FOAM MAT DRYING OF TOMATO JUICE

DATTATREYA M. KADAM[1] and S. BALASUBRAMANIAN

Food Grains and Oilseeds Processing Division, Central Institute of Post-Harvest Engineering and Technology (CIPHET), PO PAU, Ludhiana-141004, Punjab, India

[1]Corresponding author.
TEL: +91-161-2313135;
FAX: +91-161-2308670;
EMAIL: kadam1k@yahoo.com

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ABSTRACT

Experiments were carried out to determine the effect of drying air temperature and foaming agent (egg albumin) for production of tomato powder using foam-mat drying. Samples were prepared using tomato juice (4°Brix total soluble solids), incorporating egg albumin as foaming agent (0, 5, 10, 15 and 20%, w/w). Foamed tomato juice (300 ± 0.5 g) was spread on rectangular trays (2.5 mm thickness) and kept in tray dryer at 60, 65 and 70C air temperature. Incorporation of 10% egg albumin with 5 min of whipping time was found optimum for stable foam formation. The increase in foaming agent level enhanced the drying process (up to 15% egg albumin) and thereafter followed a decreasing trend. Foamed tomato juice can be dried in 510 and 450 min at 60 and 70C drying air temperature, respectively, with best acceptability. Effective moisture diffusivity of tomato juice ranged from 2.026×10^{-8} to 3.039×10^{-8} m^2/s.

PRACTICAL APPLICATIONS

Tomato is the largest produced vegetable crop all over the world and 20–40% of produce goes as waste during postharvest operations per annum. Foam mat drying technology has been revamped and renewed attention for its added ability to process hard-to-dry materials to obtain products of desired properties and retain volatiles that otherwise would be lost during the drying of nonfoamed materials. In this context, the dehydrated tomato powder holds a promising and potential market for quality vegetable juices. Dehydrated powders can be reconstituted into juice and used as a starter for the preparation of products like sauce, ketchup, chutney, soups, baby foods, etc.

INTRODUCTION

Tomatoes are an important source of minerals, iron, phosphorus, organic acid, essential amino acids, dietary fibers, beta-carotene pigments, antioxidants such as lycopene, phenolics, and vitamins (A and C) (Abushita *et al.* 1997; Clinton 1998; Vinson *et al.* 1998), and have been linked with reduced risk of prostate cancer and heart diseases (Clinton 1998; Rao and Agarwal 2000; Barber and Barber 2002). Tomato is known as productive as well as protective food. Tomato is the second largest vegetable crop produced in India with an annual production of 7.6 million tonnes that contributes about 6.1% to the world's tomato production in 2005–2006 (http://www.ikisan.com/cache/ap_Tomato.shtml).

Foaming of liquid and semisolid materials has long been recognized as one of the efficient methods to shorten drying time. In the recent years, foam mat drying technology has revamped and renewed attention for its added ability to process hard-to-dry materials to produce products of desired properties, retaining its volatiles that otherwise would be lost during the drying of nonfoamed materials (Ratti and Kudra 2005). Foam mat drying is carried out for the liquid or semi solid food by making them into foam with the addition of food foaming and stabilizing agents. The foam thus 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). In general, drying rate of foamed materials is faster than nonfoamed materials and is greatly accelerated at the end. Many researchers have reported that the increased interfacial areas of foamed materials are the responsible factor for its induced drying rate (Hart *et al.* 1963; Falade *et al.* 2003).

Because of lower foam density (300–600 kg/m^3), the mass load of foam-mat dryer is reduced significantly. Hence, this shorter drying time not only reduces the dryer load but also increases the dryer throughput by 32 and 22% for foamed apple juice and mango pulp (Rajkumar *et al.* 2005), respectively, in comparison with nonfoamed pulp. Dehydrated powders can be reconstituted into juice and used as a starter for preparation of products like sauce, ketchup, chutney, soups, baby foods, etc. Thus, dehydrated tomato juices have promising and potential scope in domestic and international market.

Advantages of the foam mat dried product are its higher stability against deteriorative microbial, chemical and biochemical reactions, reducing handling, packaging and transportation costs and negligible energy requirements during storage. Retention of color, flavor, vitamins (particularly the ascorbic acid), nutritional and organoleptic characteristics and free from any scorched odor/taste, satisfactory shelf life in the product are the main attraction of the process technology. It reconstitutes well and remains free flowing during storage (Mishra 2009).

