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Drying characteristics of Chandramukhi variety potato for thin layer and foam-mat drying

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Abstract

We have focused on the behavior of drying characteristics between thin layer and foam mat drying of potato of Chandramukhi variety. The thin layer drying was conducted at three different temperatures (50, 55, 60 °C). The foam mat drying was conducted at three different temperatures (50, 55, 60 °C) and three different concentrations of foaming agent (1%, 2%, and 3%). Glycerol monostearate (GMS) was used as a foaming agent. Drying with foaming agent resulted in increasing drying rates and substantial shortening of drying time than thin layer drying. The activation energy of drying decreases with increasing in GMS percentage. The foaming agent have a significant effect on drying rate at $p<0.05$ level.

Keywords: chandramukhi variety, foam-mat drying characteristics, activation energy, ANOVA analysis, regression model

1. Introduction

Potato, a starchy, tuberous crop from the perennial Solanumtuberosum of the Nightshade family, is a major food crop in the world. It is a rich source of carbohydrate and its protein has a higher biological value than cereals and considered to be better than milk. Global potato production rate is about 324 million metric tons per year out of which India contributes to about 36.5 million metric tons per year as per a study undertaken in 2010. Due to inadequate storage facilities and processing units only about 5% of the world's potato crop is traded internationally (Food Processing Industries Survey, West Bengal).

Drying is one of the most common methods used for preserving potatoes and extending their shelf lives by reducing the moisture content to a low level. The most common economic drying method employed for food materials to date is thin layer hot air drying. The resulting dried products usually record minimal loss of their native nutritional, chemical and physical qualities while the shelf life and onset of microbial spoilage of the products is extended [1, 2].

Another comparatively new drying technique foam- mat drying, originally developed by Morgan et al. in 1959 at the Western Regional Research Laboratory of the U.S. Department of Agriculture is a promising new development in the field of drying aqueous foods [3]. It is a process in which the transformation of products from liquid to stable foam follows air drying at relatively low temperatures to form a thin porous honey-comb sheet or mat which is disintegrated to yield a free-flowing powder having higher reconstitution properties and better quality attributes than drum dried and spray dried products [4].

This investigation has been carried out with the specific objective of doing a comparative study of characteristics of thin layer and foam mat drying of potato of Chandramukhi variety for development of potato powder.

2. Materials & Methods

2.1 Collection and Preparation of Raw Material

Potatoes used in this study were of Chandramukhi variety freshly collected from local market of South Kolkata (cultivated in Tarakeswar, Hoogly district, West Bengal, India). The potatoes had initial moisture content of 82.34%. The potato samples were washed with running tap water and distilled water respectively to make it free from soil and blotted with a tissue paper for removal of excess surface water. The potato samples were then peeled and cut into slices of equal thickness of 10±0.3 mm each. The sliced potato samples were blanched in hot water (Temperature 90±2ºC) containing 2% sodium chloride (NaCl) and 200ppm of potassium meta-bisulphate for 10 minutes and followed by preparation of mash in a mixer grinder. The potato mash was gelatinized in an autoclave at 10 psig pressure for 15 minutes [5].

2.2 Drying Equipment

The foam mat drying and thin layer hot air drying experiments were carried out in a batch type tray drier (Suan Scientific Instruments &Equipments). The drier was equipped with an electrical heater, blower (230rpm) and temperature indicators. It consisted of trays (800X400X30mm) with perforations of diameter 7mm and a temperature controller (0-200ºC).

2.3 Preparation of Foam

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

2.4 Design of Drying Experiments and Drying Procedure

A complete randomized design (CRD) with three level treatment of temperature (i.e. 50°C, 55°C, 60°C respectively) was chosen for thin layer drying. The 3^2 factorial designs with three levels of treatment temperature (i.e. 50°C, 55°C, 60°C respectively) and percentage of GMS (1%, 2%, and 3% respectively) were chosen for foam mat drying. The designs lead to 3 sets and 9 sets of experiments respectively.

The tray drier was run intermittently in order to stabilize the desired temperatures (i.e. 50ºC, 55ºC, 60ºC respectively) inside the chamber. The homogeneous foamed potato was poured to Petri plate to equal thickness of 10mm and equal weight of 10gm each and kept for drying. Same was done for non-foamed potato mash. The foamed and non-foamed potato slurries were dried at different temperatures until constant weight. The Petri plates were taken out of the drying chamber at different time intervals for determination of weight loss. The loss in weight was recorded using Dhona balance having least count of 0.1 mg on initial and final weight basis. Final moisture content of each of the sample was obtained by A.O.A.C method. A crispy powder was obtained which was grounded to a fine powder in a mixer grinder.

