep-fat frying (Zecher and Van Coillie, 1992).

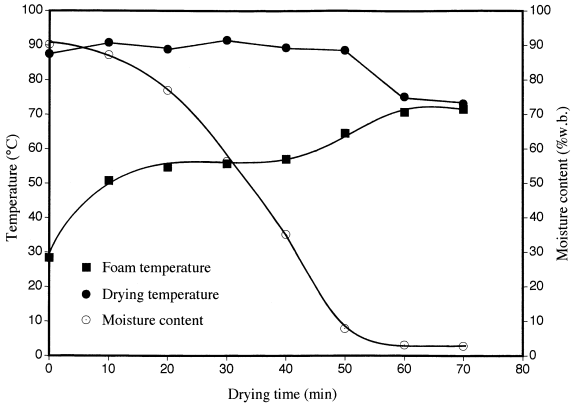

Fig. 5. Drying profile of starfruit foam (0.4% w/w methocel) at dry bulb temperature of 90°C.

3.3. Drying characteristics of the foam

The temperature and moisture data from four separate runs were averaged to obtain the curves shown in Figs. 4 and 5. Fig. 4 illustrates the changes in moisture content, foam temperature and dry bulb temperature during the drying process at 90°C. It is evident that the foam temperature increased from its initial temperature to around 42°C in the first 10 min. During this period, the starfruit aroma can be detected in the air leaving the dryer. This indicates that, during drying, some volatile constituents will inevitably be lost and this results in reduction of flavour intensity. After 10 min, the foam temperature increases at a very slow rate, indicating that the heat energy is being used to evaporate the continuous layer of water on the surface of the foam.

The drying rate profiles (Fig. 6) show the absence of a constant rate period; instead, the entire drying process of the foam occurred in the falling rate period. By examining the drying rate curves closely, it can be seen that the falling rate period can be further divided into two phases, the first (AB) and the second falling rate (BC). Similar observations were reported by Cooke et al. (1976) for foam-mat drying of mango purée. In contrast, Brygidyr et al. (1977) observed both constant rate and falling rate period in foam-mat drying of tomato purée. It thus appears that foam-mat drying profiles are product dependent. This could be attributed to the solid content and the chemical composition of the fruit. A drying characteristic similar to that shown in Fig. 6 was also reported by other workers during dehydration of agricultural materials (Chirife and Cachero, 1970; Vaccarezza et al., 1974; Diamante and Munro, 1991; Magee and Wilkinson, 1992).

As can be seen in Fig. 6, drying rate showed a rapid increase in the first 10 min of drying but started to decline thereafter. This marks the beginning of the falling rate period. At the same time, the foam temperature increased progressively. After 40 min, the foam temperature started to increase swiftly (Figs. 4 and 5). This suggests that the heat energy is now being used to increase the foam temperature because the amount of water available at the surface becomes inadequate to maintain the supply and the rate rapidly declines to a

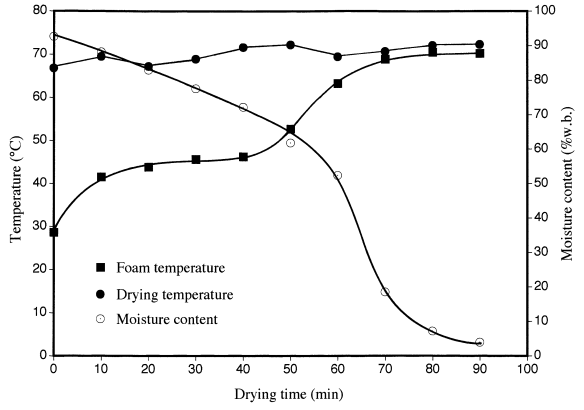

Fig. 4. Drying profile of starfruit foam (0.4% w/w methocel) at dry bulb temperature of 70°C.

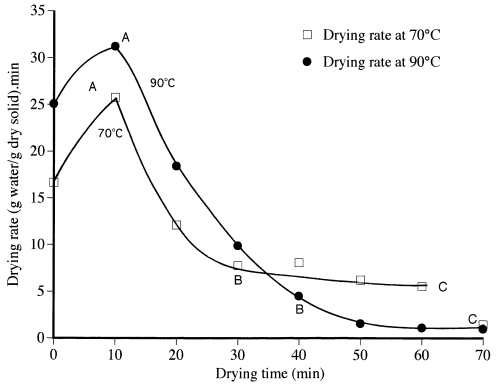

Fig. 6. Drying rate of starfruit foam at different dry bulb temperatures as a function of drying time. The letters A,B, and C denote two phases of falling rate period.

value controlled by diffusion within the foam. In other words, in the later stages of drying, i.e. after the moisture content of the foam has been reduced to around 22% (dry basis) (Fig. 4), the process there onwards tends to be mass-transfer limiting. This is evident by the product temperature approaching that of the heating medium after 60 min of drying. This happened because as the moisture content decreased, the drying rate became so slow that the cooling effect of evaporation was insignificant and the foam eventually assumed the dry bulb temperature of the air. However, the difference between dry bulb temperature and that of the foam became negligible only when about 95% of the initial water content was evaporated.

A liquid layer usually dries at the rate at which water can find its way through the previously dried material at or near the free surface where the water is evaporating (Morgan, 1974). A layer of foam dries much more rapidly than the same amount of unfoamed liquid under the same external conditions. This is because liquid moves more easily through a dry foam structure than through a dense layer of the same material. This is due to capillary action along the interstices; also, evaporation inside bubble spaces followed by gaseous diffusion through the thin dry walls aids rapid drying.

