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Research paper: optimization of process parameters of ready-to-eat pearl millet snack food (*Kharodi*)

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Abstract
The aim of this study was to standardize the process parameters for preparation of *Kharodi*, a pearl millet based ready-to-eat traditional snack food. The medium flour particle size of 0.166 mm was selected for further experiments. The effect of process parameters viz. water level (WL), cooking time (CT), drying temperature (DT) and drying time (Dt) on the product quality was investigated by conducting experiments using central composite rotatable design (CCRD). Linear and quadratic models were developed using response surface methodology (RSM) to study the relation between process parameters and responses in terms of moisture content (MC), hardness (HD), crispiness (Crp) and colour difference (ΔE). The optimal product quality were obtained at the optimal process condition as water level of 1979.92 ml, cooking time of 20 min, drying temperature of 64.99 ^{0}C and drying time of 8.79 h having moisture content of 9.93% db, crispiness 10.59, hardness 3591.23 g and colour difference 6.52.

Keywords: optimization, parameters, eat pearl, millet snack, *Kharodi*

Introduction
Traditional food processing methods play an important role in the utilization of locally raw materials. Traditionally developed products also facilitate consumption of cereals in more natural form and have long shelf life. Cereals have come to be recognized by person in all walks of life as economical, convenient, flavorful dry foods suitable for human consumption for all age groups in India. Millet is one of the most important drought-resistant crops and the 6th cereal crop in terms of world agriculture production. They have substantive potential in broadening the genetic diversity in the food basket and ensuring improved food and nutrition security (Mal *et al*., 2010) [8].
Pearl Millet (*Pennisetum glaucum*) is a tolerant, important and most widely grown type of millet in Africa and the Indian subcontinent. India is the largest pearl millet growing country, contributing 42 percent of total world production (Anon, 2007). The nutritional value of pearl millet per 100 gm is given as carbohydrate (67 g), dietry fiber (2.3 g), fat (4.8 g), protein (11.8 g), mineral (2.2 g), energy (363 kcal) with good content of calcium and iron (Hulse, Laing and Pearson, 1980) [3].
Breakfast cereals which are cooked during processing and do not require domestic cooking are described as 'ready-to- eat' cereals (Kent and Evers, 1994) [7]. The RTE foods are prepared by popping, flaking, extrusion cooking, puffing, toasting, etc., while the RTE food products include popcorns, extruded snacks, puffed grains, rice flakes, fried fryums, traditional products like *papads, kurdai, chakali,* etc., which can be consumed after frying or roasting.
Kharodi is a dehydrated traditional product which is crunchy, RTE snack food consumed directly, with onion slices or after frying. It is easily digestible, rich in protein and more popular in Maharashtra, Karnataka, Rajasthan and in Northeastern part of India. Though *Kharodi* is traditionally prepared and consumed deliciously, the procedure for making it was not standardized. Therefore, in order to standardize the process for making of *Kharodi* the present study was undertaken.

Material and Methods
Preparation of pearl millet grits
The pearl millet flour was obtained by grinding the pearl millet grain in vertical plate attrition mill. The pearl millet flour was sieved through the sieve analyzer.

In order to select proper flour particle size for preparation of *Kharodi*, three types of flour samples were prepared by selecting three grain feed rates on the attrition mill by adjusting the grain feed opening slot. The flours obtained at small, medium and large grain feed rates were designated as fine sample, medium sample and coarse sample.

Preparation of product

The product was prepared following two stages i.e. cooking of pearl millet grits and ingredients in water and drying of cooked product in the form of chunks in tray dryer. In cooking first two teaspoon oil was taken in pan and heated for 10 s and then mustard seed, cumin powder, garlic paste were added, stirred and fried till the mixture took brownish colour. Then measured quantity of water was added to fried mixture. After five minutes of heating the pearl millet grit was poured slowly in boiling water and stirred continuously. The cooking was continued for predetermined time. After cooking the product was allowed to cool for around ten minutes and chunks were dropped manually on trays using aluminum foil. The trays were put in tray dryer for the drying of the product.