2.5 Determination of Drying Rate

Curves of moisture content as a function of time were plotted. This was useful directly in determining the time required for drying. Much information were obtained when the data was converted into drying rates expressed as (–) dX/ dt and plotted against time (t).

2.6 Determination of Moisture Ratio

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

$$MR=(M_t-M_e)/ (M_o-M_e) \qquad (1)$$

Here, M_t is moisture content at any specific time, M_e is the equilibrium moisture content and M_o is the initial moisture content. As the M_e value is very small compared to M_o and M_t values, the M_e value can be neglected and the moisture ratio was simplified and it can be expressed as

$$MR= M_t/M_o \qquad (2)$$

2.7 Determination of Moisture Diffusivity

The moisture migration process during drying is complex and often involves one or more transport mechanisms such as liquid diffusion, vapor diffusion, Knudsen diffusion, surface diffusion and hydrostatic pressure differences [6]. The term effective diffusivity (D_{eff}) is defined to describe the rate of moisture movement, no matter which mechanism is involved. Fick's diffusion equation for particles with slab geometry was used for calculation of effective moisture diffusivity. The equation is expressed as:

$$MR = [(8/ \pi^2)*\exp \{(- \pi^2 D_{eff} t)/(4L^2)\}] \qquad (3)$$

The equation can be rewritten as

$$D_{eff} = [\{\ln MR – \ln (8/\pi^2)\}/\{(\pi^2 t)/(4L^2)\}] \qquad (4)$$

The slope (k_o) is calculated by plotting ln (MR) vs. time to determine the effective diffusivity at a particular temperature. Now,

$$k_o = [(\pi^2 D_{eff})/ (4L^2)] \qquad (5)$$

2.8 Determination of Activation Energy

Temperature dependence of the effective diffusivity has been shown to follow an Arrhenius relationship [7, 8] where E_a is the energy of activation (kJ/mol), R is universal gas constant (8.3143 kJ/mol), T is absolute air temperature (K), and $D_0$is the pre-exponential factor of the Arrhenius equation (m^2/s).
The activation energy can be calculated from the slope of the Arrhenius plot, ln (D_{eff}) versus 1/Ta. A plot of ln (D_{eff}) versus 1/Ta gives a straight slope of K

$$K=E_a/R \qquad (6)$$

3. Results & Discussions

3.1 Drying Characteristics

Fig 1 shows a comparative study of the change in moisture content as drying proceeds between thin layer of unfoamed potato mash (0% GMS) and foamed potato mash containing 1%, 2% , 3% of glycerol monostearate as foaming agent at 50ºC, 55 ºC and 60 ºC.
It is evident from these curves that foam mat drying is a much faster procedure than thin layer hot air drying. Moreover the combination of temperature and percentage GMS plays a significant role in decreasing the drying time. The average time for foam mat drying depending on the temperature are 165mins, 145mins and 120mins at 50ºC, 55 ºC and 60 ºC respectively and for thin layer drying the drying time was recorded to be considerably higher at about 300mins at 50ºC and 240mins (for both 55 ºC and 60 ºC).

