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Optimizing the process parameters for Foam Mat Drying of Totapuri Mango Pulp

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Abstract : Mango pulp (Totapuri variety) was foamed by adding egg albumen (5, 10 and 15%) and stabilized with methyl cellulose (0.5%). The foamed pulp was dried at four drying temperatures *viz.* 60, 65, 70 and 75°C in a batch type cabinet dryer by maintaining three foam thicknesses *viz.* 1, 2 and 3 mm. From the drying study, it was observed that, the drying time required for foamed mango pulp was lower than non-foamed pulp at all selected temperatures. The drying rate constant '*k*' value decreased with increase in pulp thickness during drying. The results of the biochemical analysis showed a significant reduction in ascorbic acid, total soluble solids and (b-carotene in the mango flakes dried at higher temperatures when compared to the pulp dried at lower temperature of 60°C. Also, these biochemical changes were significantly higher in 2 and 3 mm than in 1 mm thick foam dried samples. The study also revealed that there was no significant change in other biochemical constituents such as pH, acidity and total sugar due to the increase in drying temperature and foam thicknesses. From the foam mat drying study, it was concluded that the mango pulp treated with egg albumen (10%) with methyl cellulose (0.5%) and dried at 60°C with one mm foam thickness retained significantly higher quality traits (*P* < 0.05) than that of other foaming and drying treatments.

Key words : Totapuri mango, egg albumen, methyl cellulose, foam mat drying, foam thickness, drying rate constant, mango pulps, mango flakes and powder.

Introduction

Mango *(Mangifera indica* L.) is one of the important fruit crops grown in India, which has excellent flavour, attractive colour and delicious taste with high nutritional value. As it contains more than 80 per cent moisture, it has very poor keeping quality and cannot with stand any adverse climatic condition during storage. This results in loss of 30 per cent of fruits every year (Thind *et al.*, 2002). To overcome this post harvest losses and to increase the shelf life, the surplus mango has to be processed into shelf stable products like sterilized pulp or dried flakes and powders (Saxena and Arora, 1997; Srinivasan *et al.*, 2000).

Among the various drying techniques, foam mat drying is unique, where in the liquid or semi solid food is made into foam with the addition of food foaming and stabilizing agents. Thus, the foam formed can be spread into a thin mat / sheet and dried by using hot air. Then, the dehydrated product is conditioned and converted into powder. Generally, drying rates are comparatively higher in foamed pulps because of increased surface area at the liquid gas interface thus allowing rapid drying through internal moisture movement within the pulp. The dehydrated powder / flakes is superior to drum dried and spray dried products because of its honey comb structure and better reconstitution properties (Morgan *et al.*, 1961; Hart *et al.*, 1963; Berry *et al.*, 1965; Chandak and Chivate, 1972; Labelle, 1984; Srinivasan, 1996). Foam mat drying techniques have been used to dry various fruits such as mango (Srivastava, 1998), star fruit (Karim and Wai, 1999), papaya (Kandasamy, 2001) and banana (Sankat and Castaigne, 2004) to produce dried flakes.

Certain food products like ice cream, yoghurt, mango fruit bar, mango cereal flakes, mango cake and mango toffee require mango in the form of powder for their production. Therefore, there is a great need to develop a non-caking and quick soluble / ready mixing mango flakes / powder (Chattopadhyay, 1996). As the information on foam mat drying of mango pulp is very little, a research study was conducted to optimize the process parameters on foam mat drying for totapuri mango pulp at different temperatures with different foam thickness to produce mango flakes.

Materials and Methods

Foaming experiments

Totapuri mangoes having uniform colour and maturity were selected for the experimental work. The percentage of peel, stone and pulp present in the mangoes were determined. Flesh portions of mango were pulped using a pulper for conducting foaming and drying studies. Biochemical analyses of the fresh mango pulp namely acidity, pH, total soluble solids, total sugars, β-carotene and ascorbic acid contents were carried out to evaluate their relative loss during foam mat drying by following standard procedures.