Prediction of drying curves, generally, the moisture content of the material at any time after it has been subjected to a constant relative humidity and temperature conditions are measured and correlated to the drying parameters (Karathanos and Belessiotis 1999; Midilli *et al.* 2002; Togrul and Pehlivan 2002). Among the wide range of mathematical models, thin layer drying models have been found wide application in drying process (Madamba *et al.* 1996).

In view of scarce information on foam-mat drying of tomato juice, the present work aims at comparing the drying of foamed and nonfoamed tomato juice in terms of process feasibility and drying kinetics to evaluate the following: (1) to study the drying kinetics of tomato juice for different drying air temperature (60, 65 and 70C) using tray dryer; (2) the effect of concentration levels of foaming agent on drying; and (3) a suitable thin layer drying model and calculate the effective moisture diffusivities of foam mat dried tomato powder.

MATERIALS AND METHODS

Foam mat drying of tomato juice experiments were carried out at Central Institute of Post-Harvest Engineering and Technology (CIPHET), Ludhiana, Punjab (India).

Ripe tomato
↓
Washing
↓
Hot water dip
↓
Dip in cold water
↓
Skin removing
↓
Cutting and crushing
↓
Tomato juice
↓
Add foaming agent
↓
Whipping (5min)
↓
Pouring in tray
↓
Drying
↓
Scraping and grinding
↓
Tomato powder
↓
Packing and sealing

FIG. 1. PROCESS FLOW CHART FOR PREPARATION OF FOAM MAT DRIED TOMATO POWDER

Sample Preparation

Fully ripe, red color tomatoes were procured from local market of Ludhiana (India). Tomatoes were washed manually under tap water and sorted for good quality tomatoes without any bruise, etc. Tomatoes were cut into pieces and crushing was done to extract juice. Crushed tomato pulp/juice (4°Brix total soluble solid [TSS]) was sieved to remove seeds and skin.

Eggs weighing between 47.2 and 50.7 g were procured from local market to extract fresh egg albumin, which contains about 26.7 to 28.5 g of egg albumin. The egg albumin extract was homogenized and used as foaming agent. Foaming agent was incorporated in desired quantity (0, 5, 10, 15 and 20%) in the clarified tomato juice (300 ± 0.5 g) for each experiment (Fig. 1). Mixing/whipping was done using hand blender (ORPAT model: HHB 100E, Ajanta Limited, Morbi, India) which was operated (1,400 rpm, 5 min) for foam generation by incorporating air in it to increase surface area of tomato juice. Foam expansion (%) was calculated using Eq. (1) as described by Durian (1995) as follows:

$$\text{Foam expansion (\%)} = ([V_1 - V_0]/V_0) \times 100 \qquad (1)$$

where V_1 is the final volume of foamed juice, cm^3, V_0 is the initial volume of juice, cm^3.

Drying Experiments

Drying experiments were carried out in a commercial hot air tray dryer. The dryer (Scientific Works, New Delhi, India) consisted of an electrical heater, fan and a temperature control (30–110C, dry bulb temperature), having 20 trays (tray dimension of 900 mm × 450 mm) was used for drying foamed tomato juice (300 ± 0.5 g). Each sample of the foamed tomato juice was spread uniformly (2.5-mm thick) in rectangular stainless steel tray. They were subjected to drying at different air temperatures (60, 65 and 70C). Moisture content was recorded at an interval of 30 min using a digital balance having least count of 0.01 mg (Citizen Instruments, Pune, India) on initial and final weight basis. Experiments were conducted in triplicate. Thin layer drying equation was used to calculate the drying rate constants (Liu and Bakker Arkema 1999).

