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Optimization of Microwave Heating and Ambient Tempering for Accelerated Drying of Milk *Paneer* Using Response Surface Methodology

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ABSTRACT

The study was conducted during January to June, 2019 under college of Agricultural Engineering, Department of Post Harvest Process and Food Engineering, JNKVV, Jabalpur, M.P. (482002), India. The main objective of the research was to determine how *paneer* cube size influenced drying time and to study the effect of the combination of microwave heating tempering time and hot air drying on drying rate of *paneer* cube. A *paneer* sample was prepared using a National Dairy Development Board-developed industrial *paneer* manufacturing procedure (NDDB). Response surface methodology was implemented in this study to optimize microwave heating and ambient tempering for accelerated drying of milk *paneer*. Optimization factors included *paneer* cube size (5–25 mm), microwave power level (150–750W), heating time (2–10 min), and tempering time (1–5 min), while responses included moisture content (dry basis %) and bulk density (g cc^{-1}). Optimum parameter for highly acceptable product with (13.8 mm) cube size at the microwave power level (670.27 W), heating time (7.2 min), tempering time (4.621 min) presented the Moisture content (22.15%) and bulk density (0.36 g cc^{-1}) by using Design expert 13. The experimental values under the microwave drying condition matched the outcome predicted by analysis of variance. It shows that the model is highly fit and that response surface methodology (RSM) was successful in maximizing the microwave power level, which has a significant and advantageous impact on drying rate.

KEYWORDS: *Paneer*, microwave drying, moisture content, bulk density, RSM

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1. INTRODUCTION

A high-quality block of *paneer* has a marble-white color, a flavor that is sweet but somewhat acidic, a nutty scent, a spongy body, and a tightly woven and smooth texture. Standards (Khans and Pal, 2011) at least 50% of overall fat and a maximum of 60% moisture in the total solids for *paneer.* One day at room temperature and six days in the refrigerator are the maximum storage times for *paneer*. *Paneer* has a biological value of between 80 and 86% because of its high protein content and ease of digestion. (Srivastava and Goyal, 2007).

Drying procedures remove moisture by simultaneous mass and heat transfer (Ertekin and Yaldiz, 2004). Drying, which halts microbial and enzymatic activities and considerably reduces product weight and volume to make it easier to handle, transport, package, and store, is the most ancient and therefore most dependable method for preserving food (Soysal, 2004).

Microwave drying is a method of drying food in which microwaves penetrate the material and convert it to heat, permitting moisture to be removed (Drouzas and Schubert, 1996). Microwave drying is putting incredible breath for the generation of best quality dried product (Ozcan-Sinir et al., 2019). Microwave heating is a vital new method for the thermal processing of food and dairy products. Instantaneous heating is caused by friction between water molecules inside the product. Products with more moisture, fat, and sugar are more receptive to microwave energy and hence heat up quickly. When compared to conventional heating, microwave heating offers a number of benefits in terms of rapid and thorough heating that results in foods that are higher in quality in terms of nutrition, taste, texture, and flavour, as well as improved production (Maskan, 2000; Decareau, 1985).

Microwave heating can generate heat generated together in microwaves drying system that aids in permeating the inner layers and quickly adsorbing the moisture from the material. That heat is absorbed by the sample, which leads to progressive evaporation of water. This causes a flow of quickly evaporating vapours to move in the same direction as the moisture gradient. (Dadali et al., 2007; Soysal et al., 2006; Wang et al., 2007). As the moisture content of the material approaches the boiling point during microwave drying, the vapor pressure rises, facilitating the transport of moisture to the outside. Despite the fact that the moisture content of treated materials falls and the loss factor of those materials increases, local pressure and temperature rise (Bengtsson, 1974; Odjo et al., 2012).

The impact of numerous independent factors can be examined using a collection of computational and statistical tools known as the response-surface methodology. The analysis of wide variety of input components that have an impact on the performance metric, the qualitative properties of the product, or the investigative process can be done with the help of RSM. RSM's key benefit was that it minimised the number of tests required to assess a range of variables and associated correlations. (Zhong et al., 2012).