Levels of foaming agents used during the experiment

Foaming and stabilizing agents were used within the limits stipulated in the Prevention of Food Adulteration Act (1955) and also based on the preliminary foaming tests conducted. The food foaming and stabilizing agents such as egg albumen (5, 10 and 15 %) with methyl cellulose (0.5 %) were selected and used for the foaming experiment on wet pulp weight basis. For foaming and stabilizing the mango pulp, egg albumen and methyl cellulose were incorporated subsequently during whipping.

Foaming properties

Foaming properties such as foam expansion, foam stability and foam density were calculated at different concentrations and based on the foaming properties, the optimum level was determined.

Foam expansion

Mango pulp with foaming agent was foamed by operating a foaming unit attached with whipper/foaming blades at 1400 rpm to get maximum foam expansion with minimum density as described by Durian (1995):

$$\text{Foam expansion} = \frac{V_1 - V_0}{V_0} \times 100$$

where,

V_1 = Final volume of foamed mango pulp, cm^3
V_0 = Initial volume of mango pulp, cm^3

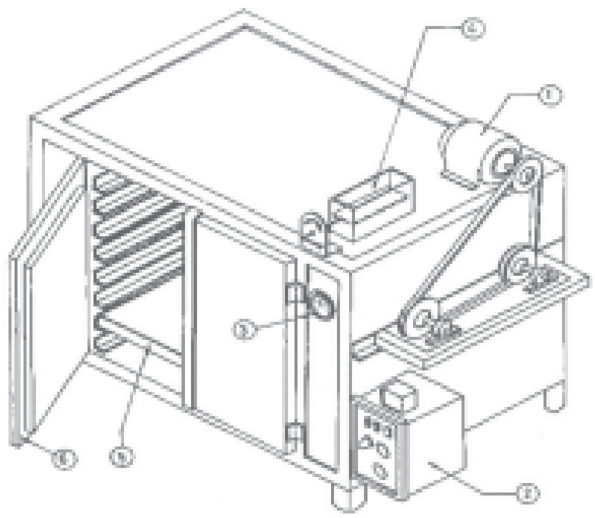
During the foaming study, all the experiments were replicated thrice and the mean values were recorded. The whipping speed, which gives maximum foam volume with minimum density and the corresponding foaming time was optimized for further foaming and drying study.

Table 1. Effect of whipping duration on foam expansion (FE)

Foaming agent	Level of Foaming Agent (%)	FE after 5 min. (%)	FE after 10 min. (%)	FE after 15 min. (%)	FE after 20 min. (%)	FE after 25 min. (%)
Egg albumen	5.0 + 0.5	10.1	25.8	55.3	70.5	70.9
with Methyl	10.0 + 0.5	10.2	45.9	75.5	97.2	98.4
cellulose	15.0 + 0.5	5.7	40.9	78.0	101.2	102.2

Table 2. Characteristics of foam produced from mango pulp.

Foaming agent	Level of Foaming Agent (%)	Wt. of fresh pulp (g)	Vol. of fresh pulp (cm^3)	Bulk density of fresh pulp (g/cm^3)	Foam volume (cm^3)	Foam expansion (%)	Foam density (g/cm^3)
Egg albumen	5.0 + 0.5	263.8	258.6	1.02	440.9	70.5	0.60
with Methyl	10.0 + 0.5	276.3	271.2	1.01	534.7	97.2	0.52
cellulose	15.0 + 0.5	288.6	284.2	1.01	571.8	101.2	0.51



1. Motor
2. Control panel board
3. Temperature indicator
4. Drying air exit
5. Drying tray
6. Door

Fig. 1. Schematic view of thin layer cabinet dryer

Foam stability

Foam stability of mango pulp was determined by taking 100 ml of the foamed pulp in a transparent graduated beaker and kept at room temperature for 3 hours. The reduction in foam volume was measured as an index for the foam stability for every 30 minutes by using the following relationship (Akiokato *et al.* 1983):

$$\text{Foam stability} = V_0 \frac{\Delta t}{\Delta V}$$

where,

ΔV is the change in volume of foam occurred during the time interval Δt and V_0 is the volume of the foam at time zero.