Table 1: Ingredients used for pearl millet based ready-to-eat snack food *Kharodi*

Sr. No.	Particular	Quantity(unit)
1	Pearl millet grits	500 g
2	Vegetable Oil	2 teaspoon
3	Garlic paste	10 g
4	Mustard seed	2 g
5	Cumin powder	1.5 g
6	Ajwain	2 g
7	Red chilli powder	5 g
8	Sesame	10 g
9	Turmeric powder	1 g
10	Salt	5 g

Moisture content (MC)

The moisture content of dried *Kharodi* during different treatment were determined by hot air oven method at 105 ºC for 24 h. For determination of moisture content, the samples in triplicate were taken in weighing boxes and initial weights were taken. The weighed sample boxes were kept in oven. After drying the dried weights were taken immediately. The percentage moisture content was calculated using the formula (AOAC, 2005) [7].

Textural Measurement (Hardness and crispiness)

The texture characteristics of dried and oven toasted (*Kharodi*) in terms of hardness and crispiness were measured using TA-XT2 texture analyzer fitted with 35 mm cylindrical probe was used to compress the chunks 20% of its original height. The studies were conducted at a pretest speed of 1 mm/s, test speed of1 mm/s, posttest speed of 10 mm/s and load cell of 5.0 kg. Hardness value was considered as mean peak compression force and expressed in grams and crispiness was measured in terms of major positive peaks (Cruzycelis, *et al*., 1996) [4]. For measurement of crispiness a macro was developed which counts number of major peaks represented in the force-time deformation curve obtained during compression (Nath and Chattopadhayay, 2007) [9-10]. Average of 10 replications was taken or both the parameters in each individual experiment.

Colour Measurement

The colour of sample was measured by using hunter lab calorimeter before testing a sample, the instrument was calibrated with standard black and white tiles with the instrument. The colour reading was expressed in terms of L, a and b values. The colour difference (ΔE) parameter as described was used to describe the colour of *Kharodi*:

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2}$$

(ΔE) indicates the degree of overall colour change of sample in comparison to colour values of an ideal sample having colour values of L*, a* and b*. Sun drying samples were taken as ideal sample having L, a, and b values of 26.84, 2.77 and 9.69, respectively.

Experimental Design for *Kharodi*

Table 2: Coded values and corresponding real values used in experiments

Independent variables	Coded value	-am(-2)	-1	0	+1	+ am
WL(ml)	Actual value	1500	1800	2100	2400	2700
CT(min)		15	20	25	30	35
DT(^{0}C)		50	55	60	65	70
Dt (hr)		5	8	11	14	17

Table 3: Experimental design (4 factors, 5 levels) and corresponding values of responses (quality parameters) obtained during preparation of *Kharodi*

Std	Run	WL	CT	DT	Dt	MC	Crp	Hd	ΔE
1	22	1800	20	55	8	15.06	10	3414	4.09
2	19	2400	20	55	8	19.86	8	2717	2.96
3	17	1800	30	55	8	15.73	8	4232	4.03
4	26	2400	30	55	8	19.57	7	2362	2.01
5	25	1800	20	65	8	9.44	12	4312	6.88
6	2	2400	20	65	8	10.85	11	4072	4.99
7	7	1800	30	65	8	8.49	10	3690	6.86
8	9	2400	30	65	8	10.51	9	3441	3.22
9	15	1800	20	55	14	13.62	10	3451	2.86
10	16	2400	20	55	14	13.49	15	3004	2.57
11	28	1800	30	55	14	11.98	13	3503	5.62
12	24	2400	30	55	14	13.95	11	3306	4.01
13	20	1800	20	65	14	5.34	14	3830	6.65
14	13	2400	20	65	14	6.14	13	3608	6.10
15	21	1800	30	65	14	4.3	12	4366	6.58
16	10	2400	30	65	14	4.84	13	3930	4.54
17	29	1500	25	60	11	10.62	11	3824	3.55
18	12	2700	25	60	11	13.41	7	3461	3.20
19	4	2100	15	60	11	13.92	10	3131	4.89
20	11	2100	35	60	11	2.80	11	3910	3.68
21	27	2100	25	50	11	8.86	9	3661	4.52
22	18	2100	25	70	11	3.14	16	2367	4.00
23	30	2100	25	60	5	22.2	01	1676	7.57
24	23	2100	25	60	17	12.02	14	3536	3.41
25	5	2100	25	60	11	12.89	8	4183	7.48
26	1	2100	25	60	11	13.15	9	3729	7.33
27	6	2100	25	60	11	8.14	11	3714	9.21
28	3	2100	25	60	11	8.61	9	4486	5.61
29	14	2100	25	60	11	10.14	6	4161	4.88
30	8	2100	25	60	11	10.32	8	4252	8.44

