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MATHEMATICAL MODELING OF FOAM-MAT DRIED PUMPKIN PULP

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ABSTRACT

Pumpkins (*Cucurbita* Sp.), also known as squashes or gourds, are vegetables of the family *cucurbitaceae*, a wide family that includes other fruits such as melon, watermelon and cucumber. Twenty five species of pumpkin is cultivated throughout the world. These studies focused on determination of moisture ratio at different time and also find out the best mathematical model for foam mat drying of pumpkin pulp. Pumpkin pulp was foamed using 3% and 4% glycerol monostearate(GMS) as foaming agent and then dried at drying temperature of 50°C and 60°C. Weight loss was used to estimate change in moisture ratio with respect to time and effective moisture diffusivity. Five 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 best fitted model for all drying conditions. Regression model-2 was also fitted very well. Moisture diffusivity was varied from 2.026×10^{-9} - 6.079×10^{-9} m^2/s.

Key Words: pumpkin, foam mat drying, GMS, moisture ratio, effective moisture diffusivity.

INTRODUCTION

Foam-mat drying is one of the simple methods of drying in which a liquid food concentrate along with a suitable foaming agent is whipped to form a stable foam and is subjected to dehydration in the form of a mat of foam at relatively low temperature (Morgan et al.,1961;Berry et al.,1965). Rate of drying in this process is comparatively very high because of an enormous increase in the liquid-gas interface, in spite of the fact that the heat transfer is impeded by a large volume of gas present in the foamed mass(Chandak and Chivate,1972).Drying occurs in multiple constant rate periods due to periodic bursting of successive layers of foam bubbles, thus exposing new surfaces for heat and mass transfer as the drying progresses (Hart et al.,1963;Martin et al.,1992).This method is suitable for any heat sensitive, sticky and viscous materials which cannot be dried by spray drying. The foam-mat dried products have better reconstitution properties because of their honeycomb structure and are superior to drum and spray dried products (Chandak and Chivate,1974). Renewed interest in foam-mat drying could be due to its simplicity, cost-effectiveness, rapid drying rate and enhanced product quality. Foaming of liquids and semi liquid materials has long been recognized as one of the methods to shorten drying time. Unlike other drying methods, foam-mat drying does not involve a large capital outlay. The product is also reduced to a light and porous form which, when packaged in polyethylene material, allows for good stability. The drawback of this method is the throughput of the dryer as the moisture is removed from the thin layer of the foam hence the material spread per unit surface of drying area is very small(Kundra and Ratti,2006).

Pumpkin is a mainly summer-growing annual of the genus Curcurbita and the family Curcurbitaceae, which also includes gourds. It is a winter squash recognized by its many creases running from the stem to the bottom on its thick-skinned shell. It is harvested and eaten in the mature fruit stage, when its color has changed from green. Pumpkins are good sources of carotenoids, and some varieties are rich in provitamins A, mainly α-carotene and β-carotene (Marek et al., 2008). Caretenoids are among the phytochemical components believed to reduce the risk of developing some degenerative diseases, and are responsible for the attractive colour of many fruits and vegetables. Pumpkin is also a valuable source of other vitamins, e.g., B_6, K, thiamine, and riboflavin, as well as minerals, e.g., potassium, phosphorus, magnesium, iron and selenium (USDA National Nutrient Database, 2004).

Over the years, foam-mat drying has been applied to many fruit and other food materials including mango, banana, guava, apple (Jayaraman et al.,1974), coffee extract (Chandak and Chivate,1974), mango (Baldry et al.,1976), egg melonge (Rao et al.,1987), soymilk (Akintoye and Oguntunde,1991),pineapple (Hassan and Ahmed,1998), star fruit (Karim and Wai,1999a), cowpea(Falade et al.,2003), banana (Sankat and Castaigne,2004; Thuwapanichayanan et al.,2008; Falade and Okocha,2010), mango (Kadam et al.,2010;Rajkumar et al.,2007), tomato juice (Kadam and Balasubramanian,2011; Kadam et al.,2011a), mandarin powder (Kadam et al.,2011b), bael fruit (Bag et al.,2011),papaya(Kandasamy et al.,2012). Since there is no report showing its application to pumpkin, this investigation has been carried out with the specific objectives to determine the moisture ratio (MR) of foamed pumpkin as well as to study how MR was changed with time and also identify the best mathematical model for foam mat drying of pumpkin pulp.