RSM was used to examine the process optimization of microwave heating and ambient tempering for the rapid drying of milk *paneer*. Building models for *paneer* drying using the selected drying technique was one of the objectives of this study, along with an analysis of the impacts of *paneer* cube size on drying time, microwave heating tempering duration, and hot air drying combined over *paneer* cube drying rate (Table 1).

Table 1: Values of the independent factors utilized in the RSM

Independent Factors	Codes	Levels				
		-2	-1	0	+1	+2
Paneer cube size (mm)	A	5	10	15	20	25
Microwave power level (W)	B	150	300	450	600	750
Heating time (min)	C	2	4	6	8	10
Tempering time (min)	D	1	2	3	4	5

2. MATERIALS AND METHODS

2.1. Material

The study was conducted during January to June, 2019 under college of Agricultural Engineering, Department of Post Harvest Process and Food Engineering, JNKVV, Jabalpur (M.P), India. In this research, fresh milk (buffalo milk) was used as the raw material for the preparation of *paneer*.

2.1.1. Sample preparation

The National Dairy Development Board created a commercial *paneer* production process for the preparation of *paneer* (NDDB). The milk used in this procedure is heated to 85°C, co-precipitated using a plate heat exchanger, pumped to a cheese vat, and then chilled to 75°C. A citric acid solution is added to hot milk and thoroughly mixed to coagulate it. Without agitation, the curd is allowed to sit for ten to fifteen minutes. Following the draining of the whey, cheese hoops made of muslin cloth are filled with the curd piles and pressed for 10 to 15 minutes at a pressure of 3 kilo gram per square centimeter to get rid of the whey, and then the blocks were submerged in 4°C cold water for three hours to cool and firm the *paneer*.

Following that, the paneer was cut using a knife and thread into five sizes of paneer cubes of 5, 10, 15, 20 and 25 mm. Each sample of *paneer* cubes to be dried was 50 g in weight.

2.2. Physical properties

The bulk density and pertinent physical characteristics of *paneer* cubes, notably their moisture content, were thought to be helpful for this inquiry.

2.2.1. Moisture content

Using the traditional air oven approach, the moisture content of *paneer* cubes were determined. (Raghavan et al., 2005)

On dry basis (%) it calculated as follows:

MC_{bd} (%)=$(W_w/W_d)\times100=m/(100-m)\times100$ ...1

And on wet basis (%) by the formula (sahay and singh 2003)

MC_{wb} (%)=$W_w/W_w+W_d)\times100$ ...2

Where,

W_d=Weight of dry matter (g)

W_w =Weight of water(g)

MC_{db}=Moisture content dry basis (%)

MC_{wb}=Moisture content wet basis (%)

2.2.2. Bulk density

A 10 ml flask was used to measure the bulk density. To fill the void spaces, *paneer* cubes were manually shook ten times after being poured into the measurement cylinder. (Mohsenin, 1986)

Bulk density =(Massofsample (g))/Volume of flask occupied by the sample (cm^3) …3

2.3. Drying kinetics analysis

2.3.1. Moisture ratio

This was found to be (Ozbek and Dadali, 2007)

$MR=(M-M_e)/(M_0-M_e)$ ...4

Where,

M=The moisture content in real time (% db)

M_0=Initial moisture content (% db)

M_e=Equilibrium moisture content (EMC) of material (db)

Me is quite little in relation to M_0 and M_e so M_0 can be disregarded and the moisture ratio can be stated in a simplified manner. (Doymaz, 2004 and Goyal et al., 2007)

$MR=M/M_0$ ...5

2.3.2. Drying rate (DR)

Following was computed for the drying rate. (Chakraverti, 1981)

DR=Amountofmoisture (g)/(timetaken(min)×{Total none dry wt of sample (W_d)/100 g)}) ...6