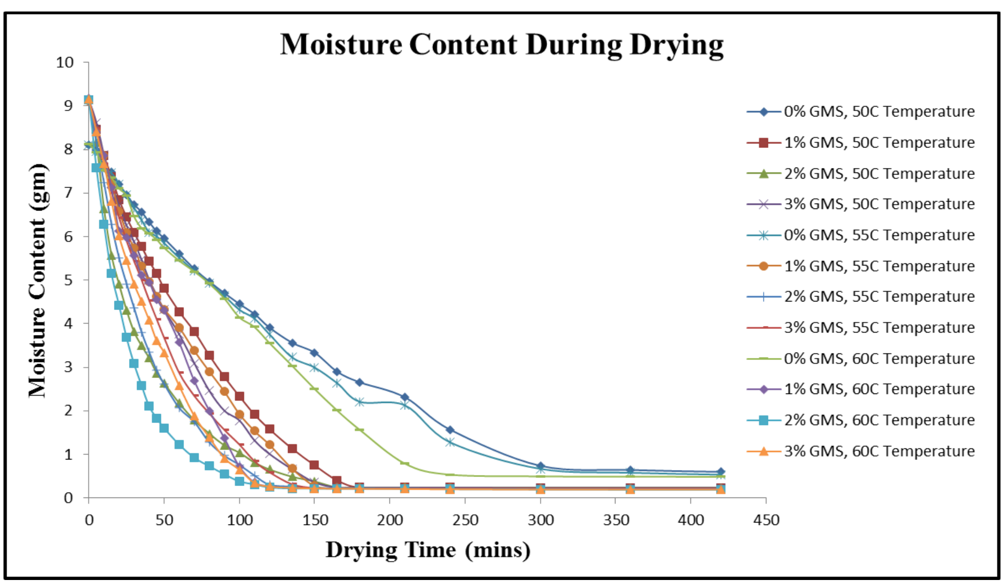

Fig 1: Moisture Content of Potato Mash with different concentrations of GMS w.r.t Drying Time at Different Temperatures

The fact that drying time was reduced by almost 50% on introduction of foaming is evident from the results. The conclusion that foam mat drying is more effective can be backed by the observation that the final moisture content of the foam mat dried powder was in the range of 1.89% - 2.35% and that of thin layer dried powder is 4.85% – 6%. The results are in accordance with the earlier observations for foam mat drying of tomato [10] and mango [11]. The considerable decrease in the drying time may be due to the stable foam structure which increases the surface area of exposure and the air incorporated inside gets heated up to provide simultaneous drying to the inner walls. Finally the honey comb structure makes it easier for the water vapor to penetrate through the thin warm walls and easily escape outside.

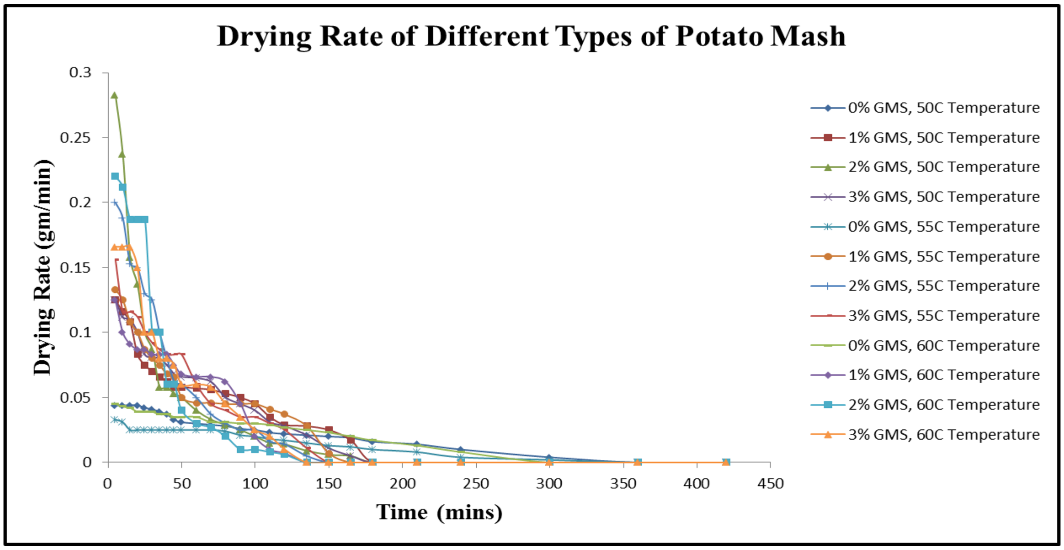

Fig 2: Drying Rate of Potato Mash with different concentrations of GMS w.r.t Drying Time at Different Temperatures

The drying rates were given in Fig 2. From this figure it is observed that though the drying rate becomes constant at times the drying occurs mostly during the falling rate period regardless of the drying conditions. Although potato has high moisture content, the constant drying rate period was not as significant as expected. ANOVA analysis of drying rate (Table 1) of different time shows that a significant different exist between thin layer drying and foam mat drying at $p<0.05$ level. It is also seen that variation in GMS (0% for unfoamed slurry and 1% to 3% for foamed slurry) has a significant effect on drying rate up to 90 minutes of drying from starting. After 90 minutes of drying the changes in drying rate take place only due to constant heating of unfoamed and foamed slurry. So, the slope of the foam mat drying rate curves are steeper than that of the hot air drying rate curves and hence the drying rate decreased rapidly in foam mat drying. The pattern observed in the foam mat drying rate of potato mash are in accordance with different drying rate studies on tomato [10], beans and peas [12]. The temperature variation for thin layer and foam mat drying has no significant effect on drying rate at $p<0.05$ level (Table 1).