Foam density

The density of the foamed mango pulp was determined in terms of mass by volume and represented as g / cm^3 (Falade *et al.* 2003):

$$\text{Foam density} = \rho \frac{V_0}{V_1}$$

where,

ρ is the density of the pulp.

Measurement of Colour

The colour of the fresh and foamed mango pulp was measured by using Hunter lab color flex meter at 10° observer and D_{65} illuminant. To measure the colour, the sample cup was filled with fresh and foamed mango pulps separately without any void space at the bottom. Then the deviation in colour of the samples to standard was observed and recorded in the computer interface in terms of L, a & b values. Here, luminance (L) forms the vertical axis, which indicates whiteness to darkness. Chromatic portion of the solids is defined by a (+) redness and a (-) greenness, b (+) yellowness and b (-) blueness. Though all the 'L', 'a' and 'b' values were recorded, only the b(+) values, which represent the measure of yellowness of mango pulp and powder were considered for the study.

Foam mat drying

The foamed mango pulp was dried at different temperatures *viz.* 60, 65, 70 and 75°C in a batch type cabinet dryer. The cabinet dryer consists of heating coils, blower, drying chamber, air outlet openings and thermostat (Fig.l). The homogeneous foamed mango pulp was evenly spread on the food grade non-sticky teflon lined trays of size (95 x 40 cm) at a foam thickness of 1, 2 and 3 mm separately. The foam thickness was arrived by multiplying the foam of known density (mass/volume) with drying area to get in terms of 'g/mm'. The lined trays were then placed on the tray stand in position for drying. The temperature inside the drying chamber was measured by using thermometer. At every 10 min interval, the trays were taken out of the drying chamber for moisture loss determination. The drying was ceased when the mass of the samples recorded constant weight.

Drying rate constant '*k*' was determined by using the relationship

$$\text{Moisture ratio (MR)} = \frac{M_\theta - M_e}{M_1 - M_e} = ae^{-k\theta}$$

where,

M_0 = moisture content, dry basis (decimal) at θ time

M_1 = initial moisture content, dry basis (decimal)

M_e = equilibrium moisture content, dry basis (decimal)

a = constant

k = drying rate constant (min^{-1})

θ = time, min

By linearising the equation

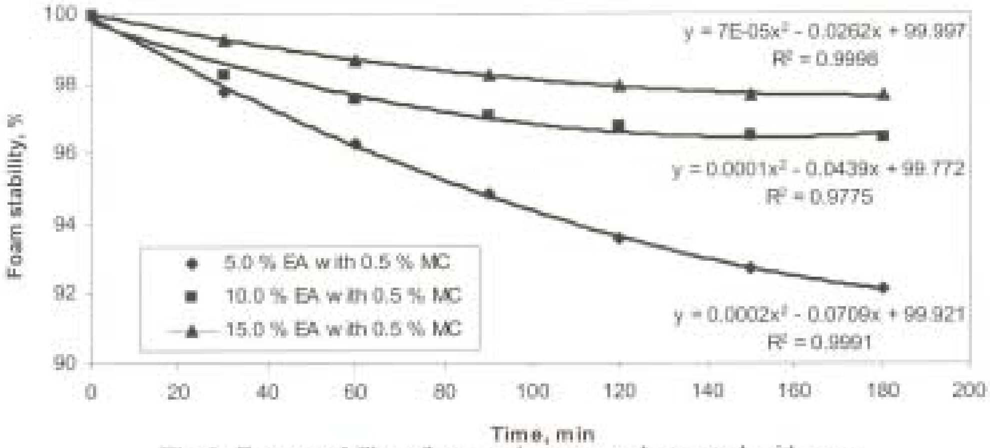


Fig.2. Foam stability of totapuri mango pulp treated with egg albumin (EA) and methyl cellulose (MC)