* Values in parenthesis are coded values

Statistical Analysis and Optimization

The response surface methodology (RSM) (Nath *et al*., 2007 and Ushakumari *et al*., 2004) [9-10, 14] was used to as statistical method for analyzing the experimental data of drying processes and solving the regression equations. The adequacy of the model was determined using model analysis, lack-of fit test, R^2 (coefficient of determination), coefficient of variation

(CV) and adequate precision ratio (APR) called as noise ratio explained by Lee *et al.*, (2000). Design Expert - 10.0 software was used to generate the response surfaces and contour plots and numerical optimization was done by the same software.

In numerical optimization the simultaneous optimization of the multiple responses is carried out by choosing the desired goals for each variable and response. Graphical optimization was also carried out by super imposition of contour plots for all the responses with respect to process variables.

Result and Discussion

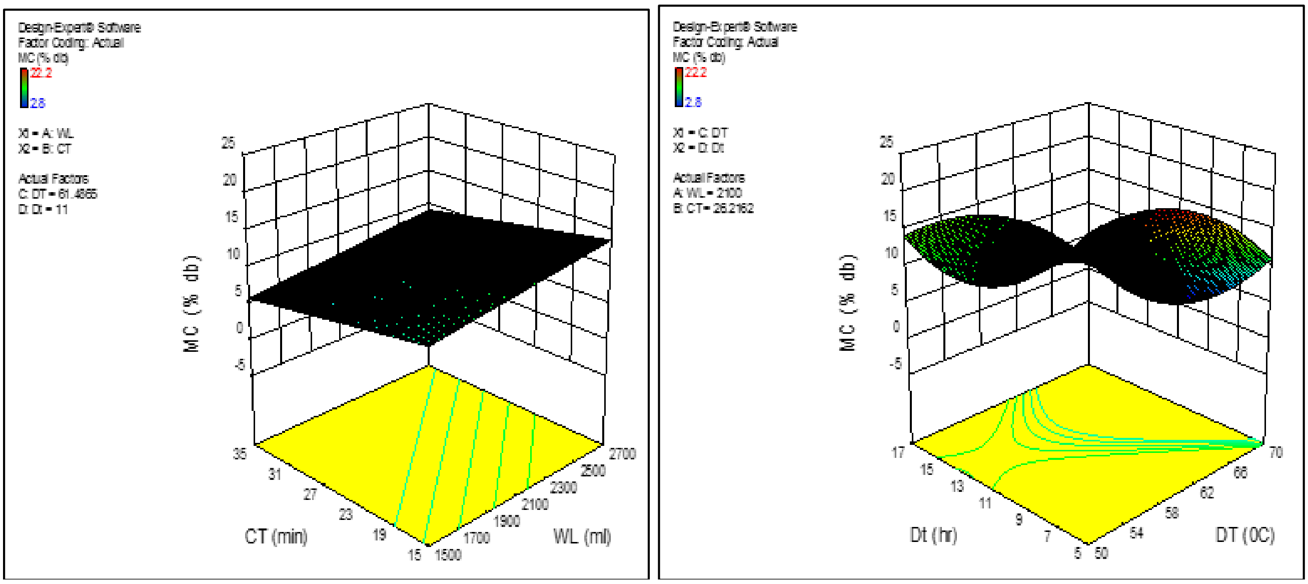
Effect of various process parameters on moisture content of *Kharodi*

