CHANGES IN THERMAL PROPERTIES AND COLOUR ATTRIBUTES OF POTATO (CHANDRAMUKHI VARIETY) DURING FOAM MAT AND THIN LAYER DRYING

Sreemoyee Chakraborty*[1], Saikat Mazumder[2], Soumitra Banerjee[1]

Address(es):
[1]Department of Food Technology, Techno India, Saltlake Sector V, Kolkata 700091, West Bengal, India.
[2] Department of Food Technology, TechnoIndiaUniversity, Saltlake Sector V, Kolkata 700091, West Bengal, India.

*Corresponding author: sreemoyee.chakraborty1989@gmail.com

ABSTRACT

Thermal properties of potato of Chandramukhi variety, including density, specific heat, thermal conductivity and thermal diffusivity during foam mat and thin layer drying were determined. The thin layer drying was conducted at three different temperatures i.e. 50ºC, 55ºC, 60ºC. The foam mat drying was also conducted at three different temperatures (50, 55, 60ºC) with three different concentrations of foaming agent (1%, 2%, and 3%). Glycerol monostearate (GMS) was used as a foaming agent. The specific heat, thermal conductivity and thermal diffusivity decreases as temperature increases from 50ºC to 60ºC in both of the drying. The foaming agent has a significant effect on drying rate and thermo-physical properties at $p<0.05$ level. Temperature and foaming both have a significant effect on color of dried powder at $p<0.05$ level. These thermal characteristics can be practically applied in modeling thermal behavior of potato mash during thermal processing operations.

Keywords: Chandramukhi variety potato, specific heat, thermal conductivity, thermal diffusivity, Hunter Lab colorimeter analysis

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 about 17-20% is wasted and due to its perishability more than 50% of surplus is wasted during transportation. Only about 5% of the world's potato crop is traded internationally (**Food Processing Industries Survey, West Bengal**). The export potential of potato can be increased by employing an ideal preservation technique that will increase the shelf life, diversify its usability, help in development of some innovative food products, as well as stabilize its international market value.

Thin layer 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. 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 (**Morgan *et al*, 1961,**), is a promising new development in the field of drying of high moisture foods. Drying of food material depends upon the heat and mass transfer characteristics of the product being dried. The thermal properties are unique and influence the efficiency of the process as well as the process itself involving changes in temperature of the process and composition of the food material (**Heldman*et al*., 2002**).

Thermal properties aid in selection and calibration of the drying equipments and understanding the transformations occurring inside the food matrix, e.g., the evolution of Biot number, the change in heating kinetics inside the particle as the drying progresses. Density, thermal conductivity, thermal diffusivity and specific heat capacity are four important thermal engineering properties of a material related to heat transfer characteristics. These parameters are essential in studying thermal processes of potato. Specific heat in thermal processes has a key role in computation of energy cost and also required dimensions for machinery and equipment design. Moreover, this parameter changes in food products along with their physical and chemical properties (**Mioe and Grodek, 2007**). Thermal conductivity of food materials is very important not only for process design, but also to predict and control of different changes occurring in food during thermal processing. Generally, this character depends on moisture content, temperature, porosity, nutritional content and component phase's distribution. Also, thermal

diffusivity is a necessary transport attribute that is needed in modelling and computations of transient heat transfer in basic food processing operations, including drying, cooling/freezing and thermal processing (**Kocabiyik*et al.* 2009**).

Research on thermal properties has been reported for agricultural crops, especially different types of seeds, such as borage seed (Boragoofficinalis) (**Yang *et al*., 2002**), cumin seed (CuminumcyminumLinn.) (**Singh and Goswami, 2000**), guna seed (Citrulluscolocynthis) (**Aviara*et al.,* 2008**), black seed (Nigella oxypetalaBoiss.) (**Gharibzahedi*et al*.,** 2012), roselle seed (Hibiscus sabdariffaL.) (**Bamgboye and Adejumo, 2010**) and Loco (Concholepasconcholepas) (**Reyes *et al*., 2011**).

This investigation has been carried out with the specific objective of determining the thermal properties of potato of Chandramukhi variety. Moreover incorporation of foam changes the structure of the food matrix which directly effects the transport processes during foam mat drying. Hence the effect of different degrees of foaming and moisture reduction under elevated levels of temperature on these properties was also studied. Colour as a physical property was determined as a measurement of the overall effect of the processing conditions on the quality and acceptability of the final dried sample.