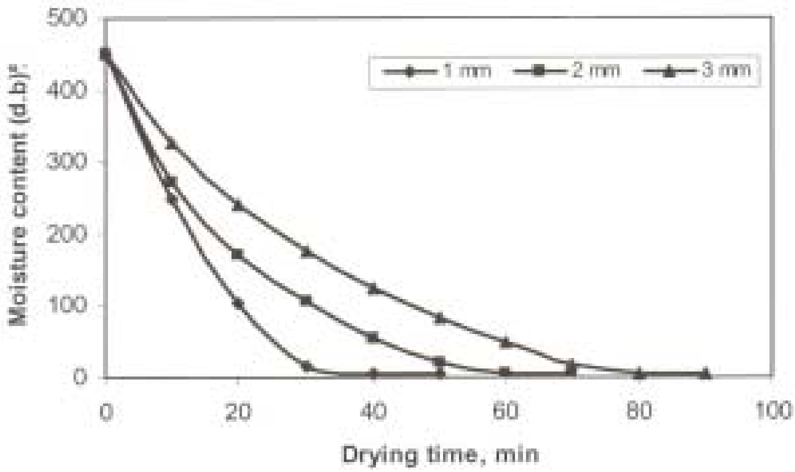


Fig. 3. Relationship between moisture content and drying time of foamed pulp

Y axis- d.b (%) is not in full view

Table 3. Biochemical composition of foam mat dried mango pulp.

Biochemical compositions	60°C			65°C			70°C			75°C			
	Foam thickness			Foam thickness			Foam thickness			Foam thickness			
	1mm	2mm	3mm	1mm	2mm	3mm	1mm	2mm	3mm	1mm	2mm	3mm	CD(5%)
Acidity (%)	0.40	0.39	0.39	0.42	0.43	0.43	0.42	0.41	0.41	0.43	0.42	0.42	0.04
pH	4.45	4.45	4.46	4.36	4.35	4.37	4.45	4.46	4.46	4.37	4.38	4.36	0.15
Total sugar (%)	7.87	7.87	7.87	7.99	7.98	7.98	7.90	7.90	7.90	7.98	7.98	7.98	0.18
TSS (°Brix)	16.45	16.35	16.31	16.45	16.31	16.25	16.30	16.20	16.20	16.45	16.27	16.20	1.02
β-Carotene (µg/100g)	3077	3072	2987	3071	3067	2949	3062	2912	2855	3069	2963	2907	9.33
Ascorbic acid (mg/100g)	16.72	14.96	13.15	15.05	12.07	11.97	10.09	8.21	7.25	12.22	10.10	9.12	1.12

Table 4. Biochemical composition of dried mango pulp (control/fresh).

Biochemical compositions	60°C			65°C			70°C			75°C			
	Pulp thickness			Pulp thickness			Pulp thickness			Pulp thickness			
	1mm	2mm	3mm	1mm	2mm	3mm	1mm	2mm	3mm	1mm	2mm	3mm	CD(5%)
Acidity (%)	0.41	0.41	0.40	0.39	0.41	0.41	0.40	0.40	0.39	0.40	0.40	0.39	0.03
pH	4.40	4.41	4.41	4.42	4.40	4.41	4.42	4.42	4.43	4.42	4.42	4.42	0.05
Total sugar (%)	7.86	7.84	7.84	7.85	7.84	7.84	7.87	7.88	7.88	7.85	7.84	7.84	0.06
TSS (°Brix)	15.17	15.1	15.0	15.15	15.10	15.10	14.45	12.1	11.1	14.50	14.80	13.65	1.62
β-Carotene (µg/100g)	3115	3100	2907	3050	3055	2795	2925	2705	2603	2900	2807	2619	10.0
Ascorbic acid (mg/100g)	14.16	12.2	9.27	11.18	10.45	7.11	7.61	4.15	3.92	9.04	6.48	4.85	2.35

$$1n\ (MR) = 1n \left[\frac{M_\theta - M_e}{M_1 - M_e} \right] = In\ a - k\theta$$

The drying rate constant '*k*' (min^{-1}) value was determined using the linearized above equation for each thickness of fresh and foam mat dried mango flakes. Biochemical properties of mango flakes *viz.* acidity, pH, total soluble solids, total sugars, β-carotene and ascorbic acid were also determined by following standard procedures for the foam mat dried mango pulp after reconstituting the flakes to their original moisture content (Ranganna, 1979). The biochemical contents of the reconstituted, foam mat dried mango flakes with three replications were statistically analysed as factorial completely randomized block design (FCRD) using AGRES statistical package and compared with fresh mango pulps to optimize the drying and foaming parameters. The level of significance was defined at $P \leq 0.05$.