The observations for moisture content with different combinations of process parameters are presented in Table 3. The experimental values of MC of *Kharodi* varied between 2.8% to 22.2% db. The ANOVA data set shows medium model F value of 16.77 (p<.0001) and a non-significant lack-of-fit which indicated that the quadratic model can be successfully used to fit the experimental data. The R^2 value was calculated by least square technique and found to be 0.814. The higher F-values for linear terms (p<.0001) and moderate values for quadratic terms (p<.05 and p<.001) of DT and Dt indicated that highly significant effect in reducing moisture content of dried *Kharodi*. Therefore, the model could be used to navigate the design space.

The second order polynomial equation fitted to experimental MC data was reduced to a form (eq.4.1) by deleting the high error generating non-significant terms (except linear terms) in order to predict MC in terms of actual values as given below:

$$MC = 85.074 + 0.002 \times WL - 0.222 \times CT - 4.824 \times DT - 4.795\ Dt - 0.045 \times DT^2 + 0.182 \times Dt^2 \quad (R^2=0.814) \ \ldots(4.1)$$

From Fig. 1 (A) it can be observed that WL and CT had linear effects and at constant level of CT there was increase in the moisture content of dried *Kharodi* with increase in WL. The moisture content of the product decreased linearly with increase in CT at constant level of WL.



(A) (B)

Fig 1: Response surface showing the effect of (A) Cooking time (CT) and water level (WL) and (B) Drying temperature (DT) and drying time (Dt) on moisture content

During drying of the dough chunks it was observed that initially up to 9 h of Dt there was reduction in moisture content of dried product with increase in DT (Pawar *et al.*, 2014) [12] but after this time at constant level of DT the effect of Dt on moisture reduction was very less. This may be due to case hardening around the inner soft core of drying chunks which might be reducing the rate of moisture removal. This is similar to the case hardening effect of temperature and time on the puffing product reported by Pardeshi *et al.* (2014) [11-12]. The combined effect of DT and Dt was more significant at higher levels. The effect of DT on moisture reduction was more dominant than Dt.

Effect of various process parameters on crispness of *Kharodi*

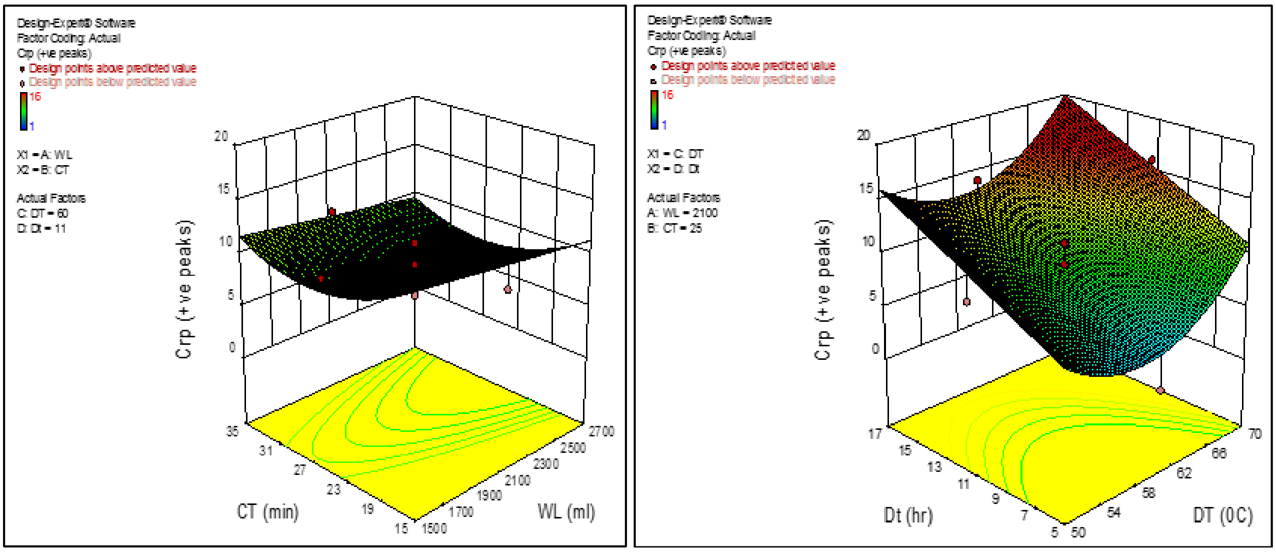
It was observed that the value of Crp was ranged between 01 to 16 with different combinations of process parameters are presented in Table 3. The quadratic model could be fitted to the experimental data. The model had moderate F-value and R^2 value (0.75) and can be fitted well in relating crispiness with independent variables.