MATERIALS AND METHODS

The major steps involved in the processing of pumpkin powder by foam-mat drying are: selection of pumpkin, peeling, pulping, incorporation of foaming agent, whipping, spreading the foam in the form of thin mat, drying under selected temperature, scraping, grinding, sieving, packing. Pumpkin used for this study were purchased from a local market of Birati, West Bengal and the pumpkin were washed in running water and kept at refrigerated condition. Pumpkins were peeled manually using a stainless steel knife and the flesh portions were pulped using a mixer grinder (Bajaj, India). The pulp was placed in a sterilized glass beaker and added water in the ratio of 1:2(pumpkin pulp: water) and then the mixture was treated with potassium meta bisulphite at 200 ppm to inhibit microbial and enzymatic activity (Doymaz, 2006, ; Bag et al.,2011] and also to retain the colour of the dried sample. Glycerol monostearate was used at 2, 3 and 4% concentration as a foaming agent within the limits stipulated in the Prevention of Food Adulteration Act.

PREPARATION OF PUMPKIN PULP FOAM

At first glycerol monostearate (GMS) was weighed in different amounts (3% and 4% respectively) then mixed with a refined vegetable oil and water in a ratio of 1:1:10 respectively and heated in boiling water bath (90^0-100^0C) and stirred till GMS gets evenly dispersed to form slurry. The pumpkin pulp and water was added (in a ratio of 1:2 respectively) to the two different slurries and stirred at 300 rpm for 5 minutes in a magnetic stirrer (Eltek, Model – 2011) to form a thick foam slurry.

DETERMINATION OF FOAMING PROPERTIES

The foaming process was optimized in terms of maximum foam expansion and maximum foam stability. Based on these foaming properties, the optimum levels were identified. The foam expansion (FE) was measured (Equation.1) as described by (Akiokato, et al., 1983) :

$FE = \{(V_1-V_0)/ V_0\}*100$------------------------ (Equation.1)

Where FE is the foam expansion (%), V_1 is the final volume of foamed pumpkin slurry (ml) and V_0 is the initial volume of pumpkin slurry (ml).

A criterion for good foam stability was its uniformity and the lack of fluid drainage in 60 minutes after its preparation. (Kadam et al., 2010). The foam obtained from the pumpkin slurries were filled into a transparent graduated cylinder and kept at room temperature (i.e. 25^0C) for 1 hours. The reduction in foam volume was measured as an index for the foam stability.

MOISTURE RATIO

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

$MR= (M-M_e)/(M_o-M_e)$ -------------------------- (Equation.2)

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(Kadam and Balasubramanian,2011; Goyal et al.,2007).

$MR= M/M_o$--- (Equation.3)

MOISTURE DIFFUSIVITY

Fick's diffusion equation for particles with slab geometry was used for calculation of effective moisture diffusivity. Thin layered foamed pumpkin pulp in a tray was considered as slab geometry (Doymaz,2006]. The equation is expressed as (Crank, 1975):

$MR=8/\Pi^2 \exp(-\Pi^2 D_{eff}\, t/4L^2)$-- (Equation.4)

Equation (4) can be rewritten as: $D_{eff} =[\ln MR- \ln(8/\Pi^2)]/(\Pi^2 t/4 L^2)$ -------------(Equation.5)

MODEL FITTING

To select a suitable model for describing the foam mat drying process of pumpkin, values of moisture ratio (experimental values) were fitted with five thin layer drying equations. The evaluated moisture ratio(MR) models are presented in Table 1. 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) (Wang et al. 2007a; Wang et al. 2007b; Eliçin and Saçılık, 2005; Toğrul and Pehlivan, 2002).For quality fit, R^2 value should be higher, χ^2 and RMSE values should be lower.