MATERIALS & METHODS

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 potato samples were washed with running tap water and distilled water respectively to make it free from dirt and 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 potatoes had initial moisture content of 82.34gm of moisture/100gm wet weight. The sliced potato samples were blanched in hot water (Temperature 90±20ºC) containing 2 gm NaCl/100 gm of water of sodium chloride (NaCl) and 2mg of potassium meta-bisulphate/1000gm of water 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 (**Chakraborty *et al*, 2013**). 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 and water was added (in a ratio of 10:1 respectively) 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.

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).

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 10gms each and kept for drying. Same was done for non foamed potato mash. The trays were then placed on the tray stand in position for drying. 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 and packed in LDPE zip pouches (0.06mm film thickness) separately.

Determination of Thermophysical Properties

The thermophysical properties i.e. specific heat, density, thermal conductivity and thermal diffusivity of the thin layer potato mash and the foamed potato mash were calculated from Choi and Okos model (**Choi and Okos, 1986**). The compositions of the potato mashes were determined at different time intervals with the different sample weights obtained and the mass fractions and volumetric mass fractions were calculated from it.

Prediction of Specific Heat

The specific heat of a food is defined as the quantity of thermal energy associated with unit mass of the food and a unit of change in temperature. A general prediction model for analysis of specific heat of food as a function of its composition and drying temperature has been developed by Choi and Okos (**Choi and Okos, 1986**) based on an extensive study and analysis of specific heat data for many types of food with different compositions and over a temperature range of 20-100ºC (**Heldman *et al*, 2002**). The specific heat of the total product is expressed as a summation of the product of component specific heat and mass fraction of the component:

$$c_p = \Sigma(c_{pi}M_i) \qquad (1)$$

where c_p is the total specific heat, c_{pi} is the component specific heat and M_i is the mass fraction of the product.

Prediction of Density

The general model for prediction of density was proposed by Choi and Okos (**Choi and Okos, 1986**) and involves around the product composition (M_i) and the density (ρ_i) for each component (**Heldman *et al.,* 2002**).

$$\rho = 1/\Sigma(M_i/\rho_i) \qquad (2)$$

The proposed model predicts the density of high moisture food (> 60%) from the compositional information and the density relationships from the general model. For intermediate and low moisture foods (<60%) the particle density can be predicted by

$$\rho_p = e_s(\rho_s - \rho_a) + \rho_a \qquad (3)$$

based on density of the product solids (ρ_s) predicted from the general model, the volume fraction of solids (e_s) from the compositional components and the density (ρ_a) of air. The total density of the food can be calculated in a similar manner as that of the high moisture foods (**Heldman *et al.,* 2002**).

Prediction of Thermal Conductivity

The general model for prediction is based on the observations made by **Choi and Okos (1986).** The thermal conductivity (k) of the food material can be given as

$$k = \Sigma(k_i E_i) \qquad (4)$$

where the volume fraction (E_i) is estimated for each component by

$$E_i = (M_i/\rho_i)/ \Sigma(M_i/\rho_i) \qquad (5)$$

Since the general model does not emphasize on the physical structure of the food material so it is applicable for high moisture (>60%) foods. In cases where the discontinuous component is same or higher in concentration than the continuous component the thermal conductivity can be can be expressed as derived and proposed by **Kopelman (1966)**

$$k = k_c[\{1- E_d(1-k_d/k_c)\}/\{1-E_d^2(1-k_d/k_c)(1-E_d)\}] \qquad (6)$$

where E_d is the volume fraction of discontinuous product component, k_c and k_d are the respective thermal conductivities of the moisture and solid fractions of the product derived from the general model (**Heldman *et al.,* 2002**).

Prediction of Thermal Diffusivity

The combination of these three properties is thermal diffusivity, a key property in the analysis of unsteady state heat transfer (**Heldman *et al.,* 2002**). Mathematically it is expressed as

$$\text{Thermal Diffusivity} = k/(c_p * \rho) \qquad (7)$$

Statistical analysis

A main effects analysis of variance (ANOVA) was used to establish the significance of differences among the values of drying rate, specific heat, density, and thermal conductivity at the 0.05 significance level. Statistical analyses were performed using Statistica (version 7) (Stat Soft, Inc., USA).

