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Foam Mat Drying Characteristics of Mango Pulp

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Abstract Mango is widely preferred because of its excellent flavour and nutritional quality. Mango pulp from *Dussehri* variety was foam mat dried using 0, 3, 5, 7, and 9% egg white as foaming agent and then dried at air drying temperature of 65, 75 and 85°C. Weight loss was used to estimate change in moiture ratio with respect to time and effective diffusivity. Seven thin layer drying models were fitted to get the best fit model, which was selected on the basis of various statistical parameters. Wang and Singh model was found to be best in almost all cases. Nutritional status in terms of total carotenes was estimated and it was observed that there was significant effect of drying temperatures and egg white concentration. Based on above parametres it was resolved that foam mat drying using 3% egg white at 65°C air drying temperature was the best combination.

Keywords Mango, Foam Mat Drying, Egg White, Drying Kinetics, Effective Moisture Diffusivity, Carotenes

1. Introduction

Mango (*Mangifera indica* L.) commonly known as king of fruits is a major fruit in Asia and around the world. Nutritional importance of mango is mainly due to carotenes and other bioactive compounds[1]. India being the largest producer of mango contributes 37% of total 30.5 million tons of global production[2]. Mango impose greater problem in storage and transportation, as it is highly perishable than other tropical and sub tropical fruits. Wide gap between total production and consumption due to poor transportation and storage facilities leads to post harvest losses[3]. To avoid post harvest losses and increase the shelf life mango has to be processed into shelf stable products. Conventional types of mango products have been developed to a considerable extent but the mango industry is eager to develop new processed products[4]. In India, few studies have been reported on the development of mango powder. Spray drying of mango pulp produced good coloured powder but no pleasant flavour[5]. Freeze-dried mango pulp with added sugar produced powder with good shelf life but the cost was prohibitive[6]. Sweetened mango powder produced by drying, which involved mixing pulp with an equal quantity of sucrose and dried in a vacuum drier at 65°C and 27″Hg vacuum for 8 h, retained 57% *β*-carotene at 38°C and 65% RH[7].

Foaming of liquid and semi-liquid materials has long been recognized as one of the efficient methods to shorten drying time. Over the past decade, this relatively old technology, known as foam mat drying, received renewed attention because of its added ability to process hard-to-dry materials to produce products of desired properties, retaining volatiles that otherwise would be lost during the drying of non-foamed materials[8,9]. Foam mat drying involves the incorporation of foaming agent into liquid foods with subsequent whipping to form stiff foam[10,11]. In general, drying rate of foamed materials is faster than non-foamed materials and is greatly accelerated during final stages of drying. Many researchers have reported that the increased interfacial area of foamed materials is the factor responsible for its enhanced drying rate.

Present investigation was aimed to study the foam mat drying characteristics of mango pulp to enhance its shelf life and finding optimal conditions to apply this technique for mango powder development with retention of nutritional quality.

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2. Material and Methods

2.1. Drying Experiment

Fully ripened mangoes (Dushehri variety) were purchase d from the local market of Ludhiana (Punjab). Mangoes were washed with water to remove dirt and foreign matter, if any. After manual grading for uniform size and shape, only sound, blemish free fruits were taken for extracting pulp. Pulp was homogenized using domestic mixer after peeling of skin and stone removal. Sample size of 300g in triplicate was agitated using hand blender (Orpat-HHB100E, Ajanta Limited, India.) at 18000rpm. Egg white (EW) @ 0, 3, 5, 7 and 9% was added to develop the foam which increases surface area due to air incorporation. Foamed pulp was spread in food grade stainless steel trays and dried in tray dryer (MSW-210, Macro Scientific Work, India) at three different drying air temperature of 65, 75 and 85oC.

Weight loss was measured after every half an hour to determine drying rate and other drying parameters. The semi dried foam mats were peeled at around 15-19% moisture content for faster drying and better quality retention. Peeled mats were reversed and dried for another half an hour in order to reduce moisture content of the mats below 3%. The dried mats were pulverized and packing for further studies.