$$\chi^2= \sum_{i=1}^{n} (MR_{exp,i} - MR_{pre,i})^2/ (N-n) \quad \text{-------------(Equation.6)}$$

$$RMSE =\sqrt{\sum_{i=1}^{n} (MR_{pre,i} – MR_{exp,i})^2/N} \quad \text{---------- (Equation.7)}$$

DRYING EXPERIMENTS

A batch type tray drier (Suan scientific instruments and equipments, India) having a heating unit, blower, drying chamber, air outlet openings was used for drying studies. The dryer was run intermittently in order to stabilize the desired temperature inside the chamber. The homogeneous foamed pumpkin pulp was evenly spread on food grade non-sticky aluminum tray size of 30.5×21.5 cm at foam thickness of 5 mm**.** These trays were kept on an aluminum tray size of 80×40 cm having 7 mm diameter holes. The temperature inside the drying chamber was measured by using a thermometer. The pumpkin pulps foamed with 3% and 4% GMS were dried at different temperatures viz., 50 and 60°C. Petri plates (with foamed pumpkin pulp) were used for to determine weight loss at different time interval. Weight loss was measured every 5,10,15 and 30 minutes interval using a digital electronic balance having least count of 0.01 mg (Keroy II, Economy Series Eb300) on initial and final weight basis. Drying was stopped when the weight of the samples recorded constant values.

PICTURIZATION OF FOAM-MAT DRYING PROCESS

Figure 1 - 7 represented the whole picture of foam mat drying experiment. Figure 1showed the mixture of pumpkin pulp and water.GMS solution (GMS: oil: water) and making GMS solution to GMS slurry was represented in Figure 2 and 3 respectively. GMS slurry was added to pumpkin pulp (Figure1) and after adding GMS slurry to pumpkin pulp the picture was represented in Figure 4. Fig 4 showed the mixture of GMS slurry and pumpkin pulp. Picture of foamed pumpkin pulp which was spread in aluminum tray was showed in Figure5. Figure 6 represented the foam mat dried pumpkin pulp before scraping. Pumpkin powder which was obtained after scrapping, grinding and sieving showed in Figure7.

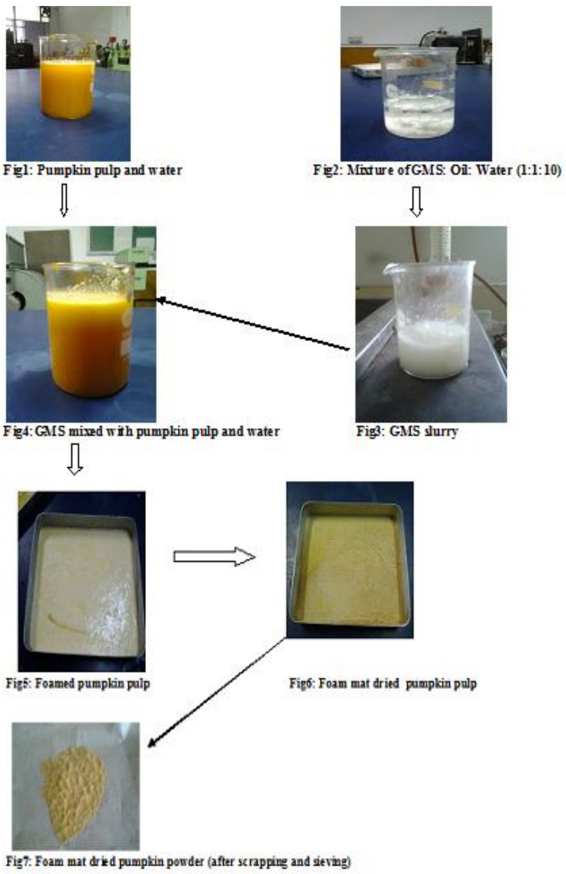

Fig1: Pumpkin pulp and water

Fig2: Mixture of GMS: Oil: Water (1:1:10)