Color Measurement of Dried Potato Powder

Color is the most important physical attribute for acceptability and determination of quality. The color of the different potato samples were estimated using Hunter Lab Colorimeter (Color flex, 45/0 spec photometer). The color was measured in terms of L*, a* and b* coordinates, where L* is the lightness (0 = black, 100 = white), a* for the red (positive values) to the green (negative values) and b* indicates the yellowness (positive values) and blueness (negative values). Total color difference (ΔE), polar coordinate chroma or saturation (C*) and L* values were used as an index to report the color quality and are calculated from the following equations:

$$C^* = (a^{*2}+b^{*2})^{0.5} \qquad (8)$$

$$\Delta E = [(L^*-L_{standard})^2 + (a^*-a_{standard})^2 + (b^*-b_{standard})^2]^{0.5} \qquad (9)$$

Regression equation Modeling

RSM Modeling

Relationships between the independent variables (temperature, percentage of GMS) and dependent variables (total color difference ΔE) for foam mat drying were studied. The regression equation was determined (using Statistica, version 7, Stat Soft, Inc., USA) using multiple regression technique by fitting second order regression equation (**Khuri and Cornell, 1987**) of the following type

$$Y = \beta_o + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{nn} \beta_{ii} X_i^2 + \sum_{i=1}^{n-1}\sum_{j=i+1} \beta_{ij} X_i X_j + e \qquad (10)$$

where β_0, β_i, β_{ii}, β_{ij} are regression coefficients of variables for intercept, linear, quadratic and interaction terms, respectively, X_i, X_j are the independent variables, Y is the dependent variables n is number of independent variables. The relationships between the responses were judged by correlation multiple R, multiple R^2 which indicates the value of correlation coefficient and co-efficient of determination between the experimental and predicted data. The significance or P-value was decided at a probability level of 0.05.

Simple Regression

A simple regression in between dependent variable (total color difference (ΔE)) and independent variable (temperature) for thin layer drying has been determined (using Statistica, version 7, Stat Soft, Inc., USA) using the first order regression equation of following type

$$Y = a + bX \qquad (11)$$

Where, a, and b is the intercept and slope respectively, and Y is dependent variables and X is independent variables. The relationships between the responses were judged by correlation multiple R, multiple R^2 which indicates the value of correlation coefficient and co-efficient of determination between the experimental and predicted data. The significance or P-value was decided at a probability level of 0.05.

RESULTS & DISCUSSIONS

Determination of Thermophysical Properties

Determination of Specific Heat

Figure1 shows the change in the specific heat of potato mash samples during drying within the range of 3.9529 kJ/kg^{o}C to 1.5579 kJ/kg^{o}C for foamed potato mats and from 3.6890 kJ/kg^{o}C to 1.7819 kJ/kg^{o}C for unfoamed thin layer potato mats. During drying with decrease in moisture content the specific heat decreased accordingly. This co-relation between specific heat with moisture content correlates with work done by **Nathakaranakule *et al*. (1998)** for cashew nuts, **Chandrasekar *et al*. (1999)** for coffee, **Bart-Plange *et al*. (2012)** for maize cow