Fitting of Drying Curves

Moisture content of tomato juice during the thin-layer drying was expressed in terms of moisture ratio (MR) using the following equation (Erenturk *et al.* 2004; Kadam *et al.* 2009).

$$MR = (M - M_e)/(M_o - M_e) \tag{2}$$

where M is the mean moisture content at time t; M_o is the initial moisture content; and M_e is the equilibrium moisture content. As the experimental M_e value is very small as compared with the M_o and M values, the M_e value was neglected and the MR was simplified according to Pala *et al.* (1996), Doymaz (2004), and expressed as Eq. (3) (Goyal *et al.* 2007).

$$MR = M/M_O \tag{3}$$

Moisture Diffusivity

Fick's diffusion equation for particles with slab geometry was used for calculation of effective moisture diffusivity. The foamed tomato juice spread on tray was considered for slab geometry (Doymaz 2006). The equation is expressed as (Crank 1975):

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

Equation (4) can be rewritten as:

$$D_{eff} = \frac{\ln MR - \ln \frac{8}{\pi^2}}{\left(\frac{\pi^2 t}{4\,L^2}\right)} \tag{5}$$

The slope (k_o) was calculated by plotting Ln (MR) versus time (t) according to equation (4) to determine the effective diffusivity for different temperatures.

$$k_o = \left(\frac{\pi^2 D_{eff}}{4\,L^2}\right) \tag{6}$$

Color Determination

Color values of foam mat dried tomato juice powder were noted using Hunter Color Laboratory (model No-CO4-1005-631 Rev.E., Hunter Associates Laboratory, Inc, Reston, VA. http://www.hunterlab.com) in terms of L, a, b and yellowness indices (YIs) values. Observations were noted at four places on individual samples and triplicate for each treatment of tomato powder. Values of L, a, b and YIs were recorded directly from Hunter Color Laboratory display screen. Yellowness is associated with scorching, soiling and general product degradation by light, chemical exposure and processing. YIs are used chiefly to quantify these types of degradation with a single value. YIs could also be calculated using the following formula (http://www.hunterlab.com). A correlation to YI as per ASTM model E 313 is calculated using X, Y and Z or L^*, a^*, b^* as follows.

$$\text{YI E313} = (100\,[C_x X - C_z Z]/Y)]$$

where X, Y and Z are the CIE Tristimulus values and the coefficients depends on the illuminant and observer. See Hunterlab Users Manual for more information about this calculation.

Rehydration and Quality Evaluation of Tomato Powder Juice

Rehydration ratio is the ratio of weight of dehydrated tomato powder to the weight of rehydrated tomato powder juice. Rehydration ratio (RR) can be written as:

$$RR = \frac{A}{B} = A : B \tag{7}$$

where A is the weight of the dehydrated sample and B is the weight of the rehydrated sample.

Foam mat dried tomato powder was dissolved in water for 10 min to get tomato juice at par with fresh. One gram of foam mat dried tomato powder was rehydrated in 11 g of water for 10 min.

Total soluble solids (TSS) of rehydrated tomato juice were measured with the help of hand refractometer in °Brix. The pH was recorded using a digital pH meter for acidity or alkalinity of the tomato juice.

Statistical Analysis

Data were analyzed as per procedure of factorial CRD using Agri Res Package (Agres Statistical Software Version 3.01.

