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RESEARCH PAPER

Drying kinetics and modeling of onion slices in two stage drying

■ NAMITA J. PATIL*, J.P. PANDEY AND S.K. GARG

Department of Post Harvest Process and Food Engineering, College of Technology, G. B. Pant University of Agricultural and Technology, Pantnagar, UDHAM SINGH NAGAR (UTTARAKHAND) INDIA (Email: namita.patil16@gmail.com)

*Author for Correspondence

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SUMMARY :

The drying kinetics of onion slices were studied in a tray dryer. Response surface methodology (RSM) was used for designing the experiments with Incomplete Composite Block (Box-Behnken) Design. The independent parameters were drying temperature (70, 80 and 90^{0}C) during first stage, cut-off time (30, 50 and 70 min) and tempering period (0, 20 and 40 min).Temperature of second stage was kept constant at 60^{0}C. Empirical models namely Page's, exponential and logarithmic model were fitted to experimental drying data. The study indicates that drying time decreased with increase in temperature and cut-off time. Drying of onion slices took place in falling rate period only. The Page model of first stage and exponential model of second stage described the drying behaviour of onion slices well.

KEY WORDS : Onion slices, Two- stage drying, Drying kinetics, RSM, Mathematical modeling

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Onion (*Allium cepa* L.) is an important vegetable crop, belonging to the family Amarylliaceae. It is valued for its distinctive pungent flavor and is an essential ingredient of the cuisine of many regions. Drying is the most common form of food preservation and is aimed at producing a high density product, which when adequately packaged has a long shelf life, after which the food can be rapidly and simply reconstituted without substantial loss of flavour, taste, colour and aroma. Onion is also used in the dehydrated form such as flakes, rings and powder in several food preparations.

Drying is a process of simultaneous heat and mass transfer. The mechanism of drying depends on the nature of the solids and on the methods of contacting the solids and the heating medium. Usually air is used as external drying medium for supplying the heat to evaporate moisture from the solid surface. Therefore, modeling the drying process and predicting the drying behaviour under different conditions is necessary to have a better understanding of the kinetics of drying. Mathematical modeling of the dehydration process is very useful in the design and optimization of dryers (Bertin, and Blazquez, 1986). However, theoretical simulations of the drying process (moisture migrations in the product being dried) require a substantial amount of computing time because of the complexity (although realistic) of the diffusion equations governing the process (Sharp, 1982). For non-isotropic and non-homogeneous nature of the agricultural products along with their irregular shape and changes in shape during drying, most of the work reported on thin-layer drying of agricultural crops is mainly empirical in nature. But work on onion drying in particular and other vegetables drying in general has been very limited.

Mazza and LeMaguer (1980) as well as Saravacos and Charm (1962) have developed theoretical models for onion drying for heated ambient air conditions. Rapusas and Driscoll

(1995) and Kiranoudis *et al.* (1992) have developed empirical relations for onions in the form of Arrhenius-type and power models, respectively. Kiranoudis *et al.* (1992) have obtained the drying characteristics of shredded onions with characteristic dimensions and air velocities high as compared to the values usually used in commercial onion dehydration.

Earlier research workers (Anand,1972; Raina *et al*., 1988; Rajkumar and Sreenarayanan, 2001; Vishwanathan *et al.,* 2003; Subanna *et al.,* 2006) have attempted single stage drying to investigate drying characteristics of onion but limited research work has been reported on two-stage drying of red onion and its modeling using response surface methodology, keeping this in view, the present study was undertaken on drying kinetics and modeling of two stage drying of onion slices.

EXPERIMENTAL METHODS

Fresh well-graded, dark pink colored, good quality onions were procured from local market, peeled and cut into slices of thickness 4 mm and pre-treated with 0.25 per cent KMS for 5 min prior to drying, 100 g of onion slices were taken as test sample.