Results and Discussion

Physiochemical properties of mango pulps

The percentage of peel, kernel and pulp recovery were found to be 13.7, 11.7 and 74.6 per cent respectively. Various biochemical contents of fresh mango pulps such as acidity (0.42), pH (4.37), total sugar (7.86%), total soluble solids (15.3°Brix), β-carotene (5960µg/100g) and ascorbic acid (20.1 mg/100g) were determined. The results obtained on physical and biochemical properties are comparable with the results as reported by Chauhan *et al.* (1998) and Kansci *et al.* (2003).

Foaming properties of totapuri mango pulp

Foam expansion

Data from table 1 describe the effect of whipping duration on foam expansion in mango pulp at different concentrations of egg albumen with 0.5% methylcellulose. It is seen that the percentage of foam expansion was increased with increase in the level of foaming agent. It is also observed that all the treatments recorded increase in foam expansion up to 20 min of whipping operation and after that it became almost constant. Hence, it was decided to conduct the foaming study with whipping duration of 20 min.

Data from table 2 describes the characteristics of foam produced from mango pulp, using egg albumen with methylcellulose. It is seen that the density of mango pulp mix varied between 1.02 and 1.01 g/cm^3. After whipping for 20 min, it got lowered between the values of 0.60 and 0.51 g/cm^3 due to foam formation.

The foaming study conducted using egg albumen with methyl cellulose (0.5%) recorded an increase in foam expansion by 26.7 and 4.0 per cent, when the egg albumen addition was increased from 5 to 10, and 10 to 15 per cent, respectively. In the case of foam density, egg albumen with 10 and 15 per cent recorded 0.52 and 0.51 g/cm^3, respectively. This increase in the egg albumen level from 10 to 15 per cent lowered the foam density only by 4.5 per cent. This might be due to the saturation point of egg albumen solubility under the given set of experimental condition. Hart *et al.* (1967) stated that the foam density in the range of 0.2 - 0.6 g/cm^3 was highly suitable for foam mat drying. The foam density of 0.51-0.6 g/cm^3 recorded in the present study is within the range described above and hence suitable for foam mat drying.

Foam stability of foamed mango pulp

Foam stability studies were conducted by adding egg albumen to a level of 5, 10 and 15 per cent along with 0.5 per cent methylcellulose for 3 h at room temperature and the result is shown in Fig.2. From the figure, it is