Nomenclature

Abbreviation	Full form
χ^2	Reduced chi-square
a, b, c, n	Empirical constants in drying models
D_{eff}	Effective moisture diffusivity, m^2/s
K	Drying constant
L	Thickness of foam mat, m
M	Moisture content at time t, kg moisture.
M_e	Equilibrium moisture content, kg moisture.
M_o	Initial moisture content, kg moisture.
MR	Dimensionless moisture ratio
N	Number of observations
R^2	Coefficient of determination
RMSE	Root mean square error
MBE	Mean biased error
T	Drying time, h
Z	Number of drying constants
EW	Egg white

2.2. Moisture Ratio

Moisture ratio of samples during drying was determined using following equation:

$$MR = (M-M_e)/(M_o-M_e) \quad (1)$$

As the M_e value is very small compared to M_o and M values, the M_e value can be neglected and the moisture ratio was simplified and it can be expressed as[9, 12].

$$MR = M/M_o \quad (2)$$

2.3. Moisture Diffusivity

Fick's diffusion equation for particles with slab geometry was used for calculation of effective moisture diffusivity. Thin layered foamed mango pulp in a tray was considered as slab geometry[13]. The equation is expressed as[14]:

$$MR = \frac{8}{\pi^2}\exp\left(\frac{-\pi^2 D_{eff} t}{4L^2}\right) \quad (3)$$

Equation (3) can be rewritten as:

$$D_{eff} = \frac{\ln MR - \ln \frac{8}{\pi^2}}{\left(\frac{\pi^2 t}{4L^2}\right)} \quad (4)$$

The slope (K_o) is calculated by plotting Ln (MR) vs. time according to equation (6) to determine the effective diffusivity for different temperatures.

$$k_o = \left(\frac{\pi^2 D_{eff}}{4L^2}\right) \quad (5)$$

2.4. Model Fitting

To select a suitable model for describing the foam mat drying process of mango, drying curves were fitted with seven thin layer drying equations. The evaluated moisture ratio models are presented in Table 1. The non-linear regression analysis was done using STATISTICA 6.0 (Stat soft). Coefficient of determination, R^2 was one of the main criteria for selecting the best model. In addition to R^2, the goodness of fit was determined by various statistical parameters such as reduced chi-square (χ^2), Root mean square error (RMSE) and Mean bias error (MBE). For quality fit, R^2 value should be higher and χ^2, MBE and RMSE values should be lower[9, 12, 15].

Table 1. Thin Layer Drying Models and Their Equations

Model	Equation
Newton [22]	MR = Exp(-kt)
Henderson and Pabis[23,24]	MR = a Exp(-kt)
Logarithmic[25]	MR = a Exp(-kt) + c
Two term[26, 27]	MR = a Exp(-kt) + b Exp(-nt)
Two term exponential[28]	MR =a Exp(-kt) + (1-a) Exp(-kat)
Wang and Singh[29]	MR = 1 + (at) + (bt^2)
Diffusion approach[30]	MR = a Exp(-kt) + (1-a) Exp(-kbt)

2.5. Nutritional Quality

Nutritional quality in terms of total carotene content was estimated using the Rangana[16] method.

3. Results and Discussion

3.1. Drying Characteristics

Moisture content of fresh mangoes was found to be 79.25 ± 1.77% (wet basis). The average drying time for foam mat drying was 390, 330 and 300 min at 65, 75 and 85°C respectively (Figure1). The final moisture content of powdered samples was in the range of 1.12-3.05%. Drying air temperature had significant effect on drying time, which is evident from the fact that drying time, reduced with increase in drying air temperature. Moisture reduction per hour was higher at initial stages and then started to decrease with the increasing drying time. The results are in accordance with the earlier observations for foam mat drying of tomato[9]. It was observed that drying occurred primarily in falling rate period and no constant rate period was observed at all drying temperatures. It can be deduced from Figure1 that concentration of foaming agent has significant effect on drying rate. At 65°C drying, sample with 3% egg white had minimum moisture ratio with respect to time, however in case of drying at 75 and 85°C, minimum moisture ratio was noticed with 3 and 5% and 3 and 7% egg white respectively. From above it can be concluded that 3% egg white concentration is good due to effective drying rate. Although samples with 5 and 7% egg white had similar drying rate, but being higher concentrations, these could be avoided to prevent excessive use of foaming agent.