The tray dryer (cabinet type) was used for present study. It consists of an air delivery system, air heating system, drying chamber with trays, temperature controller etc. The pre-treated samples were spread uniformly in a single layer on the tray of drier. The first stage of drying process was carried out at 70, 80 and 90^{0}C for 30, 50 and 70 min, then these samples were tempered for a period of 0, 20 and 40 min and then second stage of drying was carried out at 60^{0}C till onion slices attains final moisture content of 4 to 6 per cent (db). The dried samples were then packed in polythene bag to avoid moisture migration from atmosphere as these dried slices are hygroscopic in nature.

Experimental design:

Response surface methodology (RSM) was employed for the experimental design. The RSM allows design of experiments with minimum number of experiments, without affecting the accuracy of results and determine the interactive effects of the variables on the responses (Myers, 1971).It provides statistically acceptable results and can be used for optimization of the process (Box *et al*., 1978.). Incomplete Composite Block (Box and Behnken) design was used to design the experiments with three variables, each to be examined at three levels. The three independent variables were high temperature during first stage (Td), cut-off time ($_{tc}$) and tempering period ($_{tp}$). The levels of temperature were 70, 80 and 90^{o}C for first stage, 30, 50 and 70 min for cut-off time and 0, 20 and 40 min for tempering period. Coaded and real values of independent variables are given in Table A. The experimental design resulted in 17 combinations on which experiments were performed (Table B).

Table A: Coded and real values of independent variables

Independent variables	Coded levels		
Name	-1	0	1
		Real values	
T_d=Temperature (^{O}C)	70	80	90
t_c=Cut-off time (min)	30	50	70
t_p=Tempering period (min)	0	20	40

Table B : Experimental design for experiments

Exp. No.	Coded levels T_d	t_c	t_p	Real values T_d	t_c	t_p
1.	-1	-1	0	70	30	20
2.	1	-1	0	90	30	20
3.	-1	1	0	70	70	20
4.	1	1	0	90	70	20
5.	-1	0	-1	70	50	0
6.	1	0	-1	90	50	0
7.	-1	0	1	70	50	40
8.	1	0	1	90	50	40
9.	0	-1	-1	80	30	0
10.	0	1	-1	80	70	0
11.	0	-1	1	80	30	40
12.	0	1	1	80	70	40
13.	0	0	0	80	50	20
14.	0	0	0	80	50	20
15.	0	0	0	80	50	20
16.	0	0	0	80	50	20
17.	0	0	0	80	50	20

Drying kinetics:

The observed weight losses of the sample with time for each drying run were converted to different drying parameters such as drying rate (dm/dt), equilibrium moisture content (EMC) and moisture ratio (MR) using following formula:

$$\frac{dm}{dt} = \frac{M_2 - M_1}{\Delta t} \quad ......(1)$$

$$EMC(\%db) = \frac{M_1 \times M_3 - (M_2)^2}{M_1 + M_3 - 2M_2} \quad ......(2)$$

$$MR = \frac{M - M_e}{M_0 - M_e} \quad ......(3)$$

where,

M_1 Moisture content (% db) at time t_1, M_2 Moisture content (% db) at time t_2, M_3 Moisture content (% db) at time

$t_{3,}$M Average moisture content (% db) at time t (min) during drying, M_0 Moisture content (% db) at the initiation of drying *i.e.* at 0 time, M_e Equilibrium moisture content (% db), Δt difference in time.

Empirical modeling:

The MR curves explain drying behavior better than that of moisture content curves. MR data were fitted into Page's, exponential and logarithmic model in order to select the best predictive model for two stage drying of onion slices. The models are given below:

Page model:

$$MR = \frac{M - M_e}{M_0 - M_e} = e^{(-Kt^n)} \quad \text{...... (4)}$$

where,

t Drying time, min., k, n constants of page's equation.

This model was fitted in experimental data in linearized form using regression technique. The linearization was as follows:

$$(-\ln MR) = \ln k + n\,(\ln t) \quad \text{......(5)}$$

Exponential model:

$$MR = \frac{M - M_e}{M_0 - M_e} = e^{(-kt)} \quad \text{......(6)}$$

where,

k,-drying constant.