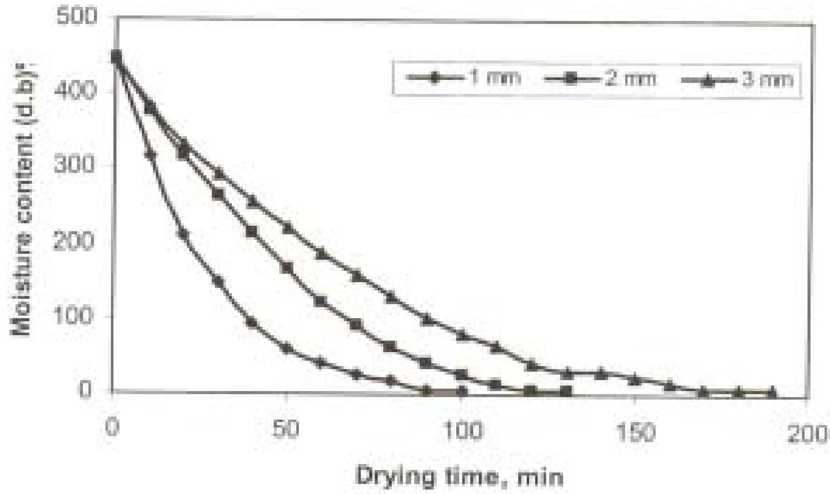


Fig. 4. Relationship between moisture content and drying time of fresh pulp

Y axis- d.b (%) is not in full view

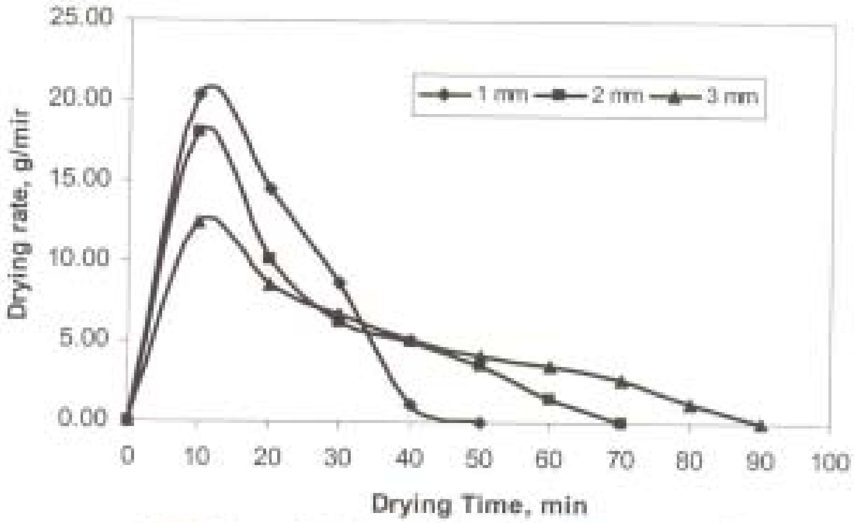


Fig.5. Rate of drying of foamed mango pulp at 60°C

Table 5. Drying characteristics of foamed and non foamed Totapuri mango pulps at 65°C.

Treatments	Foam thickness (mm)	Drying time (min)	Initial moisture content (%) (w.b)	Final moisture content (%) (w.b)	Initial drying rate (g/min)	Final drying rate (g/min)
Egg albumen (10%)	1	40		5.07	0.186	0.020
with Methyl	2	60	81.87	5.07	0.308	0.020
cellulose (0.5%)	3	80		5.07	0.320	0.024
Control (non foamed)	1	80		6.03	0.221	0.014
	2	110	81.76	6.03	0.252	0.019
	3	170		6.10	0.329	0.160

Table 6. Drying characteristics of foamed and non foamed Totapuri mango pulps at 70°C.

Treatments	Foam thickness (mm)	Drying time (min)	Initial moisture content (%) (w.b)	Final moisture content (%) (w.b)	Initial drying rate (g/min)	Final drying rate (g/min)
Egg albumen (10%)	1	30		4.64	0.207	0.035
with Methyl	2	50	81.87	4.63	0.316	0.029
cellulose (0.5%)	3	60		4.60	0.357	0.043
Control (non foamed)	1	60		6.03	0.239	0.032
	2	100	81.76	6.01	0.308	0.018
	3	150		6.01	0.338	0.018

seen that the foam stability was higher with higher level of egg albumen and 0.5% methylcellulose. However, the increase was higher when the level of addition of egg albumen was increased from 5 to 10 per cent and the increase was only 1 per cent, when the egg albumen level was increased from 10 to 15 per cent. The increase in the egg albumen level from 10 to 15 per cent, increased the foam stability value from 97.1 to 98.2 per cent after 90 min and 96.4 to 97.6 per cent after 180 min of foam stability study period (Table 2 and Fig. 2). Hence, to reduce the addition of foaming agent and subsequently its cost of production, it was decided to add only 10 per cent of egg albumen with 0.5