Fig3: GMS slurry

Fig4: GMS mixed with pumpkin pulp and water

Fig5: Foamed pumpkin pulp

Fig6: Foam mat dried pumpkin pulp

Fig7: Foam mat dried pumpkin powder (after scrapping and sieving)

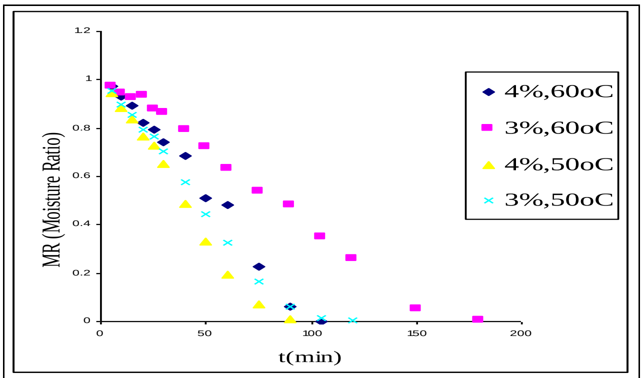

Fig8: Moisture ratio w. r. t drying time at different temperatures and GMS concentration

RESULT AND DISCUSSION

FOAMING PROPERTIES OF USED GMS CONCENTRATION

Pumpkin pulp was foamed with 3% and4%GMS. Foam stability was measured up to one hour(60 minutes).Foaming properties were listed in Table2.Foam expansion showed highest result when pumpkin pulp foamed with 3% GMS. Foams were stable for both GMS concentration at room temperature.

DRYING CHARACTERISTICS

Moisture reduction was higher at initial stages and then started to decrease with the increasing of drying time. Concentrations of foaming agent and drying temperatures have significant effect on drying process. Pumpkin foamed with 4% GMS concentration took less time than 3% for both 50 and 60^{o}C drying temperatures. Drying time was lower at 60^{o}C than 50^{o}C.For all experiments moisture ratio (MR) was higher at initial stage of drying and after different time interval MR was decreased.MR was quite much higher at 60^{o}C than 50^{o}C for both 3% and 4% GMS concentration.MR with respect to time was graphically plotted and showed in Figure 8.

FITNESS OF DRYING MODELS

The moisture ratio data obtained from foam mat drying of pumpkin pulp at different temperatures using different concentrations of GMS were fitted into thin layer drying models (Table1). The model constant, coefficient of correlation and results of statistical analysis are listed in Table 3. Three criteria for adequacy of the model fit, namely, coefficient of determination (R^2), reduced Chi square (χ^2), root mean square error (RMSE) were used. The best model describing the thin layer drying characteristics of pumpkin foam mat drying was chosen as the one with the highest R^2 and lowest χ^2 and RMSE.

Wang & Singh model showed best result with respect to highest R^2 and lowest χ^2 and RMSE value. For Wang & Singh model R^2 value was 0.99, χ^2 and RMSE values varied from (0.00127-0.00554) and (0.00221-0.06798) respectively. Regression model-2 also fitted very well as a mathematical model of drying,R^2 value of was Regression model-2 0.99, χ^2 and RMSE values varied from(0.00105-0.00395) and (0.01217-0.07415).Page and Regression model-1 showed good result with respect to coefficient of correlation and statistical analysis. Thomson model did not fit as good as other model. Value of R^2 of Thomson model was relatively low than other model. In many cases 3% and 4% GMS along with 50^{o}C showed better result than 60^{o}C. All the models fitted gave R^2 more than 0.90.