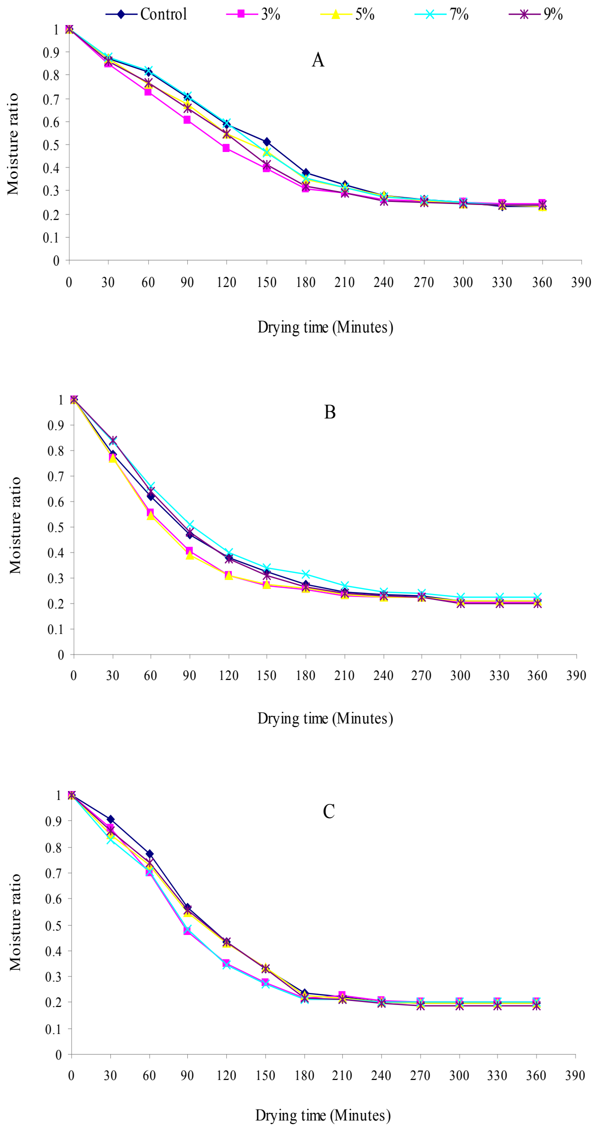

Figure 1. Effect of egg white (%) on drying rate of foam mat dried mango pulp at (A) 65°C, (B) 75°C and (C) 85°C drying air temperatures

3.2. Moisture Diffusivity

The effective moisture diffusivity ranged between 1.53×10^{-8} and 2.63×10^{-8} m^2/s for temperature range from 65 to 85°C (Table 2). Moisture diffusivity of mango foam mats increased with increase in drying air temperature. Moisture diffusivity was maximum for 3% egg white at 65°C and 7% at 75°C along with highest R^2 values.

3.3. Model Fitting

The moisture ratio data of foam mat drying of mango pulp at different temperatures using different concentrations of egg white were fitted into thin layer drying models (Table 1). The coefficient of correlation and results of statistical analysis are listed in Table 3. Four criteria for adequacy of the model fit, namely, coefficient of determination (R^2), reduced Chi square (χ^2), mean biased error (MBE) and root mean square error (RMSE) were used. The best model describing the thin layer drying characteristics of mango foam mat drying was chosen as the one with the highest R^2 and lowest χ^2, MBE and RMSE. All the models fitted gave R^2 more than 0.9, however out of these, Wang and Singh model was the best fitted with R^2 more than 0.99 for 65 and 85°C, whereas, Logarithmic and diffusion approach model were found suitable for 75°C.

Table 2. Effective moisture diffusivity and its linear equation for foam mat drying of mango pulp

Temp (°C)	EW %	Equation	k0 values	D_{eff}	R^2
65	0	y = -0.0042x-0.1599	-0.0042	1.53E-08	0.9064
	3	y = -0.0046x-0.0158	-0.0046	1.68E-08	0.9627
	5	y = -0.0045x-0.0643	-0.0045	1.64E-08	0.9533
	7	y = -0.0045x-0.0358	-0.0045	1.64E-08	0.9424
	9	y = -0.0044x-0.1005	-0.0044	1.60E-08	0.9203
75	0	y = -0.0052x-0.1938	-0.0052	1.90E-08	0.9296
	3	y = -0.0051x-0.2904	-0.0051	1.86E-08	0.8679
	5	y = -0.0050x-0.3003	-0.0050	1.82E-08	0.8630
	7	y = -0.0052x-0.1405	-0.0052	1.90E-08	0.9468
	9	y = -0.0055x-0.1613	-0.0055	2.01E-08	0.9309
85	0	y = -0.0071x+0.0616	-0.0071	2.59E-08	0.9601
	3	y = -0.0068x-0.0455	-0.0068	2.48E-08	0.9136
	5	y = -0.0070x+0.0368	-0.0070	2.55E-08	0.9522
	7	y = -0.0069x-0.0395	-0.0069	2.52E-08	0.9123
	9	y = -0.0072x+0.0556	-0.0072	2.63E-08	0.9551