pea and cashew kernel and **Isa *et al*. (2014)** for melon. One of the reasons of change in specific heat of potato mash was may be due to its change in percentage composition during drying. So as the moisture content decreases and eventually becomes negligible, the composition of the potato mash becomes constant and hence the specific heat finally becomes constant. The ANOVA analysis of specific heat at different time of drying (Table 1) shows that the variation in GMS percentage (0% for unfoamed slurry and 1% to 3% for foamed slurry) has a significant effect (at $p<0.05$ level) on specific heat before specific heat become constant. Whereas, variation temperature of drying has a significant effect on specific heat only at the initial stages (Table 1). One probable cause is initially when the temperature was rising up it had a significant effect on specific heat. But as temperature elevation stopped no further significant effect on specific heat was observed.
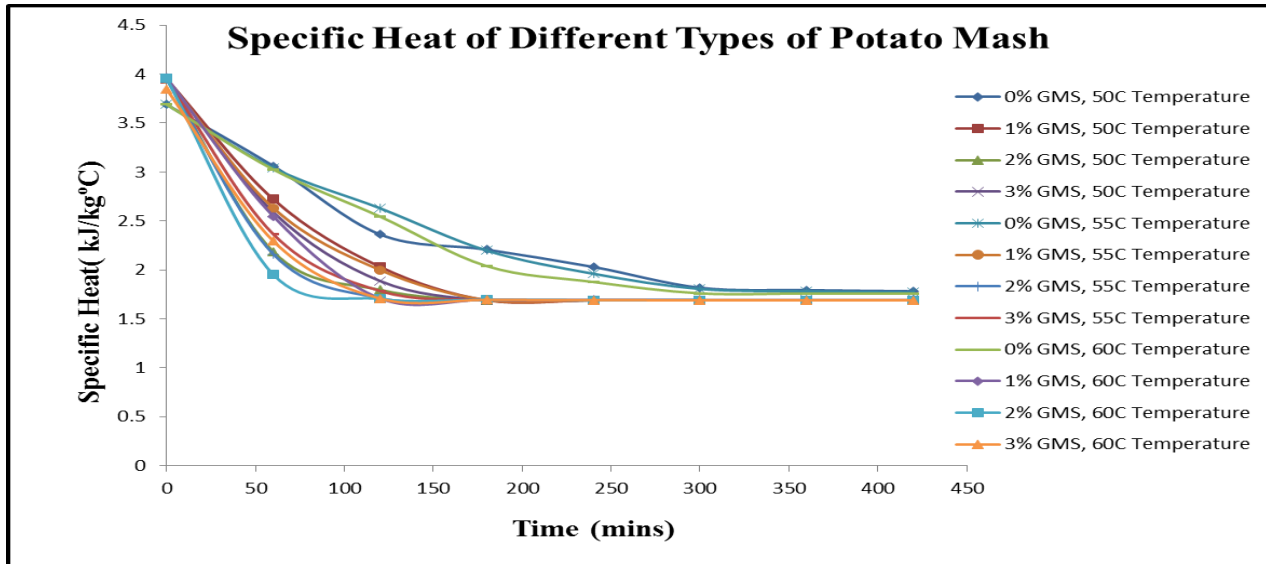

Figure 1 Specific Heat of Potato Mash with different concentrations of GMS during Drying at Different Temperatures

Table 1 ANOVA analysis of specific Heat (C_p)

Effect	Variation of percentage of GMS		Variation of drying temperature	
	F value	P value	F value	P value
60 min C_p	100.69	0.00002*	7.2629	0.02498*
120 min C_p	25.482	0.00082*	1.0780	0.39812
180 min C_p	37.780	0.00027*	0.84826	0.47377
240 min C_p	9.1565	0.01172*	0.89873	0.45561
300 min C_p	0.20068	0.89228	0.94526	0.43968

*- significant at $p<0.05$ level

Determination of Density

Figure 2 shows the increase in density of potato mash within the range of 1024.47kg/m^3 to 1555.21kg/m^3 for foam mat drying and from 1073.66 kg/m^3 to

1522.81 kg/m^3 for thin layer drying. This change in density with decrease in moisture content was also observed by **Kibar*et al*. (2010)** for rice, **Seifi and Alimardani (2010)** for corn, **Gupta and Das (1997)** for sunflower seed and **Balasubramanian (2001)** for cashew. The ANOVA of density at different time of drying shows that a significant difference in density is observed mainly for variation in percentage of GMS (0% for unfoamed slurry and 1% to 3% for foamed slurry) at $p<0.05$ level (Table 2). The probable cause is during foaming the volume of the potato mash increased due to air incorporation. As drying progressed the moisture was removed and the volume decreased. Since the volumetric contraction was higher than moisture removed, so it may be a reason why density increased with decrease in moisture content. The variation of temperature has a significant effect on density only at 120 minutes. This might be due to that after 60 minutes the temperature elevation stopped (which discussed previously for specific heat). After that, the penetration of temperature to the core of the foamed and unfoamed slurry started and almost reached completion at 120 minutes.
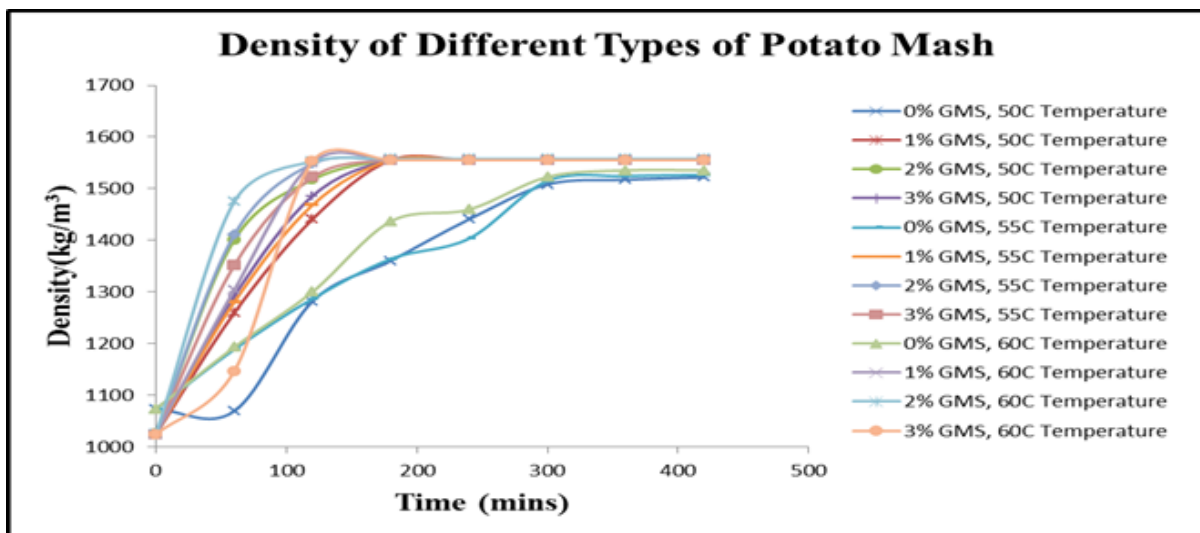