Similar to how the drying rate will be influenced by the difference in moisture content between of material was dried with EMC at the drying state:

$DR=M_{t+dt}-M_t/dt$ ...7

Where,

DR=Drying rate (g/g min)

M_t=Moisture content at time t (% db)

M_{t+dt}=Moisture content at time t+dt (% db)

d_t=Time of successive measurement (min)

2.4. Experimental methodologies

Five different microwave generating powers-150, 300, 450, 600, and 750 W duty cycles of the microwave ovens magnetron tube-were tested for drying *paneer* cubes in five different sizes-5, 10, 15, 20, and 25 mm. From the raw *paneer*, each sample of *paneer* cube to be dried was 50 g in weight and selected. The *paneer* cubes were microwave dried for 10 minutes, pausing every 2 minutes to allow the cubes to finish drying or tempering in the atmosphere for 5 minutes. By utilizing a digital scale to weigh the plate, moisture loss was calculated. Each microwave generating power was used for three distinct drying tests. To establish the drying parameters, the values from these trials were averaged.

2.4.1. Experimental design, statistical analysis and optimization

RSM is a statistical technique that identifies ideal conditions using quantitative data from a suitable experimental design. *Paneer* cube size (A), microwave power level (B), microwave heating time (C), and tempering time were the variables selected for microwave drying trials (D). On the basis of early drying trials, the variable values were chosen. 27 experiments were run using the CCRD with 5 levels of variable (CCRD).Response Surface Methodology (RSM), which looks at the relationship between a number of explanatory variables and response variables, was used to analyze the collected data utilizing the trial programmers.

In order to fit the model represented by equation (1) to the experimental observations and to evaluate the statistical significance of the model analysis, lack of fit test, and R^2 (coefficient of determination) analysis, (Lee et al., 2000 and Bezerra et al., 2008) claim that regression analysis and variance estimation (ANOVA) were used.

$$Y_k=\beta_0+\sum_{i=1}^{k}\beta_iX_i+\sum_{i=1}^{k}\beta_{ii}X_i^2+\sum_{i=1}^{k-1}\sum_{i=i+1}^{k}\beta_{ij}X_iX_j \quad ...8$$

In which Y is the response (predicted moisture content and bulk density), β_i represent the linear coefficient, β_{ii} represent the quadratic coefficient, β_{ij} represent the effect of the combination X_i and X_j are independent factors with coded values, and X_i, X_j, and X_i^2 represent the interaction and quadratic term, respectively.

When points were omitted from the regression and model fluctuations could not be explained by random error, lack-of-fit is a measurement with model's inability to accurately reflect data of experimental domain. When the probability value indicates a significant lack of fit, the response predictor is dropped. The ratios of the standard deviation towards the total variation is known as the R^2 (coefficient of determination), which measures the degree of fit. (Haber, 1977).

The CV displays the difference between the experimental data and the model prediction. The Design Expert software used which also performed numerical optimization. It is important to note that its 3D figure was produced by changing another two variables inside the experimental range while holding one variable unchanged only at the centre point. The streamlined approval to create was displayed as three-dimensional surface graphs for graphical improvement (Wang et al., 2001).

3. RESULTS AND DISCUSSION

The initial bulk densities of *paneer* cubes in five varied sizes as 5, 10, 15, 20 and 25 mm were determined to be, respectively, 0.580, 0.453, 0.438, 0.428, and 0.416 g cm^{-3}. It was discovered that as *paneer* cube size rose, density dropped due to an increase in *paneer* cube volume. Because *paneer* cubes lost weight when moisture evaporates, bulk density decreased as microwave heating time and power levels were increased. After 10 minutes of drying a 5 mm *paneer* cube at a 150W power level, the maximum bulk density was determined to be 0.6035 g cm^{-3}. After 10 minutes of drying at a 750 W power level, a *paneer* cube measuring 25 mm in size had a minimum bulk density of 0.03012 g cm^{-3}.