3.4. Total Carotene

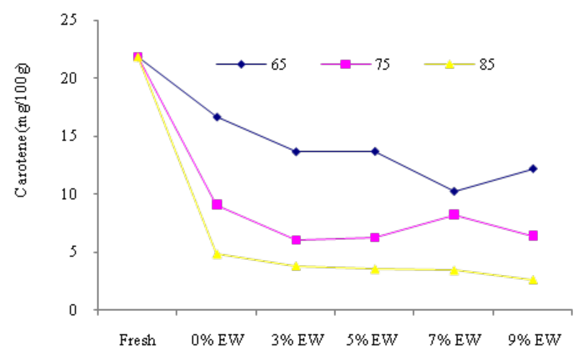

Figure 2. Changes in total carotenes with foam mat drying at 65, 75, and 85°C temperature

Mango is a major source of carotenes, which are known to be important since decades for various health benefits and role in disease prevention. Total carotene of fresh mango was found to be 21.84 ± 3.88 mg/100g. Total carotene content of freshly prepared foam mat dried mango powder was in the range of 16.59- 4.25 mg/100g. Foam mat drying at different temperature using different concentrations of egg white had significant effect on the carotene content (Figure 2). Decrease in carotene content was observed with increasing concentration of egg white and temperature. The loss of total carotene could be attributed to its photosensitive nature, isomerization and epoxide forming nature of carotenoids[17, 18]. Decline was more pronounced in case of 75 and 85^{o}C than at 65^{o}C. Decline in carotene content with drying and dehydration was reported by Chen, Peng, & Chen[19] in Taiwanese mango, Wen-ping, Zhi-jing, He, & Min[20] in fruits of *Lycjum barbarum* and Lavelli, Zanoni, & Zaniboni[21] in dehydrated carrots.

Table 3. Statistical Quality Analysis of Fitted Thin Layer Drying Mathematical Modelsto Foam Mat Drying of Mango Pulp