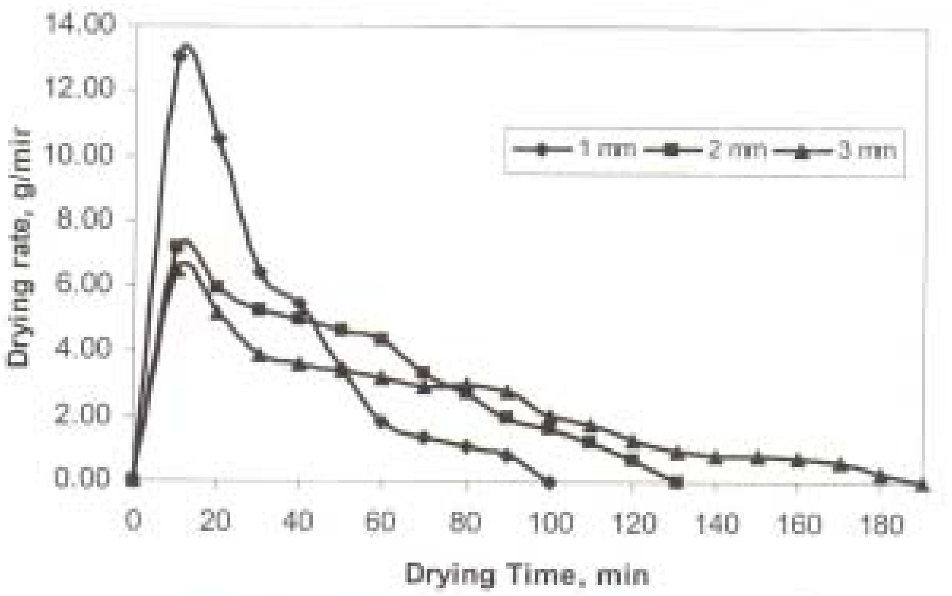


Fig.6. Rate of drying of fresh mango pulp at 60^{0}C

Table 7. Drying characteristics of foamed and non foamed Totapuri mango pulps at 75^{o}C.

Treatments	Foam thickness (mm)	Drying time (min)	Initial moisture content (%) (w.b)	Final moisture content (%) (w.b)	Initial drying rate (g/min)	Final drying rate (g/min)
Egg albumen (10%)	1	30		4.48	0.208	0.017
with Methyl cellulose	2	50	81.87	4.45	0.324	0.017
(0.5%)	3	60		4.43	0.402	0.038
Control (non foamed)	1	50		5.81	0.247	0.042
	2	80	81.76	5.80	0.339	0.028
	3	120		5.80	0.405	0.340

per cent of methylcellulose for further foam mat drying studies. Similar result was reported by Patino *et al.* (1995) and Pernell *et al.* (2002) for egg albumen.

Colour values for the mango pulps

The colour of the fresh and egg albumen mixed foamed mango pulps were determined by using Hunter lab colour flex meter in terms of L, a and b values.

The colour values (L, a & b) of the fresh pulp was found to be 54.1, 15.4 and 60.4 and for the egg albumen (10%) with methylcellulose (0.5%) foamed pulp; it was 59.4, 14.2 and 55.3, respectively. It is clear from the results that there was a little reduction in the colour of the pulp due to the incorporation of egg albumen and methylcellulose as the 'b' value was decreased when compared to the fresh pulp.

Drying characteristics of fresh and foamed mango pulp

Foam mat drying of foamed mango pulps was carried out using the optimized level such as egg albumen (10%) with methyl cellulose (0.5%) at three foam thickness *viz.* 1, 2 and 3 mm and four drying temperatures of 60, 65, 70 and 75°C in a batch type (cabinet) thin layer dryer. The biochemical contents of the foam mat dried mango flakes were determined and statistically analysed. The biochemical results of the foamed and fresh mango pulp dried at 60, 65, 70 and 75°C are presented in tables 3 and 4 for comparison.