Figure 2 Density of Potato Mash with different concentrations of GMS during Drying at Different Temperatures

Table 2 ANOVA analysis of Density

Effect	Variation of percentage of GMS		Variation of drying temperature	
	F value	P value	F value	P value
60 min Density	7.6260	0.01802*	0.53722	0.61007
120 min Density	79.917	0.00003*	6.7141	0.02945*
180 min Density	46.948	0.00015*	1.0884	0.39509
240 min Density	54.850	0.00009*	1.1014	0.39136
300 min Density	99.743	0.00002*	1.4908	0.29811

*- significant at $p < 0.05$ level

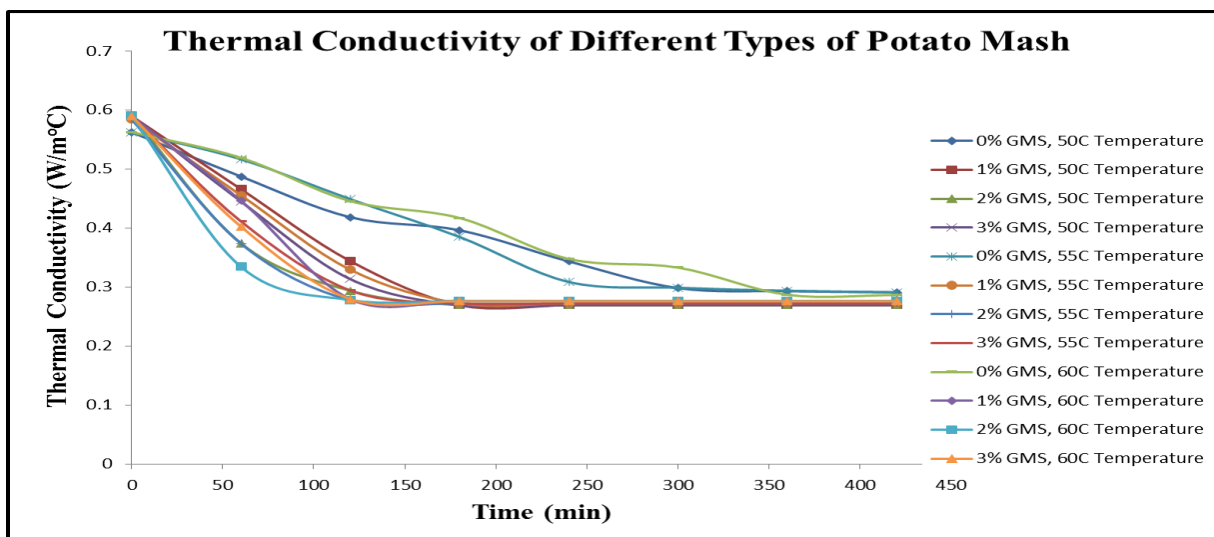### Determination of Thermal Conductivity