Table 1: ANOVA analysis of Drying Rate

	Variation of GMS %		Variation of drying temperature	
Effect	**F value**	**P value**	**F value**	**P value**
5 min drying rate	28.61	0.001*	0.32	0.740
10 min drying rate	31.46	0.00046*	0.53	0.615
15 min drying rate	26.88	0.001*	1.47	0.303
20 min drying rate	27.87	0.001*	2.34	0.177
25 min drying rate	11.96	0.006*	1.79	0.245
30 min drying rate	18.67	0.002*	1.07	0.401
35 min drying rate	10.26	0.009*	1.31	0.337
40 min drying rate	13.65	0.004*	0.63	0.563
45 min drying rate	31.02	0.00047*	2.05	0.209
50 min drying rate	7.490	0.019*	0.150	0.864
60 min drying rate	8.558	0.014*	0.124	0.886
70 min drying rate	13.00	0.005*	1.33	0.333
80 min drying rate	14.86	0.003*	0.95	0.439
90 min drying rate	14.48	0.004*	1.53	0.290
100 min drying rate	3.116	0.110	2.305	0.181
110 min drying rate	1.857	0.238	1.469	0.302

*- significant at $p<0.05$ level

The data for moisture content was converted to moisture ratio and the Logarithm of Moisture Ratio v/s Drying Time curve (Fig 3) was plotted and effective moisture diffusivity was calculated from the slope.

The effective moisture diffusivity ranged between 1.033E-07 and 1.205E-07 m^2/s for temperature range from 50 to 60ºC and different concentrations GMS (Table 2) and for thin layer drying effective moisture diffusivity ranged between 6.889E-08 and 8.612E-08 m^2/s for temperature range from 50 to 60ºC. This shows that due to higher moisture diffusivity the foamed potato mats reach their equilibrium moisture content faster than the thin layer potato mats at any particular temperature. Moisture diffusivity of potato foam mats increased with increase in drying air temperature. Moisture diffusivity was maximum for 2% glycerol monostearate at 60ºC.

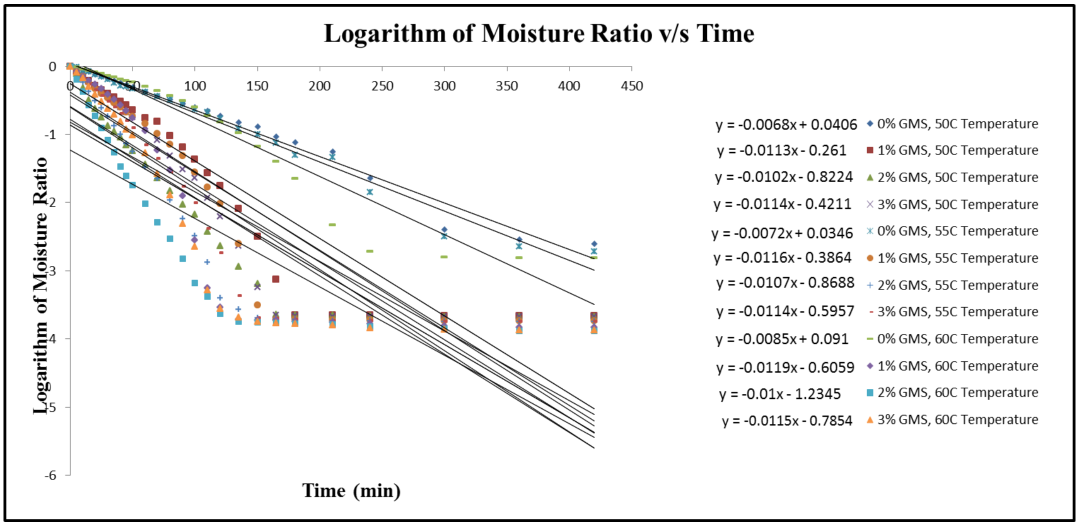

Fig 3: Logarithm of Moisture Ratio of Potato Mash with different concentrations of GMS w.r.t Drying Time at Different Temperatures