The microwave drying process decreased the *paneer* cube's moisture content from 114.59% (db) to 19.57%, depending on microwave power levels and cube size (db). Weight loss increased as *paneer* cube size increased, the amount of moisture removed from material increased every 2 minutes of the drying cycle, and also with incremented in microwave power level during the drying of 50 g *paneer* cubes at 5 microwave power. The total weight loss was 15.32(5) g at 150W, 29.78(5) g at 300W, 36.84(5) g at 450W, 39.78(3) g at 600W, and 41.18(2) g at 750W. Depending on the size of the material, the highest value of moisture removed from it at 600W was attained between 8 and 10 minutes into the drying process. Minimum moisture was removed from the sample of minimum size (5 mm) cubes while maximum moisture removed from the sample of the biggest size (25 mm) of *paneer* cubes in the 10 min. drying period. The higher moisture content food product during the microwave drying normally had higher moisture loss factor which allows more microwave energy to be drawn to the moisture (Feng et al., 2012). Higher value of exposure time and power level resulted in faster moisture removal and vice-versa (Sunanda et al., 2017).

For microwave powers 150W to 750W, the average drying rate of *paneer* cubes varied from 1.252/100 g.min to 3.810 g/100 g.min depending on the drying rate measured in time under microwave power levels. At the time of first drying process, the material's extraordinarily high moisture content caused greater moisture diffusion. The decrease in microwave power absorption brought on by the product's drying caused a decrement with drying rate. The rate of drying increased as power levels rose. As a resulted, the drying rate was significantly and favorably impacted by the microwave power level. It was concluded, that microwave drying can increase the drying rate, preserve colour as the use of higher power level (Amanda et al., 2021). The drying time and energy consumption decrease, whereas drying rate increase with increase in the microwave power level (Celen, 2019)

The MR exhibited a trend toward decline as microwave heating duration increased. For the drying of a 25 mm *paneer* cube in MR 0.996, the maximum depletion was observed at 750W, while the minimum depletion in MR 0.503 was discovered at 150W.

3.1. *Response surface analysis of bulk density*

Bulk density significantly fell as microwave power rose (P 0.0001). Bulk densities of the *Paneer* cubes were differed from 0.03012 to 0.6035 g cm^{-3} on average. According to the ANOVA result (Table 2), every independent factor had a highly significant effect on bulk density (P 0.0001). Given that the coefficient of determination (R^2=0.9664) and adjusted determination coefficient (Adj R^2=0.9272) both were close to 1, the regression model seemed to be adequate. The "Adeq Precision" signal-to-noise ratio (SNR) has a value of 17.2258 (>4), indicated that this model can faithfully replicate the tests. As the coefficient of variation (CV) becomes down, the model's repeatability increased.

Table 2: Evaluation of the bulk density Regression Model's relationships between independent and dependent variables

Source of Variation	Sum of squares	Degree of freedom	Mean square	F-value	P-value
Residual	0.004	12	0.0003		
Lack of Fit	0.0039	10	0.0004	12.97	0.0737
Pure error	0.0001				
Cor total	0.1179	26			

R^2: 0.9664, R^2 (adj.): 0.9272, R^2 (Pred.): 0.8082, Adeq. Precision: 17.2258 , C.V.%: 2.55%

(Hosein et al., 2019) reported that Adeq Precision compares the range of predicted values at design points to the average prediction error. A ratio greater than 4 is desirable. The ratio of 53.523 indicated an adequate signal to noise ratio. So this model can be used to navigate the design space.

The link between the projected value and the actual value is shown in Figure 1 the empirical model can commendably explain the correlation between the variables and bulk density, advancing the validity of the regression model. The following second-order model had based on these findings and represents the multiple regression equation that describes how processing parameters affect bulk density in coded values.