The linearization was as follows:

$$(-\ln MR) = kt \quad \text{......(7)}$$

Logarithmic model:

$$MR = \frac{M - M_e}{M_0 - M_e} = a + b \times \ln(t) \quad \text{......(8)}$$

where,

a, b- Drying constants.

EXPERIMENTAL FINDINGS AND ANALYSIS

The fresh sample of onion slices were dried in tray dryer from initial moisture content of 85 to 89 per cent (wb) to the safe level of moisture content of 4 – 6 per cent (db) as reported by various researchers Van arsdel and Copley (1963) and Mangaraj *et al.* for higher moisture food.

Variation in moisture content with drying time for centre point experiments is shown graphically in Fig.1, exhibiting a non-linear decrease of moisture with drying time for both the stages. The figure reveals that the rate of moisture decrease was very rapid at the first stage, then it reduced considerably and finally reached to zero in second stage. Similar trends were observed for remaining experiments. The gap in trend lines in the figure indicated the tempering period. The moisture content of onion decreased with time for all conditions of drying air temperature, cut-off time and tempering period.

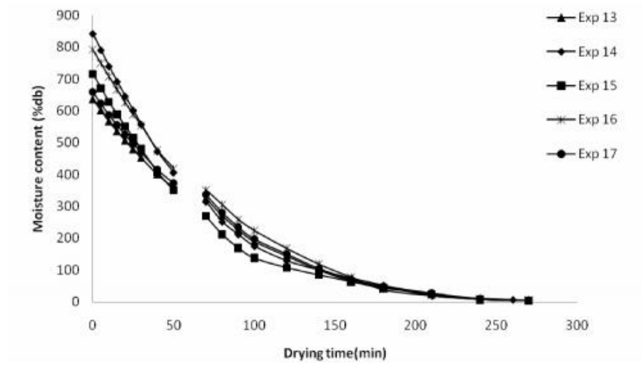

Fig. 1: Variation of moisture content with drying time (centre point exp)

Drying rates were calculated using equation 1 and variation of drying rate with time for centre point experiments are plotted in Fig. 2. The rate of drying was decreased continuously with the increase in time, being faster at higher temperatures in the first stage. Similar trends were obtained for remaining experiments. It is evident from Table 1 that the drying rate was found in increasing order after tempering only in four experiments (exp no.1, 3, 13, 17) whereas remaining experiments showed a decreasing trend and the effect of tempering period was more for the drying process carried out at low temperatures during the first stage and 20 min period of tempering. This effect may be because of high moisture content. This is in accordance with the findings of Burande (1992). It was observed that by increasing the period of tempering from 20 min to 40 min did not show any significant effect on drying rate thus, tempering period had pronounced effect only at high moisture content with low drying temperature.

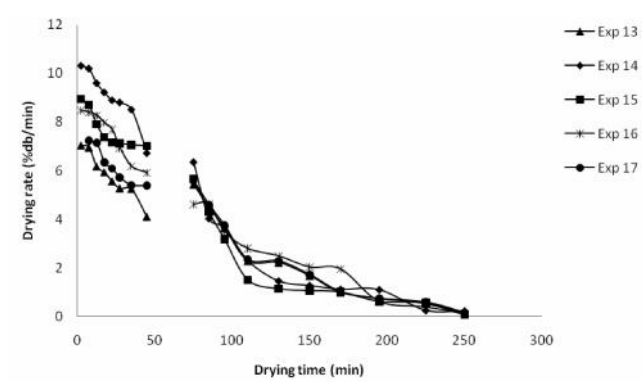

Fig. 2: Variation of drying rate with drying time (contre point exp)

Onion did not indicate any constant rate-drying period and that the entire drying took place only in falling rate period. The moisture loss data were first analyzed for equilibrium moisture content. Equilibrium moisture content for each experimental run was varied between 2.83 to 5.13 per cent. The value of moisture ratio was determined using equation 3.