Table 2: Effective moisture diffusivity and its linear equation for foam mat drying and thin layer drying of potato mash

Temperature (ºC)	%GMS	Equation	k_0 values	D_{eff}	R^2
50	0	y = -0.0068x + 0.0406	-0.0068	6.889E-08	0.982
	1	y = -0.0113x - 0.261	-0.0102	1.033E-07	0.8433
	2	y = -0.0102x - 0.8224	-0.0113	1.144E-07	0.7684
	3	y = -0.0114x - 0.4211	-0.0114	1.155E-07	0.7962
55	0	y = -0.0072x + 0.0346	-0.0072	7.295E-08	0.9829
	1	y = -0.0116x - 0.3864	-0.0116	1.114E-07	0.7941
	2	y = -0.0107x - 0.8688	-0.0107	1.185E-07	0.7035
	3	y = -0.0114x - 0.5957	-0.0114	1.175E-07	0.7511
60	0	y = -0.0085x + 0.091	-0.0085	8.612E-08	0.9278
	1	y = -0.0111x - 1.2345	-0.0111	1.124E-07	0.6508
	2	y = -0.0119x - 0.6059	-0.0119	1.205E-07	0.698
	3	y = -0.0115x - 0.7854	-0.0118	1.195E-07	0.6975

3.2 Determination of Activation Energy

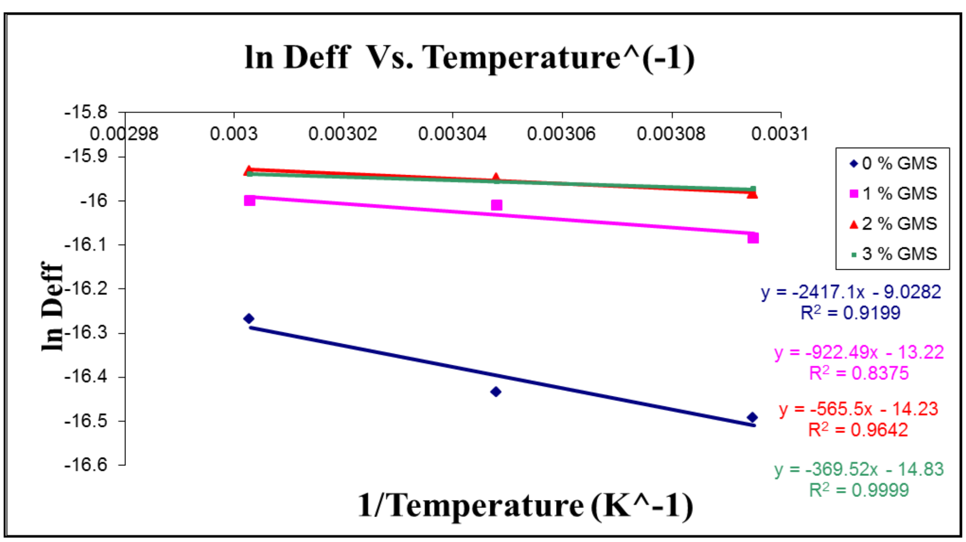

Fig 4: Plot showing logarithm of Effective Moisture Diffusivity with respect to Temperature inverse for different types of samples.

Activation energy at the three different temperatures was calculated from Fig 4.

The activation energy of the different potato mashes containing 0%, 1%, 2% and 3% GMS calculated from Fig 4 are 20.095 kJ/mol, 0.7669 kJ/mol, 0.4701 kJ/mol and 0.3072 kJ/mol respectively. This shows the foamed potato mats require less energy for drying than unfoamed potato mat.

4. Conclusion

From the present study on foam mat drying of potato mash, it can be concluded that drying of potato mash took place mainly during the falling rate period. Foaming with different glycerol monostearate concentrations had significant effect on drying up to the level of 2% as evident from moisture ratio curves and diffusivity data. Further increase in emulsifier concentration either had similar or negative impact on drying. Activation energy for foam mat drying is less than thin layer drying. The highest effective moisture diffusivity obtained was 6.889E-08 m^2/s at 60ºC with 2% emulsifier concentration which is also the condition when the drying occurs the fastest.

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