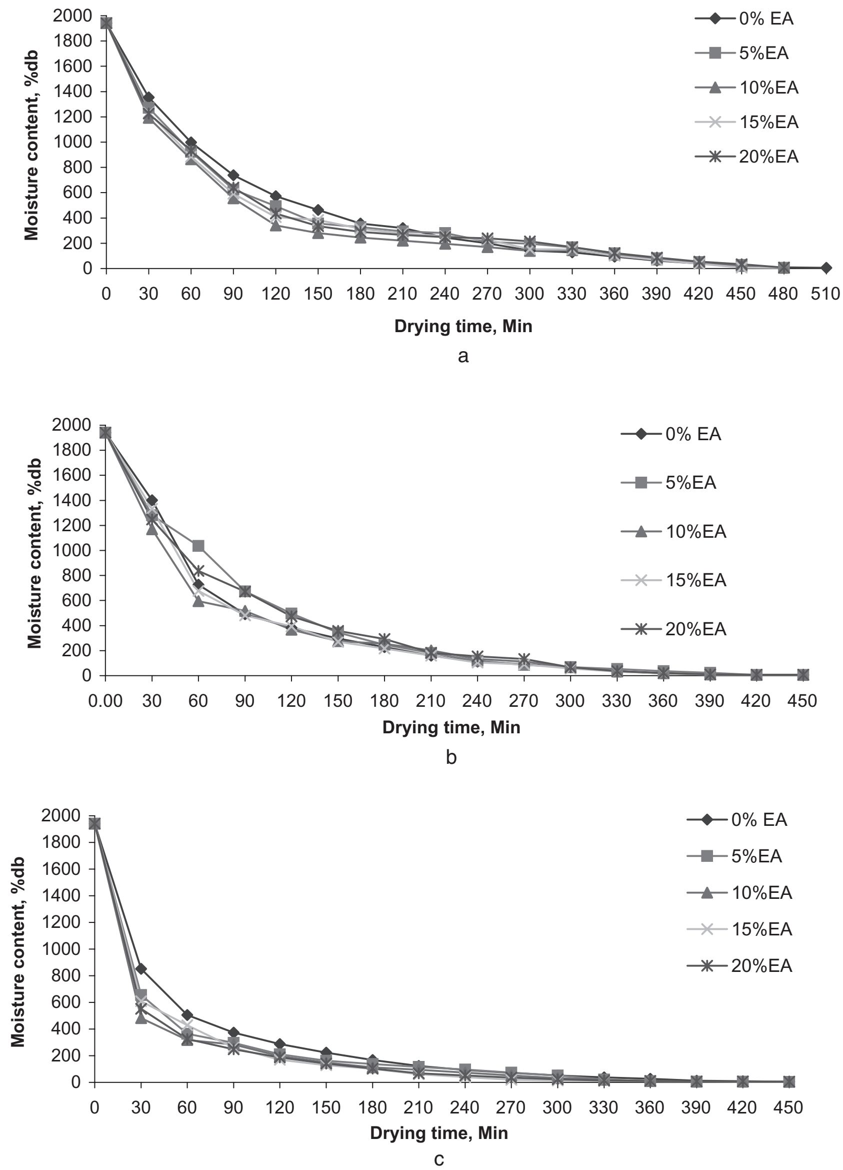

FIG. 2. EFFECT OF EGG ALBUMIN CONCENTRATION LEVEL ON DRYING RATE OF FOAM MAT DRIED TOMATO JUICE AT (a) 60, (b) 65 AND (c) 70C DRYING AIR TEMPERATURE
EA, egg albumin.

[1994]. USA: Pascal International Software Solutions). If the factorial effects are found to be significantly different through analysis of variance (ANOVA), then these were subjected to multiple comparison procedure using least significant difference (LSD) at 5% level of significance. The identification of best combinations was done through one-way classified ANOVA followed by multiple comparison procedure.

RESULTS AND DISCUSSION

Drying Characteristics

Tomatoes having 86.85% of juice with 4°Brix TSS and 13.15% of seeds and skin were used for the experiments. The effect of drying air temperatures on foam mat dried tomato powder is illustrated in Fig. 2 for 60, 65 and 70C. Moisture content decreased with the increase in drying air temperature. Moisture content also decreased with increase in foaming agent up to 15% (w/w) after which decreasing trend was observed. Foam mat drying of tomato juice took about 510 and 450 min at 60 and 70C drying air temperature, respectively. The results obtained were generally in agreement with some literature studies on drying of various food products (Erenturk *et al.* 2004; Doymaz 2006; Goyal *et al.* 2007) and foam mat dried mango powder (Rajkumar *et al.* 2005). It is evident that the air temperature has an important effect on foam mat drying (Fig. 2) and foam mat drying of 10% egg albumin incorporated tomato juice is shown in Fig. 3. When the temperature