Figure 3 shows the decrease in thermal conductivity within the range of 0.5903 W/m°C to 0.2694 W/m°C during foam mat drying and 0.5626 W/m°C to 0.2912 W/m°C for thin layer drying. The positive relationship of thermal conductivity with moisture content of all the potato mash samples agreed with other researchers such as **Perusella*et al*., (2010)** for banana, **Bart-Plange*et al*., (2009)** for cowpea and maize and **Singh and Goswami (2000)** for cumin seeds. Since water has a higher thermal conductivity compared to dry agricultural materials and thus may contribute to high thermal conductivity in them at the initial stages

of drying. As drying progressed the thermal energy decreased which may be as a result of removal of large amount of moisture from it. The ANOVA analysis (Table 3) shows that throughout the process a significant difference was observed mainly for variation in percentage of GMS (0% for unfoamed slurry and 1% to 3% for foamed slurry). The addition of GMS incorporates the air into the potato mash. Due to variation of air incorporation for different percentage GMS initial volume was different for different potato slurry. Hence, the variation of GMS has a significant effect on thermal conductivity at $p < 0.05$ level.

Table 3 ANOVA analysis of Thermal Conductivity

| Effect	Variation of percentage of GMS		Variation of drying temperature	
	F value	P value	F value	P value
60 min Thermal conductivity	31.457	0.00046*	0.94329	0.44034
120 min Thermal conductivity	35.194	0.00033*	1.2146	0.36067
180 min Thermal conductivity	243.62	0.00000*	3.1447	0.11638
240 min Thermal conductivity	24.663	0.00090*	1.4600	0.30434
300 min Thermal conductivity	14.973	0.00342*	3.2019	0.11318

*- significant at $p < 0.05$ level

Figure 3 Thermal Conductivity of Potato Mash with different concentrations of GMS during Drying at Different Temperatures

Determination of Thermal Diffusivity

Figure 4 shows the decrease in thermal diffusivity within the range of 1.4644 X 10^{-04} m²/s to 1.0271 X 10^{-04} m²/s for foam mat drying and from 1.4372 X 10^{-04} m²/s to 1.0717 X 10^{-04} m²/s for thin layer drying. **Hobani and Al-Askar, (2000)**, found the thermal diffusivity of Khudary and Sufri dates to decrease linearly with decreasing moisture content. Other researchers such as **Aviara and Haque (2001)**, **Tansakul and Lumyong (2008)**, **Shyamal et al., (1994)** reported a

positive relationship between thermal diffusivity and moisture content for sheanut kernel, straw mushroom and wheat respectively. Moisture has a higher ability to conduct thermal energy than dry materials. Since the potato mashes contained high percentages of liquid the initial thermal diffusivity was high. As time elapsed the removal of moisture took place which may be the cause of decrease in thermal diffusivity and hence when the moisture content became negligible the thermal diffusivity also became constant.
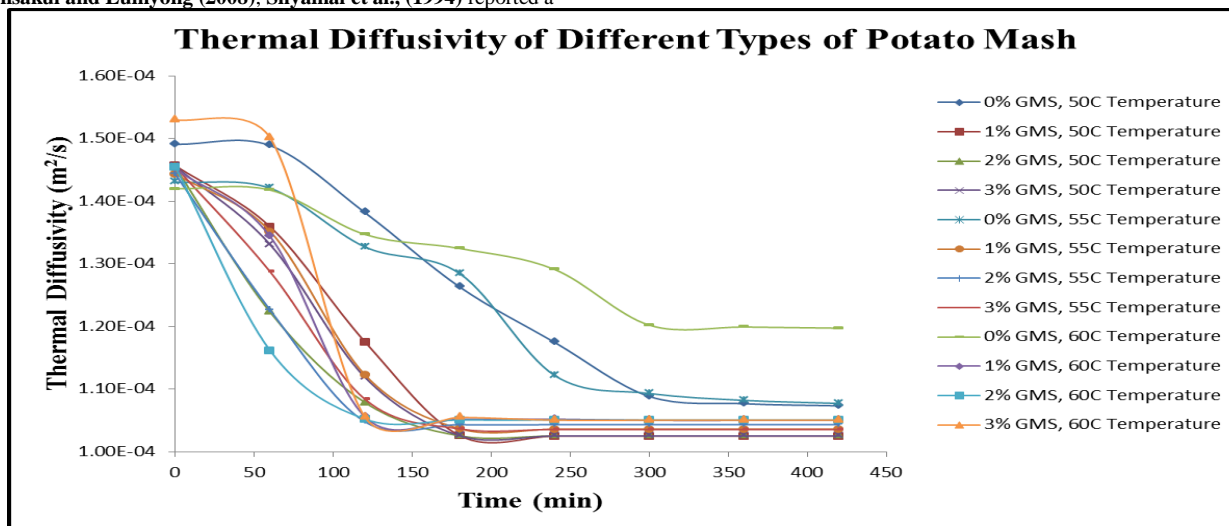
Figure 4 Change in Thermal Diffusivity of Potato Mash with different concentrations of GMS during Drying at Different Temperatures