Bulk density=+0.850196-0.002085A+0.000067B+0.017100C+0.017100D-7.50684E-06AB-0.000175AC-0.000681AD-0.000019BC-0.000026BD-0.001916CD+0.000036A2-1.43748E-07B2+0.000665C^2 +0.001359D^2 ...9

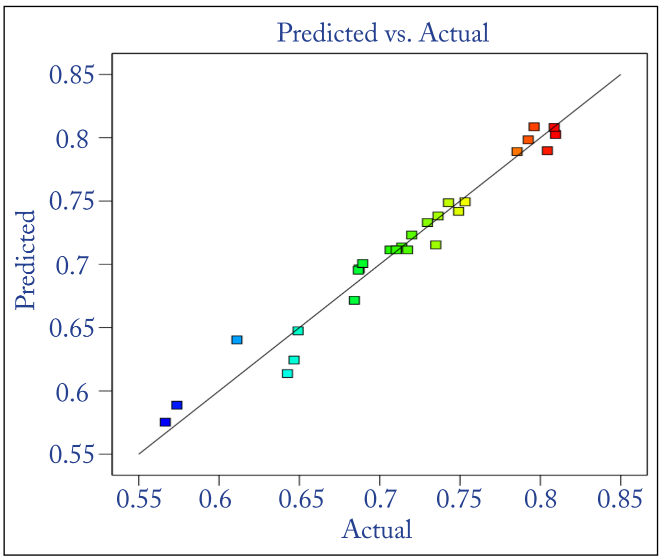

Figure 1: Comparing predicted and experimental data the bulk density values

Effect of process variable can be seen Figure 2 that bulk density decrease with increased microwave power level and microwave

Effect of process variable can be seen in Figure 2 that bulk density decreases with increased microwave power level and microwave heating time. It was determined that bulk density decreased with an increment with drying temperature and that moisture content was dependent on air temperature (in the microwave cavity). Bulk density decreases with increase in the level of vacuum acquiring puffed nature of the products (Chauhan et al., 2015). In Figure 3 bulk density decreased with increasing *paneer* cube size because larger *paneer* cubes had more volume than smaller *paneer* cubes, so bulk density decreased as volume increased.

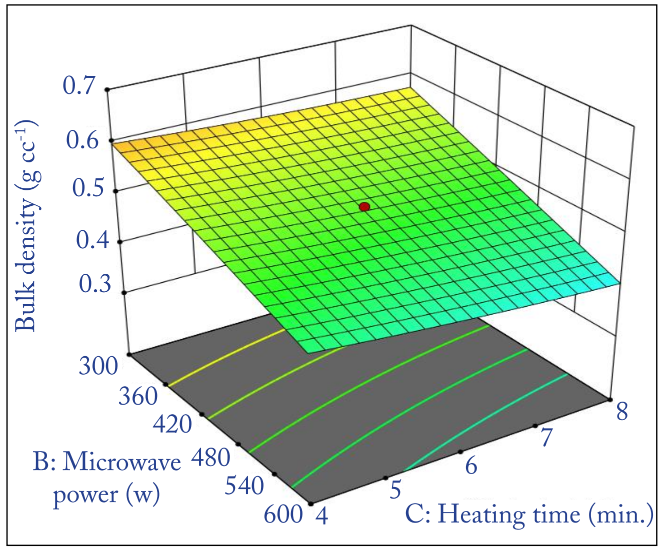

Figure 2: Impact of paneer cube bulk density upon microwave heating time and power level