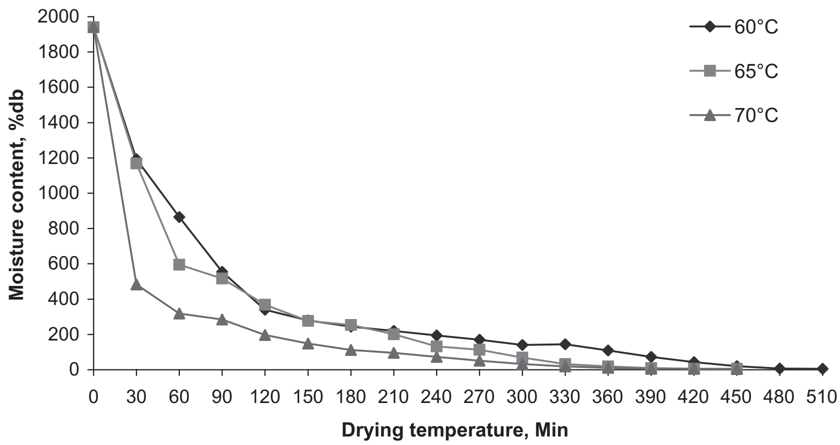

FIG. 3. EFFECT OF DRYING AIR TEMPERATURE ON FOAM MAT DRYING USING 10% EGG ALBUMIN

was increased, the drying time reduced. Similar results are witnessed in earlier studies on drying of garlic slices (Madamba *et al.* 1996), onion slices (Sarsavadia *et al.* 1999), and cauliflower, cabbage and onion (Singh 1994).

Fitting of Drying Curves

Moisture content data at different drying air temperature were converted to more useful MR. The curve fitting computations with drying time were done by using thin layer drying models (Newton, Henderson and Pabis, Logarithmic, Two term, Two term exponential and Wang and Singh). In all the cases, the R^2 values were greater than 0.96 indicating a good fit. The results show that the highest values of R^2 and lowest values of χ^2, MBE and RMSE were obtained with the Logarithmic model with highest R^2 value of 0.985. Thus the Logarithmic model may be assumed to represent the thin layer tray drying behaviour of foam mat drying of tomato juice. There was almost 30 min drying time reduction with an increase of 5C drying air temperature.

Moisture Diffusivity

The effective moisture diffusivity, D_{eff} was calculated using method of slopes (Maskan *et al.* 2002; Doymaz 2004; Goyal *et al.* 2007). Effective moisture diffusivity of foam mat tomato juice ranged from 2.026×10^{-8}–3.039×10^{-8} m^2/s. (Table 1). It was noted that the moisture diffusivity of tomato juice increased with drying air temperature (Fig. 4a–c). However, there was no significant effect of egg albumin percentage on D_{eff} values of foam mat dried tomato powder. The maximum R^2 value of 0.985 was observed in 15% egg albumin incorporated tomato powder dried at 65C and minimum (0.891) at 60C.

Color

It was observed that redness value was more in lower concentration of foaming agent as compared with higher concentration level of 20% egg albumin. It may be caused by the higher percentage of egg albumin that itself is white in color (Table 2). L^*, a^*, b^* and YI values of foam mat dried tomato powder varied from 42.98 to 55.48, 19.46 to 26.45, 16.14 to 20.34 and 89.86 to 110.42, respectively. Statistical analysis showed that L^*, a^*, b^* and YI values were highly significant at different drying air temperature. The identification of best combinations was done through one-way classified ANOVA followed by multiple comparison procedure using LSD. Mean comparison by LSD was done and followed ascending order. The drying air temperatures under each group are on par. *L* and *b* color values were best in 75C followed by 65 and 70C, which can be treated as Rank 1 and Rank 2. Color value *a* was

TABLE 1. EFFECTIVE DIFFUSIVITY (D_{EFF}) OF FOAM MAT DRIED TOMATO JUICE WITH EGG ALBUMIN

Egg albumin, %	Drying temperature					
	60C		65C		70C	
	$D_{eff} \times 10^{-8}$ (m^2/s)	R^2	$D_{eff} \times 10^{-8}$ (m^2/s)	R^2	$D_{eff} \times 10^{-8}$ (m^2/s)	R^2
0	2.532	0.956	3.039	0.985	2.786	0.984
5	2.026	0.898	3.039	0.979	3.039	0.957
10	2.279	0.908	3.039	0.969	3.039	0.972
15	2.279	0.891	3.039	0.985	3.039	0.972
20	2.026	0.892	3.039	0.976	2.786	0.977