Color Measurement of Dried Potato Powder

It was observed that L* values are higher in case of foam-mat drying than in case of thin layer drying and the values increased as the drying air temperatures increased from 50 to 60°C in all the cases (Table 4). This may be due to the fact that foam mat drying with addition of GMS up to 2% decreased the drying time by almost 50% so the length of exposure to heat was less and thus the whiteness of the powder was preserved but above 2% GMS there was no significant change. **Shi *et al*. (1999)** for tomato and **Jakubczyk *et al*. (2011)** for foam-mat dried apple showed that higher L* value is desirable in dried products. The total color difference (ΔE) between raw potato and foam mat dried potato was less than that between raw and thin layer dried potato. The color saturation or vividness (C*) of the foam mat dried powder is comparable to the fresh raw potato slices. Drying at 60ºC with 2% GMS has shown the saturation of 16.44 which is closest to the standard raw potato.

Table 4 Effect of Drying on Color of Potato Powder

Temperature (ºC)	%GMS	L*	a*	b*	ΔE	C*
Raw Potato Slices (Standard)		69.33	-1.47	15.71	-	±15.78
50	0	65.75	2.01	23.35	±9.126	±23.43
	1	71.85	1.97	21.29	±7.023	±21.38
	2	72.79	1.83	20.48	±6.754	±20.56
	3	72.87	1.85	21.10	±7.253	±21.18
55	0	63.37	2.20	23.83	±10.723	±23.93
	1	73.39	1.68	18.35	±5.777	±18.42
	2	74.77	1.32	17.18	±6.288	±17.23
	3	74.79	1.37	17.91	±6.535	±17.96
60	0	61.53	2.45	24.05	±12.073	±24.17
	1	75.94	1.01	19.32	±7.929	±19.34
	2	78.70	0.89	16.42	±9.688	±16.44
	3	78.63	0.93	17.38	±9.748	±17.40

Regression Analysis

RSM Modeling

The RSM modeling was fitted to response data of total color difference (ΔE). It was found that temperature and square term of temperature both have significant effect on total color difference (ΔE) at p<0.05. The model equation is

$$T.C.D \ (\Delta E) = 227.4916 - 8.1574*T + 0.0746*T^2 - 3.1052*\%GMS - 1.992*\%GMS^2 + 0.0795*T*\%GMS \quad (12)$$

In equation 12, T denotes temperature (^{0}C). The value multiple R (0.98) and multiple R^2 (0.97) was found to be very good which indicates that the model was very effective for prediction of total color difference.

Simple Regression

A simple regression has been done to obtain the model equation for dependent variable (total color difference (ΔE)) and independent variable (temperature) for thin layer drying (Table 4). The model equation is

$$T.C.D \ (\Delta E) = -5.56783 + 0.2947*Temperature \ (^0C) \quad (13)$$

It was found that temperature has significant effect on total color difference (ΔE) at p<0.05. The value multiple R (0.99) and multiple R^2 (0.99) was found to be very good which indicates that the model was very effective for prediction of total color difference.
Joglekar and May (1987) have suggested for a good fit of a model, regression coefficient (R^2) should be at least 80%. The above two model (i.e. equations 12, 13) can be effective for prediction purpose because R^2 value is more than 80% (i.e. R^2> 0.80).

CONCLUSION

Change in temperature and degree of foaming agent significantly affected the thermal properties of potato. As drying progressed the decrease in moisture content showed a considerable decrease in specific heat capacity, thermal conductivity and thermal diffusivity while density increased due to loss of moisture. Knowledge of these thermal properties is important for mathematical modelling and simulation of heat and moisture transport systems. However, it is also observed that the moisture content significantly affects different thermal characteristics.The variations in temperature also had significant effect on the color of the potato. Moreover the dried sample with 2% GMS seemed to have retained the color comparable to the original color of raw potato.

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