The high F-value of Dt (41.90) than the other terms indicated its significant effect on crispness of dried product. Both the linear and quadratic effects of DT and Dt were highly significant in influencing the crispness of dried product. Non-significant lack-of-fit indicated the adequacy of the developed model and it can be used to navigate the design space.

The quadratic relationship between response and independent variables in terms of actual values after deleting the non-significant values (except linear terms) is given below (eq. 4.2):

$$Crp = 179.672 - 0.001 \times WL - 1.427 \times CT - 5.425 \times DT + 0.75 \times Dt + 0.026 \times CT^2 + 0.046 \times DT^2 \quad (R^2 = 0.75) \ \ldots (4.2)$$

The generated response and contour plots showed that WL had slightly reducing effect on the Crp of dried product whereas CT initially up to 27 min had reducing effect on Crp at constant level of WL and after that it had increasing effect in Fig 2 (A). Thus, the cooking parameters have their effect on Crp through the amount of moisture in the chunks getting dried during drying process. During drying at constant level of DT the Dt had increasing effect on Crp within the experimental range whereas at constant level of Dt the DT initially up to 60 ^{0}C had reducing effect on Crp and after that it had increasing effect in Fig 2(B).



(A) (B)

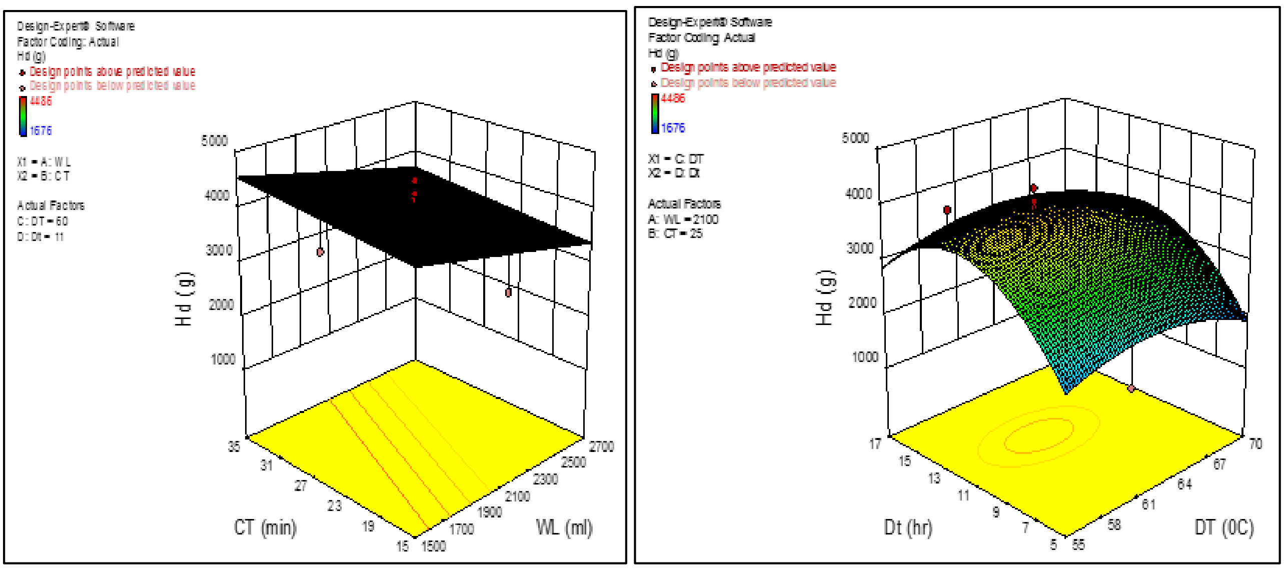
Fig 2: Response surface showing the effect of (A) Cooking time (CT) and water level (WL) and (B) Drying temperature (DT) and drying time (Dt) on Crispiness