Table1: Thin layer drying models and their equations

Model Equation	Model Name
MR= at^2+ bt + 1	Wang and Singh (Wang and Singh ,1978)
MR= Exp(-kt^n)	Page (Kumar et al., 2006; Doymaz, 2005)
MR= Exp[-(at^2+ bt)]	Regression model-1
t = aMR^2 + bMR + c	Regression model-2
t= a$[\ln(MR)]^2$ +bln(MR)	Thompson (Thompson et al., 1968)

Table2: Foaming properties of used GMS percentage

Concentration of GMS (%)	Foam Expansion (%)	Reduction of foam volume w. r. t initial foam volume (ml) after a time (min) interval of								
		5	10	15	20	25	30	40	50	60
3%	17%	0	0	0	0	0	0	0	0	0
4%	12%	0	0	0	0	0	0	0	0	0

Table3: Statistical analysis of fitted thin layer drying mathematical models

Model Name	Drying Condition(%GMS, temperature)	Model Constant			R^2	χ^2	RMSE
Wang & Singh		**a**	**b**				
	4%,60°C	-0.000006	-0.008		**0.99**	**0.00554**	**0.06798**
	3%,60°C	-0.000006	-0.005		0.99	0.00200	0.04120
	4%,50°C	-0.00005	-0.013		0.99	0.00169	0.00261
	3%,50°C	-0.00005	-0.012		0.99	0.00127	0.00221
Page		k	n				
	4%,60°C	0.00154	1.625		0.97	0.02259	0.02218
	3%,60°C	0.00148	1.432		0.97	0.01466	0.11272
	4%,50°C	0.00344	1.498		0.97	0.00268	0.04468
	3%,50°C	0.00271	1.510		0.97	0.00254	0.04637
Thomson		a	b				
	4%,60°C	-3.95	-56.43		0.91	0.01548	0.13457
	3%,60°C	-10.12	-104.3		0.93	0.01245	0.13124
	4%,50°C	-4.94	-50.78		0.93	0.01121	0.11256
	3%,50°C	-4.42	-54.75		0.93	0.01101	0.11125
Regression-1		a	b				
	4%,60°C	0.001	-0.035		0.95	0.01347	0.12145
	3%,60°C	0.0001	-0.008		0.97	0.00349	0.02405
	4%,50°C	0.0001	-0.006		0.99	0.00146	0.02589
	3%,50°C	0.0001	-0.002		0.99	0.00126	0.01598
Regression-2		a	b	c			
	4%,60°C	-10.64	-85.81	99.47	0.99	0.00140	0.03415
	3%,60°C	20.19	-183.3	169.5	0.99	0.00395	0.07415
	4%,50°C	26.06	-106	84.91	0.99	0.00120	0.02517
	3%,50°C	51.92	-152.1	107.1	0.99	0.00105	0.01217

MOISTURE DIFFUSIVITY DURING DRYING

The effective moisture diffusivity ranged between 2.026×10^{-9} and 6.079×10^{-9} m^2/s for 50 and 60°C temperature (Table 4). Moisture diffusivity of pumpkin foam mats increased with increase in percentage of GMS along with drying temperature. 4% GMS along with 50 and 60°C drying temperature showed higher moisture diffusivity value than 3% GMS for both drying temperature.4% GMS along with 60°C drying temperature showed highest value, 6.079×10^{-9} m^2/s.

Table4: Effective moisture diffusivity and its linear equation for foam mat drying of pumpkin pulp

Drying Condition	Moisture diffusivity(D_{eff})(m^2/s)	Equation
4%,60°C	6.079×10^{-9}	lnMR = - 0.0006t - 0.21
3%,60°C	3.039×10^{-9}	lnMR = - 0.0003t - 0.21
4%,50°C	5.066×10^{-9}	lnMR = - 0.0005t - 0.21
3%,50°C	2.026×10^{-9}	lnMR = - 0.0002t - 0.21

CONCLUSION

From the present study on foam mat drying of pumpkin pulp, it can be concluded that increase in drying temperature decreased drying time. Foaming with different GMS concentrations had significant effect on drying time. Wang & Singh model was the best fitted model to describe the drying process. Regression model-2 also fitted very well. Mathematical models of drying showed better result at lower temperature than higher. Moisture diffusivity increased with drying temperature and

GMS concentration. Pumpkin powder can be used in food products such as bakery, confectionaries as a source of β-carotene and vitamin A.

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