Fig. 5 shows the drying curve at a dry bulb temperature of 90°C. Increasing the temperature would increase the heat energy capacity of the drying air. At the early stages of drying, moisture content is still high; thus by using a high temperature the drying rate can be increased and drying time can be shortened.

As a comparison, drying curves at 70 and 90°C are shown in Fig. 7. It is evident that drying at a higher temperature (90°C) can reduce the drying time. At 90°C, the moisture content of the foam can be reduced down to 5% in just 60 min, i.e. 30 min faster than at 70°C. However, dried foam obtained at 90°C was found to have an inferior flavour. It thus appears that, although drying rate is increased at a high temperature, a compromise has to be made so that the quality of the dried product is not impaired. One alternative is to commence drying at high temperature for a given time and then reduce the temperature to complete the drying process. This is based on observation of drying rate curves depicted in Fig. 6 which show that, at 90°C, drying rate was appreciably faster than drying at 70°C up to about 30 min; after this point drying proceeded at a slower rate. Therefore, by reducing the temperature after 30 min, the undesirable effect of heat can be minimised (e.g. browning and loss of flavour) and some energy saving can be achieved.

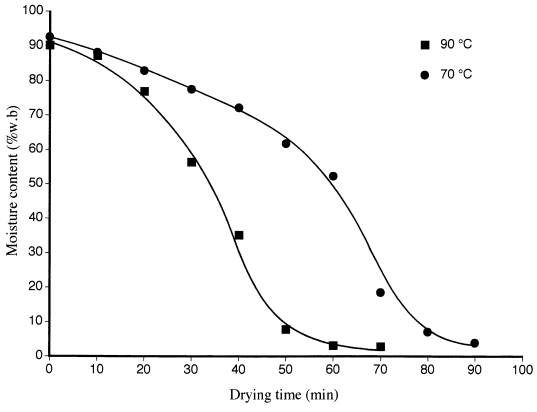

Fig. 7. Comparison of drying profiles for starfruit foam at two dry bulb temperatures.

3.4. Product evaluation

The results of colour evaluation for foam-mat and freeze-dried powder and the rehydrated samples are presented in Tables 1 and 2, respectively. Evidently the freeze-dried powder was brighter (higher L value) than the foam-mat dried powder; however, the difference in lightness is not statistically significant ($p > 0.05$). On the other hand, a value for foam-mat powder dried at 90°C showed appreciable difference from powder dried at 70°C and freeze-dried powder. This means that the colour of foam-mat powder dried at 90°C was closer to red. From visual inspection, it can be seen that the colour of the foam-mat powder was slightly brown. This may be attributed to the non-enzymic browning or caramelisation of the sugars occurring during the drying process. The same colour trends were observed in the rehydrated samples. The browning which inevitably occurred during drying is undesirable because consumers always asscociate it with poor quality. The phenomenon could possibly be minimised by adding sulfite or other anti-browning agents.

The foam-mat dried and freeze-dried products were free flowing, finely divided powders, which were readily rehydratable in cold water. The former was rated quite fairly in simple taste panel assessments (by semi-trained

Table 1
Hunter colour values of foam-mat and freeze-dried starfruit powder

Drying method	Sample no.[a]	Hunter values		
		L	a	b
Foam-mat (at 70°C)	1	78.4	−0.8	27.2
	2	79.1	−1.1	26.5
	3	78.1	−0.2	24.8
	4	77.2	−1.0	25.0
Foam-mat (at 90°C)	1	69.3	2.7	24.8
	2	68.5	5.6	23.5
	3	66.4	4.3	21.3
	4	69.5	3.8	22.2
Freeze drying	1	71.4	0.5	34.1
	2	69.9	−0.7	32.4
	3	71.9	−0.4	31.7
	4	72.9	0.3	34.8

[a] Samples from four separate runs under similar drying conditions.

Table 2
Hunter colour values of rehydrated foam-mat and freeze-dried samples

Drying method	Sample no.[a]	Hunter values		
		L	*a*	*b*
Fresh purée	1	60.7	−7.7	27.1
	2	64.8	−6.5	26.0
	3	59.8	−8.1	26.7
	4	62.7	−6.9	25.4
Foam-mat (at 70°C)	1	61.6	−1.6	25.9
	2	63.7	−0.6	26.3
	3	62.8	−0.5	26.8
	4	59.9	−0.9	24.5
Foam-mat (at 90°C)	1	52.4	5.3	19.6
	2	53.6	6.2	20.5
	3	51.2	6.1	18.4
	4	52.8	4.5	21.5
Freeze drying	1	58.5	−0.7	28.2
	2	59.1	−0.1	27.1
	3	57.4	−0.5	26.4
	4	59.3	−1.0	27.1

[a] Samples from four separate runs under similar drying conditions.

panellists). The general opinion was that the rehydrated foam-mat powder was slightly lacking in flavour compared to freeze-dried powder; this is especially true for the product dried at 90°C. This assessment reflects the flavour losses during drying and could possibly be improved by flavour encapsulation using, for instance, a maltodextrin.

4. Conclusions

This exploratory work studies the feasibility of using the process of foam-mat drying to produce fruit powder of acceptable quality at a reasonable cost. The present study has indicated that, under the experimental conditions employed, desirable powder characteristics can be obtained using this technique. Methocel could be used successfully as a foaming agent at relatively low concentration. However, drying conditions, especially at 90°C, caused substantial loss of flavour and browning of the product.

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