Model	Temp (^{o}C)	EW%	R^2	χ^2	MBE	RMSE	Model Constants			
Newton	65	0	0.9819	0.0013	0.0037	0.0098	k:0.005			
		3	0.9635	0.0025	0.0032	0.0132	k:0.005			
		5	0.9836	0.0012	0.0029	0.0091	k:0.005			
		7	0.9731	0.0020	0.0049	0.0120	k:0.005			
		9	0.9720	0.0020	0.0039	0.0120	k:0.005			
	75	0	0.9617	0.0026	0.0023	0.0147	k:0.007			
		3	0.9272	0.0051	0.0071	0.0204	k:0.008			
		5	0.9201	0.0055	0.0072	0.0213	k:0.008			
		7	0.9723	0.0019	0.0024	0.0127	k:0.006			
		9	0.9705	0.0022	0.0047	0.0135	k:0.007			
	85	0	0.9700	0.0028	0.0079	0.0160	k:0.007			
		3	0.9689	0.0028	0.0074	0.0159	k:0.007			
		5	0.9839	0.0014	0.0043	0.0112	k:0.007			
		7	0.9734	0.0023	0.0058	0.0145	k:0.008			
		9	0.9806	0.0018	0.0050	0.0126	k:0.007			
Hederson and Pebis	65	0	0.9859	0.0022	0.0036	0.0120	k:0.005	a:0.976		
		3	0.9822	0.0026	0.0056	0.0130	k:0.005	a:1.003		
		5	0.9918	0.0013	0.0022	0.0091	k:0.005	a:1.006		
		7	0.9873	0.0021	0.0014	0.0117	k:0.005	a:1.027		
		9	0.9859	0.0022	0.0036	0.0120	k:0.005	a:1.003		
	75	0	0.9833	0.0025	0.0069	0.0137	k:0.007	a:0.953		
		3	0.9671	0.0050	0.0115	0.0193	k:0.007	a:0.938		
		5	0.9641	0.0054	0.0119	0.0200	k:0.007	a:0.933		
		7	0.9868	0.0020	0.0052	0.0123	k:0.006	a:0.975		
		9	0.9855	0.0024	0.0065	0.0134	k:0.007	a:0.982		
	85	0	0.9886	0.0024	-0.0009	0.0139	k:0.007	a:1.061		
		3	0.9852	0.0030	0.0037	0.0154	k:0.007	a:1.061		
		5	0.9928	0.0014	0.0003	0.0106	k:0.007	a:1.029		
		7	0.9870	0.0026	0.0035	0.0143	k:0.008	a:1.019		
		9	0.9919	0.0016	-0.0006	0.0115	k:0.007	a:1.041		
Logrithmic	65	0	0.9917	0.0015	0.0000	0.0093	k:0.009	a:0.857	c: 0.173	
		3	0.9943	0.0009	0.0000	0.0074	k:0.005	a:0.995	c: 0.035	
		5	0.9939	0.0010	0.0000	0.0078	k:0.006	a:0.926	c: 0.102	
		7	0.9881	0.0021	0.0000	0.0113	k:0.006	a:0.971	c: 0.070	
		9	0.9905	0.0017	0.0000	0.0099	k:0.007	a:0.908	c: 0.128	
	75	0	0.9988	0.0002	0.0000	0.0036	k:0.011	a:0.835	c: 0.177	
		3	0.9973	0.0005	0.0000	0.0056	k:0.014	a:0.830	c: 0.190	
		5	0.9973	0.0005	0.0000	0.0056	k:0.015	a:0.825	c: 0.195	
		7	0.9973	0.0005	0.0000	0.0055	k:0.010	a:0.854	c: 0.170	
		9	0.9963	0.0007	0.0000	0.0068	k:0.011	a:0.876	c: 0.155	
	85	0	0.9888	0.0027	0.0000	0.0138	k:0.007	a:1.094	c:-0.039	
		3	0.9878	0.0028	0.0000	0.0140	k:0.010	a:0.961	c: 0.091	
		5	0.9928	0.0016	0.0000	0.0106	k:0.007	a:1.020	c: 0.012	
		7	0.9893	0.0024	0.0000	0.0130	k:0.010	a:0.953	c: 0.086	
		9	0.9920	0.0019	0.0000	0.0114	k:0.007	a:1.061	c:-0.025	
Two term	65	0	0.9922	0.0015	0.0013	0.0090	k:1.000	a: 0.051	c:0.949	b:0.005
		3	0.9830	0.0030	0.0046	0.0127	k:1.000	a:-0.048	c:1.048	b:0.005
		5	0.9918	0.0016	0.0024	0.0091	k:1.000	a:-0.012	c:1.012	b:0.005
		7	0.9881	0.0024	0.0023	0.0113	k:1.000	a:-0.055	c:1.055	b:0.005
		9	0.9859	0.0027	0.0037	0.0120	k:1.000	a:-0.005	c:1.005	b:0.005
	75	0	0.9875	0.0024	0.0040	0.0119	k:1.000	a: 0.119	c:0.881	b:0.006
		3	0.9753	0.0048	0.0060	0.0167	k:1.000	a: 0.173	c:0.827	b:0.006
		5	0.9737	0.0051	0.0059	0.0171	k:1.000	a: 0.186	c:0.814	b:0.006