From the biochemical analysis (Table 3), it was found that there was a significant reduction in total soluble solids (16.31 to 16.20 °Brix), β-carotene (3077 to 2855μg/100g) and ascorbic acid (16.72 to 7.25 mg/100g) in the foam mat dried mango flakes due to heat sensitive nature of the mango pulp during drying. Also, it was observed that the biochemical changes were comparatively higher in 2 and 3 mm thick foam mat dried flakes at 65, 70 and 75°C than in one mm thick foam dried at 60°C. But the variations in other biochemical contents such as acidity (0.39 to 0.43 %), pH (4.46 to 4.35) and total sugar (7.99 to 7.87 %) were insignificant due to drying at higher temperatures with higher foam thickness. It is also obvious that the fresh pulp (control) had a significant change in the biochemical contents during drying due to high viscous nature and led to long drying time (Table 4). Similar biochemical changes were reported by Srivastava, (1998) for mango and Kandasami, (2001) for papaya.

Based on the statistical analysis of foam mat dried totapuri mango flakes, it was found that one mm thick foam mat dried at 60°C retained significantly higher amount of biochemical / nutritional qualities than other treatments. Hence, the drying characteristics of egg albumen with methylcellulose treated and fresh (control) mango pulps are discussed below. The drying data at 65, 70 and 75°C are shown in tables 5 to 7 for comparison.

Effect of thickness on drying of foamed and fresh mango pulp

The effect of foam thickness on the moisture content of foamed mango pulp during drying at 60°C is shown in Fig.3. From the figure, it is observed that the time taken for drying of foamed mango pulp from 451 to 5.3 per cent moisture content (d.b.) was 40, 60 and 80 min for 1, 2 and 3 mm foam thickness, respectively. While the time taken for drying of fresh mango pulp from 448 to 6.4 ± 0.2 per cent moisture content (d.b.) was 100, 130 and 190 min for 1, 2 and 3 mm thick pulp, respectively (Fig.4).

The drying curves clearly showed that the mango pulps dried with lower foam thickness dried at a faster rate as compared to the foamed mango pulps dried with higher foam thickness. This might be due to the complete exposure of mango pulps at lower foam thickness to the drying air. It is also noted that the reduction in the moisture content of fresh mango pulp at any point of time during drying was lower when compared to the foamed mango pulps at all thicknesses studied. This might be due to high viscosity and bulk density of fresh pulp with less exposed surface area during drying. This result is similar to the drying data reported by Prakash *et al.* (2004) for carrot.

Effect of thickness on drying rate of foamed and fresh mango pulp

From Figure 5, it is observed that the drying rate was 20.3, 17.9 and 12.4 g/min at the beginning of drying and the same was reduced to 1.0, 1.4 and 1.1 g/min at the end of the drying for 1, 2 and 3 mm thick foams, respectively. It is also seen from the figures 3 and 5, that the drying of foamed mango pulp at all thicknesses occurred at falling rate period because of the quick removal of moisture from thin surfaces of foam. The quantity of moisture removed is more in the three mm thick foam as compared to one mm thick foam due to the availability of higher quantity of moisture in larger thickness. But for the fresh pulp, the drying rate was 13.0, 7.2 and 6.4 g/min at the beginning of drying and the same was reduced to 0.7, 0.6 and 0.2 g/min at the end of the drying for 1, 2 and 3 mm thick pulps, respectively (Fig.6). The drying rate of the fresh mango pulp (non foamed mango pulp) was lower than the drying rate of the foamed mango pulp at all thickness ranges studied due to less surface area exposed during drying. Also the result showed that due to foaming there is beneficial effect in increasing drying rate and in turn reducing drying time. These drying results are in confirmation with the results reported for high moisture foods like tomato (Jayaraman *et al.*, 1975) and papaya (Levi *et al.*, 1983).

Drying rate constant

Based on the equation, the drying rate constant 'h' was determined for various pulp thicknesses. The results showed that the ‘A’ value decreased with increase in the pulp thickness. Also the *‘k’* value for foamed pup (0.023, 018 and 0.012 /min) was higher than the fresh pulp (0.019, 0.016 and 0.010 /min) at 1, 2 and 3 mm thickness, respectively. It is obvious that the drying rate is higher in foamed pulps due to larger surface area exposed to drying air when compared to fresh (non foamed) mango pulps.

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