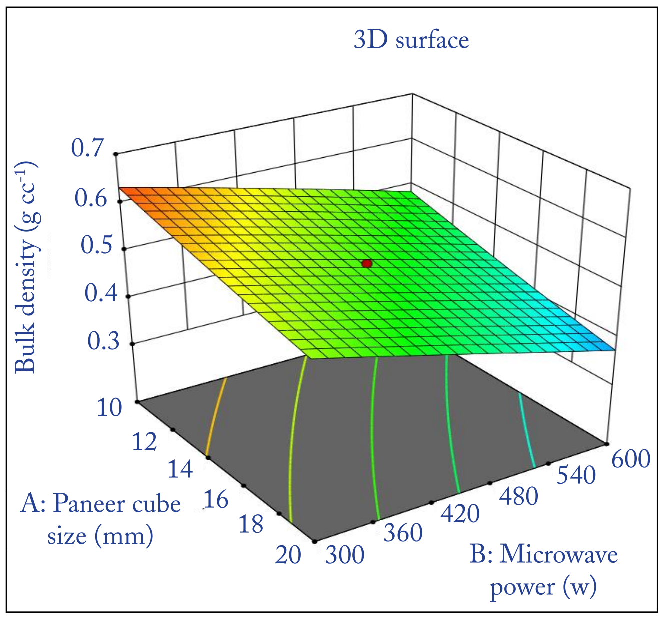

Figure 3: Effect of paneer cube sizes and microwave power on bulk density

3.2. Response surface analysis of moisture content

The calculated moisture content value is made known in Table 3 for different combinations of the procedure parameters. Figure 4 depicts the relationship among the anticipated value and the actual value. The empirical representation performs a respectable job of capturing the correlation between the variables and moisture content, as can be shown. The association between the coded values and natural values of the independent variables was found to be as follows:

MC. (d.b.)=+10.40209+0.161179A-0.002826B+0.119805C+0.117360D-0.000210AB+0.007436AC+

0.006571AD-0.001555BC-5.08452E-06BD-0.029435CD-0.004135A2+ 7.82455E- 06B2-0.010816C^2-0.015426D^2 ...10

Table 3: Examination of the moisture content regression model based on the correlation between the independent and dependent factors

Source of variation	Sum of suares	Degree of freedom	Mean square	F-value	P-value
Residual	1.83	12	0.1522		
Lack of fit	1.54	10	0.1543	1.09	0.5698
Pure error	0.2836				
Cor total	89.58	26			

R^2: 0.9796; R^2 (adj.): 9229; R^2 (Pred.): 0.8236; Adeq. Precision: 21.9486; CV %: 4.15%

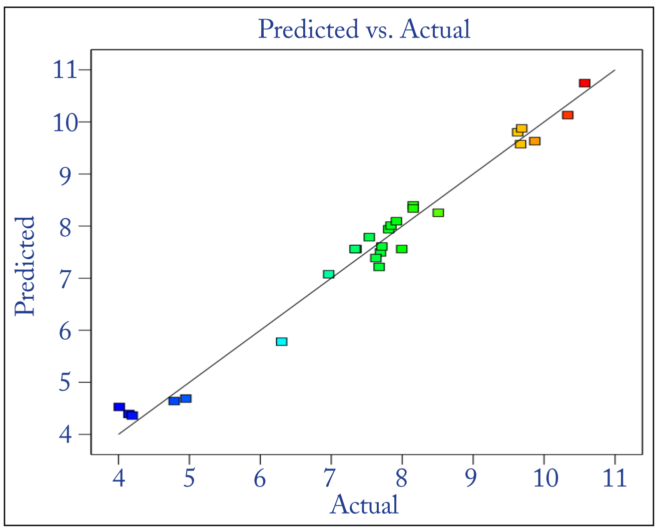

Figure 4: Predicted values versus experimental values for the moisture content

The adj-R^2 value was 0.9229, and the R^2 value was 0.9796. A high R^2 value suggests so as to the variance could be there satisfactorily explained through the records fitting the model. The model was repeatable if the CV was fewer than 10. The model's F-value, which was 41.17, suggested that it was significant. The signal-to-noise ratio is calculated with adequate precision. A ratio of at least 4 is preferred (Myers, 2002). This number was 21.9486 for the proposed model, which is a very high-quality signal-to-noise ratio. All of these statistical metrics demonstrate the model's dependability.