Selection of the model:

The three drying models namely Page model, exponential model and the logarithmic model were fitted to the drying data in order to study the two stage drying behaviour of onion slices. Two statistical parameters R^2 and SEE were calculated for these drying models for both stages separately and it was found that both the Page model and exponential model gave the higher values of R^2 and lower values of SSE for first stage where as exponential model had higher R^2 and lower SEE in the second stage (Table 2). For first stage data Page's model showed a close agreement between actual and predicted values of moisture ratio than exponential model. Therefore, the Page model for first stage and Exponential model for second stage were selected as the best model to describe the drying behaviour of onion slices. Plots of actual and predicted results of Page model and exponential models moisture ratio values with drying time for both stages are shown in Fig. 3. Values of parameter n for page model varied from 0.9181 to 1.0788 for first stage, with an average of 1.026. The value of n was close to 1, which is in agreement for high moisture products indicated in literature; 0.065-0.92 for dehydrated peas (Burande, 1992), 1.032 for cauliflower (Pandey, 2000) and 1.006, 0.955 and 0.9229 for 1.0, 1.5, 2.0 cm potato cubes, respectively (Goyal, 2002). The values of parameter k for exponential model varied from 0.0198 to 0.0437 for second stage. These models were also used to compute the drying time corresponding to the 6 per cent moisture content (db) for all experimental runs

Table 1: Effect of tempering period on drying rate of onion slice

Exp No.	Initial moisture content, (%db)	Moisture content at time of tempering, (%db)	Initial drying rate (%db/min)	Drying rate: Before tempering, (%db/min)	Drying rate: After tempering, (%db/min)	Per cent increase in drying rate
1.	662.20	495.20	7.134	4.054	4.275	+5.17
2.	632.60	424.47	8.996	4.673	3.663	-27.60
3.	700.64	307.20	7.638	4.500	5.332	+15.61
4.	602.74	148.14	10.147	4.841	1.342	-260.73
5.	804.16	537.79	7.504	4.258	4.104	-3.75
6.	821.66	321.51	12.553	9.36	4.912	-90.62
7.	823.36	468.33	8.956	5.401	3.176	-70.06
8.	714.99	300.30	10.497	5.477	4.180	-31.00
9.	708.41	468.15	9.361	6.370	4.761	-33.79
10.	887.17	301.87	11.095	6.742	5.330	-26.48
11.	701.28	451.35	9.262	6.141	4.871	-26.05
12.	689.89	260.45	7.582	4.429	3.246	-36.43
13.	636.92	359.32	7.030	4.082	5.431	+24.83
14.	842.51	405.08	10.311	6.720	6.343	-5.95
15.	716.33	350.59	8.930	7.020	5.665	-23.92
16.	792.06	418.38	8.474	5.923	4.611	-28.43
17.	658.15	372.55	7.232	4.200	5.587	+24.83

Table 2 : Minimum and Maximum R^2 and SEE

Model	Stage 1				Stage 2			
	R^2		SEE		R^2		SEE	
	Min	Max	Min	Max	Min	Max	Min	Max
Page	0.9977	0.9999	0.005	0.0592	0.9530	0.9978	0.0488	0.2742
Logarithmic	0.9047	0.9767	0.0232	0.0834	0.9203	0.9959	0.0181	0.0933
Exponential	0.9513	0.999	0.006	0.1608	0.902	0.9989	0.0314	0.6706