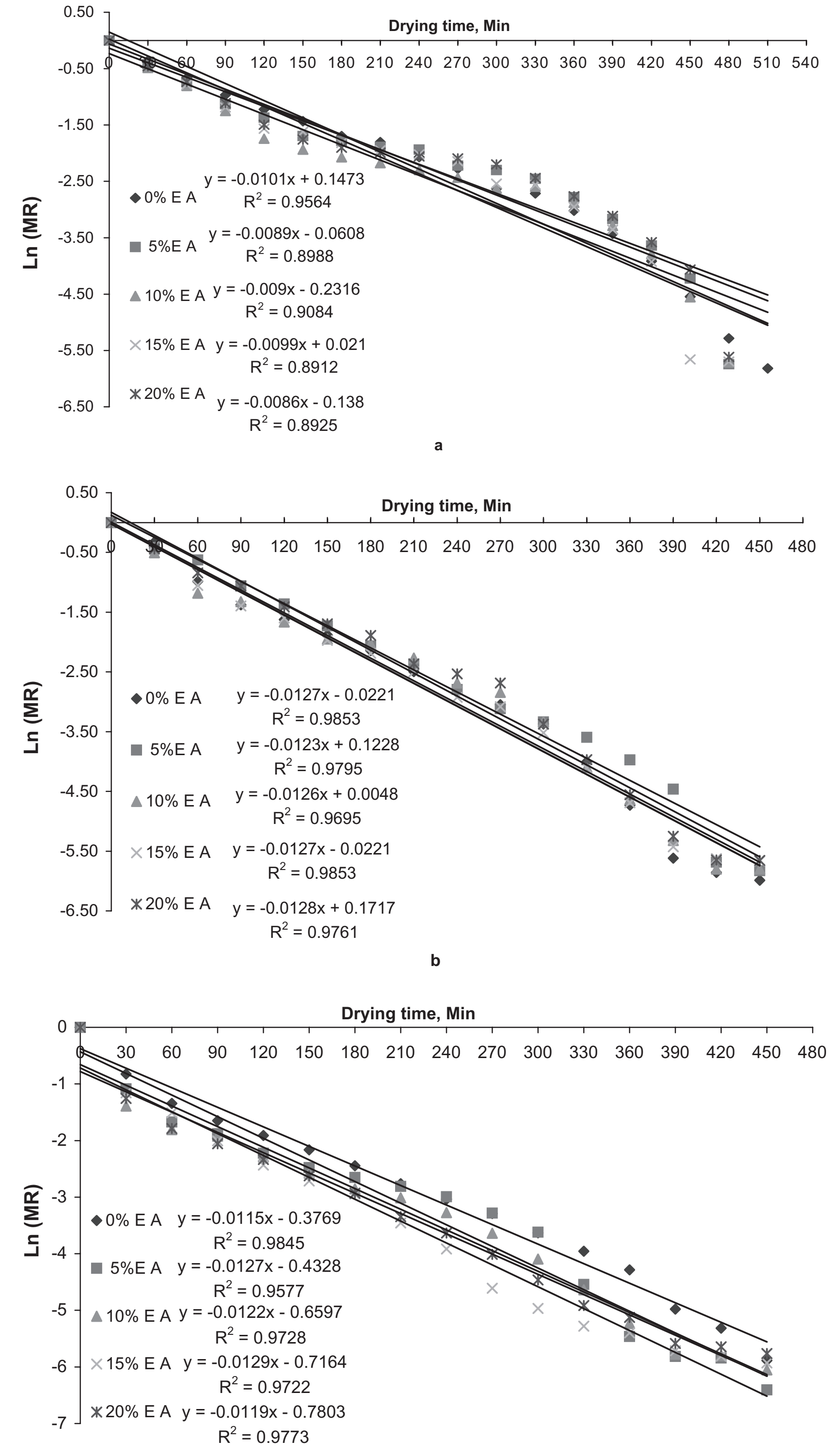

FIG. 4. INFLUENCE OF EGG ALBUMIN CONCENTRATION LEVEL ON THE EFFECTIVE DIFFUSIVITY OF FOAM MAT DRYING OF TOMATO JUICE AT (a) 60, (b) 65 AND (c) 70C DRYING AIR TEMPERATURE
EA, egg albumin.

best in 70C (Rank 1), 65C (Rank 2), and 75C (Rank 3). Similarly, YI value was best in 70 and 65C (Rank 1), followed by 65 and 75C (Rank 2). It is clear that the drying air temperature of 70C is best and it can help to get better color results.