Figure 5 shows that moisture loss increased with microwave power level and heating time because as power level increased, more electromagnetic field energy became available for heating *paneer* cubes over time. The higher microwave power level increased the temperature gradient, and the long duration of heating time increased the amount

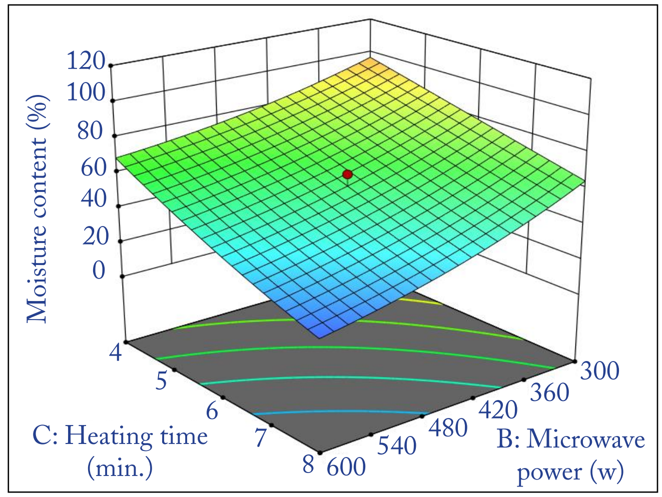

Figure 5: Impact of microwave heating duration and power levels upon moisture content

of moisture removed. The moisture content decreased exponentially with elapsed time under all drying conditions. The drying behavior of SFP during microwave convective drying exhibited the typical trend reported by many researchers (Feng and Tang, 1999; Khraisheh et al., 1997; Prabhanjan et al., 1995) for drying of foods materials. The effect of *paneer* cube size and tempering time on moisture content (db%) was shown in Figure 6, reduction of moisture content with an increase in the size of *paneer* cubes. This was probably due to the fact that the evaporation rate is higher at higher moisture content. Because tempering under atmospheric circumstances created variations in the water vapour pressure between both the inside and surface region, which act as a catalyst for moisture transfer, it resulted in an increment with in reduction in moisture content as tempering duration was increased.

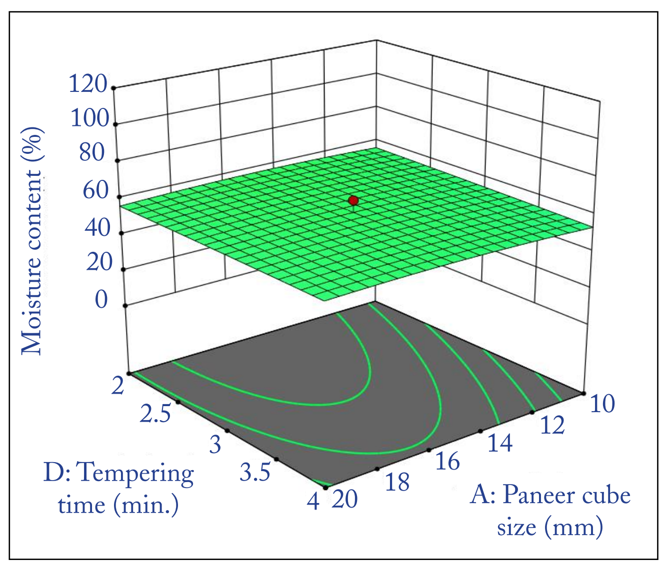

Figure 6: Effect of tempering time and size of paneer cube on moisture content

4. CONCLUSION

The RSM was used to optimize the *paneer* cubes bulk density and moisture ratio during the manufacturing process. The regression model was sufficient, according to the ANOVA of the coefficient of determination. With an experimental moisture content of 22.15 (db%) and a bulk density of 0.36 g cc^{-1}, the results of the analytical regression model showed that the microwave power, *paneer* cube size, heating time, and tempering time were identified as being 670.27 W, 13.8 mm, 7.2 min and 4.621 correspondingly.

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