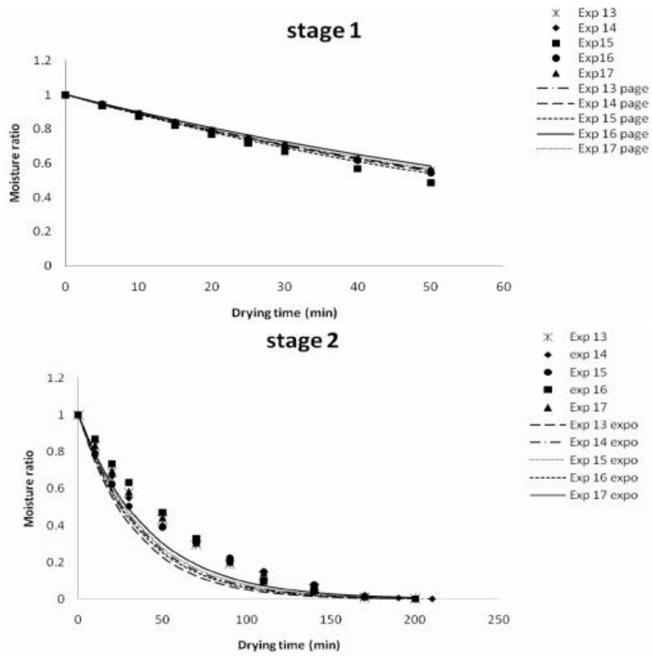

Fig. 3: Variation of moisture ratio with drying time (centre point exp)

and results are reported in Table 3.

Effect of drying temperature, cut-off time and tempering period on drying time:

Full second order model, equation 9 was fitted into drying time and experimental conditions using multiple regression analysis :

$$D_T=262.73-28.46T_d-21.69t_c+0.22t_p-8.46T_dt_c + 13.83T_dt_p+12.80t_ct_p+2.82T_d^{2}-15.34t_c^{2}-2.76\,t_p^{2} \quad .....(9)$$

The co-efficient of determination (R^2) for the regression model for drying time was 86.78 per cent, which implies that the model could account for 86.78 per cent variability in data. Total effect of individual parameter on drying time was calculated using the sequential sum of squares and it is given in the Table 4. Temperature, cut-off time affected the drying time significantly at 5 per cent level of significance. With increase in drying temperature and cut-off time, drying time was decreased. Effect of temperature was maximum on drying time followed by cut-off time in deceasing order. However, no effect of tempering period on drying time was observed. The contours are shown in Fig. 4 for various combinations of

Table 3: Experimental and predicted drying time

Exp. No.	Initial MC % (db)	Equilibrium MC% (db)	Final MC % (db)	Drying time to reach final MC (min)	Drying time to reach6% db MC (min)
1.	662.20	3.27	4.80	300	282.39
2.	632.60	3.13	4.47	270	264.64
3.	700.64	4.29	5.36	270	252.71
4.	602.74	3.14	4.01	220	201.10
5.	804.16	2.83	3.53	360	325.75
6.	821.66	2.86	4.52	260	218.92
7.	823.36	3.46	5.26	300	278.99
8.	714.99	3.30	4.32	260	227.49
9.	708.41	3.17	4.04	300	267.52
10.	887.17	5.05	5.43	240	201.75
11.	701.28	5.13	5.53	270	261.90
12.	689.89	4.65	5.45	250	247.34
13.	636.92	4.79	5.23	270	258.62
14.	842.51	3.77	4.15	280	256.90
15.	716.33	3.70	4.49	270	257.26
16.	792.06	4.56	5.71	270	272.37
17.	658.15	3.12	5.00	270	268.50

Table 4 : Total effect of individual parameters on drying time

Source	DF	SS	MS	F-value
Model	9	13011.83	1445.76	5.11**
Temperature (T_d)	4	7565.80	1891.45	6.68**
cut-off time (t_c)	4	5697.99	1424.50	5.03**
Tempering period (t_p)	4	1453.50	363.37	1.28
Error	7	1980.87	282.98	
Total	16			

*** and ** indicate significance of values at P=0.05 and 0.01, respectively, F_{tab} = (Model –6.71(1%) and 3.68(5%),(Levels- F_{tab} = 4.12 (5%) and 7.85 (1%)