Rehydration Ratio and Quality

Foam mat dried tomato powder can be dissolved completely within 10 min in water to get juice at par with fresh tomato

TABLE 2. EFFECT OF DRYING TEMPERATURE AND FOAMING AGENT CONCENTRATION LEVEL ON L^*, a^*, b^*, YI COLOR VALUES OF FOAM MAT DRIED TOMATO POWDER

Drying air temperature, C	Egg albumin, %	Color values*			
		L	*a*	*b*	YI
60	0	52.61 ± 1.01	21.43 ± 0.56	19.18 ± 0.84	99.00 ± 5.03
	5	55.48 ± 0.48	19.46 ± 0.34	19.05 ± 0.06	89.86 ± 1.39
	10	50.64 ± 1.46	21.22 ± 0.71	17.25 ± 0.45	94.10 ± 4.96
	15	54.42 ± 0.76	20.84 ± 0.66	20.34 ± 0.54	96.47 ± 3.83
	20	53.29 ± 0.93	20.74 ± 0.57	18.96 ± 0.47	94.86 ± 3.80
65	0	53.92 ± 0.83	22.56 ± 0.43	18.99 ± 0.33	95.90 ± 2.81
	5	47.84 ± 1.62	24.91 ± 0.79	18.72 ± 0.57	110.42 ± 5.71
	10	49.27 ± 2.36	25.07 ± 1.47	18.8 ± 1.05	107.93 ± 10.59
	15	49.13 ± 0.33	24.32 ± 0.58	18.64 ± 0.34	106.47 ± 2.63
	20	50.04 ± 1.29	24.22 ± 0.82	18.79 ± 0.57	105.18 ± 5.44
70	0	42.98 ± 0.94	26.45 ± 0.84	16.71 ± 0.58	118.17 ± 5.60
	5	51.45 ± 0.37	23.19 ± 0.21	16.14 ± 0.16	92.56 ± 1.17
	10	51.68 ± 1.46	24.34 ± 0.82	18.13 ± 0.52	100.27 ± 5.53
	15	48.24 ± 1.65	25.33 ± 1.02	17.22 ± 1.27	105.72 ± 9.40
	20	48.59 ± 1.11	24.83 ± 0.72	17.05 ± 0.63	104.18 ± 5.40
	Grand mean	52.06	21.91	18.21	96.36
	SEd	1.71	0.62	0.48	4.88
	$CD_{0.05}$	3.88	1.42	1.10	11.05
	$CD_{0.01}$	5.58	2.04	1.58	15.88
	CV%	4.67	4.05	3.78	7.17

* Mean ± standard deviation.

juice. One gram of foam mat dried tomato powder was rehydrated for 10 min in 11 g of water to prepare tomato juice. Rehydration ratio was 1:12. This ratio was used to measure the TSS and pH value of rehydrated tomato juice which was varied from 2.0 to 2.4°Brix and 4.08–4.41, respectively, at all the air-drying temperature and concentration levels. TSS and pH values were within the range of fresh tomato juice hence it can be used safely.

CONCLUSIONS

Increase of foaming agent level enhanced the drying process (up to 15% egg albumin) followed with a decreasing trend. Tomato juice dried at 60, 65 and 70C temperature took 510, 450 and 420 min, respectively. There is almost 30-min reduction in drying time with increase of 5C in drying air temperature. The optimum level of egg albumin was found to be 10% with whipping for 5 min. TSS and pH values of rehydrated tomato powder were between 2.0–2.4°Brix and 4.08–4.41, respectively. Effective moisture diffusivity of tomato juice ranged from 2.026×10^{-8} to 3.039×10^{-8} m^2/s.

NOMENCLATURE

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 slice, m
M	moisture content at time t, kg moisture/kg dry matter
MBE	mean bias error
M_e	equilibrium moisture content, kg moisture/kg dry matter
M_o	initial moisture content, kg moisture/kg dry matter
MR	dimensionless moisture ratio
N	number of observations
r^2	coefficient of determination
$RMSE$	root mean square error
t	drying time, h
z	number of drying constants

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