Table 3. Continued

Model	Temp (°C)	EW%	R^2	χ^2	MBE	RMSE	Model Constants			
		7	0.9880	0.0024	0.0039	0.0118	k:1.000	a: 0.062	c:0.938	b:0.006
		9	0.9861	0.0030	0.0053	0.0131	k:1.000	a: 0.048	c:0.952	b:0.007
	85	0	0.9946	0.0015	0.0022	0.0096	k:1.000	a:-0.167	c:1.167	b:0.008
		3	0.9946	0.0015	0.0022	0.0096	k:1.000	a:-0.167	c:1.167	b:0.008
		5	0.9943	0.0015	0.0018	0.0095	k:1.000	a:-0.078	c:1.078	b:0.007
		7	0.9876	0.0032	0.0049	0.0140	k:1.000	a:-0.055	c:1.055	b:0.008
		9	0.9946	0.0015	0.0014	0.0094	k:1.000	a:-0.110	c:1.110	b:0.008
Two term expotential	65	0	0.9907	0.0015	0.0037	0.0098	k:0.012	a:0.313		
		3	0.9886	0.0017	0.0034	0.0104	k:1.595	a:0.003		
		5	0.9917	0.0013	0.0028	0.0092	k:0.929	a:0.005		
		7	0.9863	0.0022	0.0048	0.0121	k:1.759	a:0.003		
		9	0.9858	0.0022	0.0038	0.0120	k:0.948	a:0.005		
	75	0	0.9925	0.0011	0.0022	0.0092	k:0.020	a:0.261		
		3	0.9812	0.0029	0.0046	0.0146	k:0.023	a:0.262		
Two term expotential	75	5	0.9792	0.0031	0.0046	0.0153	k:0.023	a:0.258		
		7	0.9933	0.0010	0.0030	0.0088	k:0.016	a:0.294		
		9	0.9915	0.0014	0.0041	0.0102	k:0.016	a:0.320		
	85	0	0.9847	0.0032	0.0078	0.0161	k:4.703	a:0.001		
		3	0.9842	0.0032	0.0070	0.0159	k:3.155	a:0.002		
		5	0.9918	0.0016	0.0042	0.0113	k:2.964	a:0.002		
		7	0.9865	0.0027	0.0057	0.0146	k:2.474	a:0.003		
		9	0.9901	0.0020	0.0046	0.0127	k:3.610	a:0.002		
Wang and Singh	65	0	0.9950	0.0008	0.0038	0.0072	a:-0.005	b:0.000		
		3	0.9978	0.0003	0.0000	0.0046	a:-0.004	b:0.000		
		5	0.9976	0.0004	0.0023	0.0049	a:-0.005	b:0.000		
		7	0.9925	0.0012	0.0054	0.0090	a:-0.004	b:0.000		
		9	0.9961	0.0006	0.0030	0.0063	a:-0.005	b:0.000		
	75	0	0.9936	0.0010	-0.0052	0.0085	a:-0.007	b:0.000		
		3	0.9836	0.0025	-0.0077	0.0137	a:-0.007	b:0.000		
		5	0.9815	0.0028	-0.0083	0.0144	a:-0.007	b:0.000		
		7	0.9960	0.0006	-0.0016	0.0068	a:-0.006	b:0.000		
		9	0.9955	0.0007	-0.0012	0.0074	a:-0.007	b:0.000		
	85	0	0.9906	0.0020	0.0091	0.0126	a:-0.006	b:0.000		
		3	0.9927	0.0015	0.0063	0.0108	a:-0.007	b:0.000		
		5	0.9963	0.0007	0.0043	0.0076	a:-0.006	b:0.000		
		7	0.9950	0.0010	0.0042	0.0089	a:-0.007	b:0.000		
		9	0.9951	0.0010	0.0055	0.0089	a:-0.006	b:0.000		
Diffusion approach	65	0	0.9926	0.0013	0.0014	0.0088	k:0.006	a: 0.997	c:-1.827	
		3	0.9971	0.0005	0.0020	0.0053	k:0.038	a:-0.074	c: 0.135	
		5	0.9918	0.0014	0.0024	0.0091	k:0.119	a:-0.012	c: 0.042	
		7	0.9883	0.0021	0.0024	0.0112	k:0.046	a:-0.075	c: 0.112	
		9	0.9859	0.0024	0.0037	0.0120	k:0.102	a:-0.006	c: 0.051	
	75	0	0.9993	0.0001	0.0007	0.0028	k:0.009	a: 0.958	c:-0.486	
		3	0.9978	0.0004	0.0016	0.0050	k:0.012	a: 0.928	c:-0.280	
		5	0.9977	0.0004	0.0016	0.0051	k:0.012	a: 0.915	c:-0.233	
		7	0.9978	0.0004	0.0020	0.0050	k:0.008	a: 0.986	c:-0.967	
		9	0.9971	0.0005	0.0026	0.0060	k:0.008	a: 0.992	c:-1.115	
	85	0	0.9948	0.0013	0.0026	0.0094	k:0.071	a:-0.195	c: 0.114	
		3	0.9870	0.0030	0.0060	0.0145	k:0.300	a:-0.091	c: 0.028	
		5	0.9944	0.0013	0.0020	0.0094	k:0.061	a:-0.098	c: 0.126	
		7	0.9876	0.0028	0.0049	0.0140	k:0.204	a:-0.055	c: 0.040	
		9	0.9949	0.0012	0.0019	0.0091	k:0.052	a:-0.150	c: 0.154	

4. Conclusions

From the present study on foam mat drying of mango pulp, it can be concluded that increase in drying temperature decreased drying time. Foaming with different egg white concentrations had significant effect on drying up to the level of 3% as evident from moisture ratio curves and diffusivity data. Further increase in egg white concentration either had similar or negative impact on drying. Foam mat drying data followed Wang and Singh model for 65 and 85^{o}C and Logarithmic and diffusion approach for 75^{o}C. Total carotene content was highest in case of samples dried at 65^{o}C. In nutshell, it can be recommended that foam mat drying of mango pulp can be carried out using 3% egg white as foaming agent and 65^{o}C air drying temperature with the retention of nutritional quality.

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