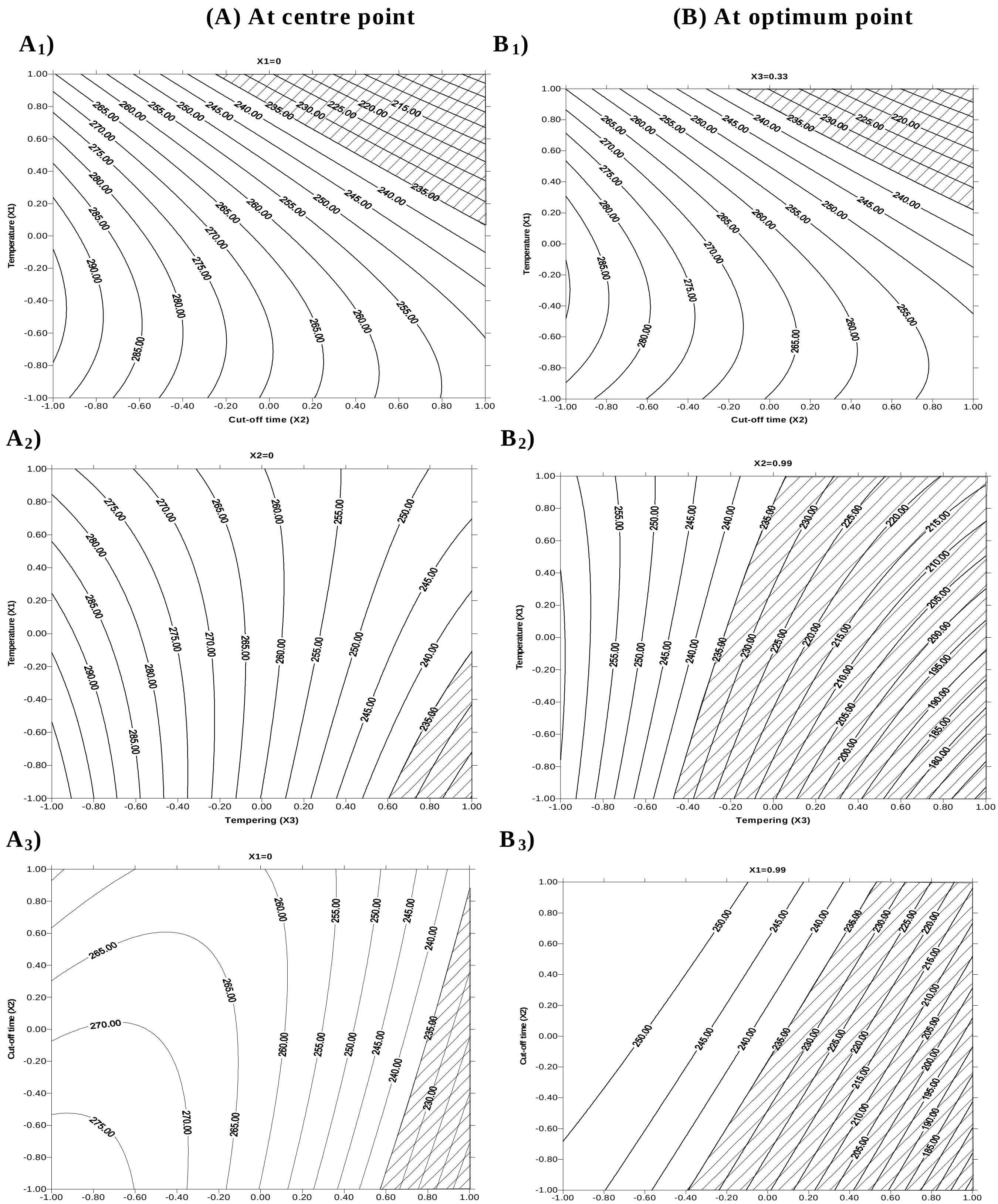

Fig 4. Contour plots for drying time

interactive terms either at optimum value or centre point.

Conclusion:

The drying time decreased with increase in temperature and cut-off time. Tempering period did not affect drying time significantly. Tempering period had pronounced effect only at high moisture content with low drying temperature. The constant rate period was found to be absent, only falling rate period was observed in all the experimental conditions. The page model of first stage and exponential model of second stage described the drying behavior of onion slices well.

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