The combined effect of both parameters at higher levels increased Crp at faster rate. The effect of drying temperature was the most prominent followed by cooking time and water level.

Effect of various process parameters on hardness of *Kharodi*

The observation for hardness with different combinations of the process parameters are varied between 1676 g to 4486 g within the combination of variables studied. Though the quadratic model was significant ($p<.05$) the linear terms were not significant and only the quadratic effect of Dt was significant ($p<.01$) and that of DT to some extent. The reason for this could be that during drying initially the case hardening of product takes place which prevents the removal of moisture from the product as a result soft core of the chunk remains for longer period during drying. This leads to slow drying and a non-uniform pattern of hardness development in the product and high hardness of the product even at higher moisture contents irrespective of process parameters (Pawar *et al.*, 2014) [12]. Similar results were obtained by Pardeshi *et al.* (2014) [11-12] for wheat-soy RTE snack food. Moreover, the predictability of the model was negative and hence it was not considered for further analysis.

$$Hd = -28123.8 - 0.706 \times WL + 16.5 \times CT + 929.69 \times DT + 773.642 \times Dt - 7.561 \times DT^2 - 32.338 \times Dt^2 \quad (R^2 = 0.46) \ldots (4.3)$$



(A) (B)

Fig 3: Response surface showing the effect of (A) Cooking time (CT) and water level (WL) and (B) Drying temperature (DT) and drying time (Dt) on hardness

It shows that WL had reducing effect and CT had increasing effect with increase in their levels. The response surface and contour plots for DT and Dt Fig 3 (B) show that the effect of Dt was dominant over DT in increasing hardness of the dried product. At constant level of DT the increase in Dt up to 13 h increased the hardness sharply and afterwards there was gradual decrease in hardness with further increase in Dt. Similar trend of increase in hardness with increase in convective heating temperature and time was observed by Pawar *et al.* (2014) [12] for sorghum-soy food.

Effect of Various Process Parameters on Colour difference (Δ*E*) of *Kharodi*

It was observed that the value of colour difference was ranged 2.57 to 8.44 with different combinations of the process parameters are presented in Table 3. The quadratic model could be fitted to experimental data at relatively low level of significance (p<.01) with R^2 of 0.53. The low model F-value of 3.57 implies the model is significant relative to the noise. The lack of fit was not significant. The F-values of other terms indicate that the linear term of DT only had significant (p<.05) effect on ΔE whereas the quadratic effect of WL was most significant (p<.01) followed by CT and DT (p<.05). The predicted R^2 (0.38) and adjusted R^2 (-0.02) were not in close agreement, showing that model was not fitting well to the data. This may be due to non-linear change in L, a, b values with corresponding increase in levels of process parameters (except DT).

$$\Delta E = -143.534 + 0.037 \times WL + 1.218 \times CT + 3.145 \times DT - 0.061 \times Dt - 9.417E-06 \times WL^2 - 0..024 \times CT^2 - 0.025 \times DT^2$$
$(R^2 = 0.53)$ ...(4.4)

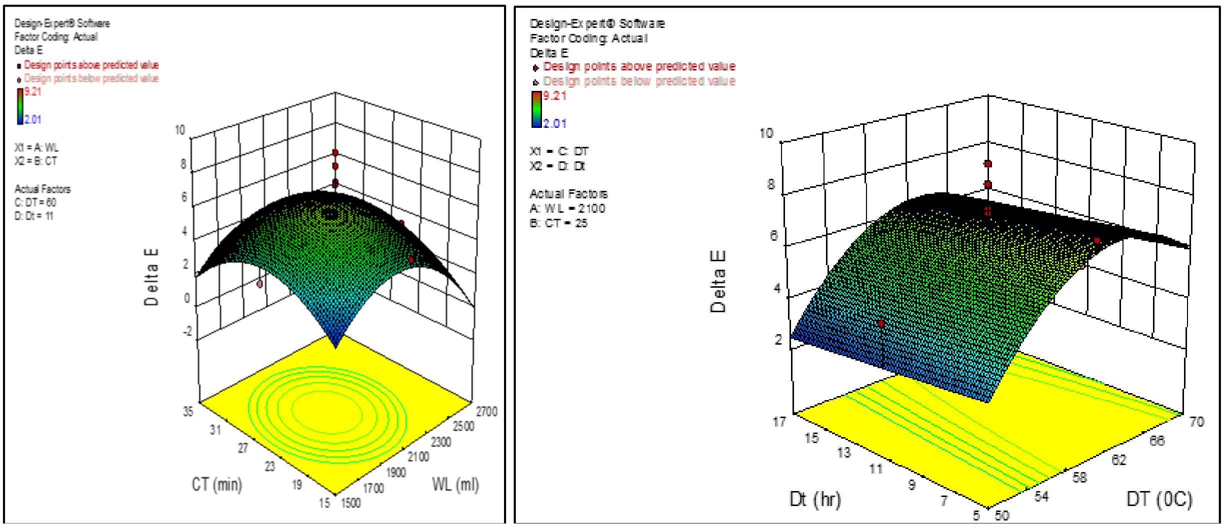


Fig 4: Response surface showing the effect of (A) Cooking time (CT) and water level (WL) and (B) Drying temperature (DT) and drying time (Dt) on Colour difference

The response surface and contour plots generated Fig 4(A) revealed that WL and CT had quadratic effects and the ΔE followed curvilinear behavior. Both the parameters increased ΔE till it reaches to maxima at central levels and then decreased with further increase in their levels. The response surface of DT and Dt Fig 4(B) showed the dominant effect of temperature on colour. There was sharp increase in ΔE with increase in DT levels up to 65 ^{0}C and then reducing effect with further increase at constant levels of Dt.

There was improvement in colour of dried product at initial levels of cooking time and drying temperature due to release of white starch from dull green coloured pearl millet grits in water and forming white crust on the chunks during drying.

Optimization

The software generated ten optimum conditions of independent variables with the predicted values of responses. Solution no. 1, having the maximum desirability value (0.5107) was selected as optimum condition of the drying. The similar findings have been reported by Pawar *et al.* (2014) [12]. Fig 5 shows the superimposed contours for MC, Crp, HD, and ΔE for pearl millet based RTE snack food (*Kharodi*) at varying WL, CT, DT and Dt. Graphically optimized range of process parameters from superimposed contours is as follows:

Water level (WL): 1860 – 2100 ml	Cooking time (CT): 18.9 – 20.5 min
Drying temperature (DT): 61 – 67 °C	Drying time (Dt): 7.5 – 12 h

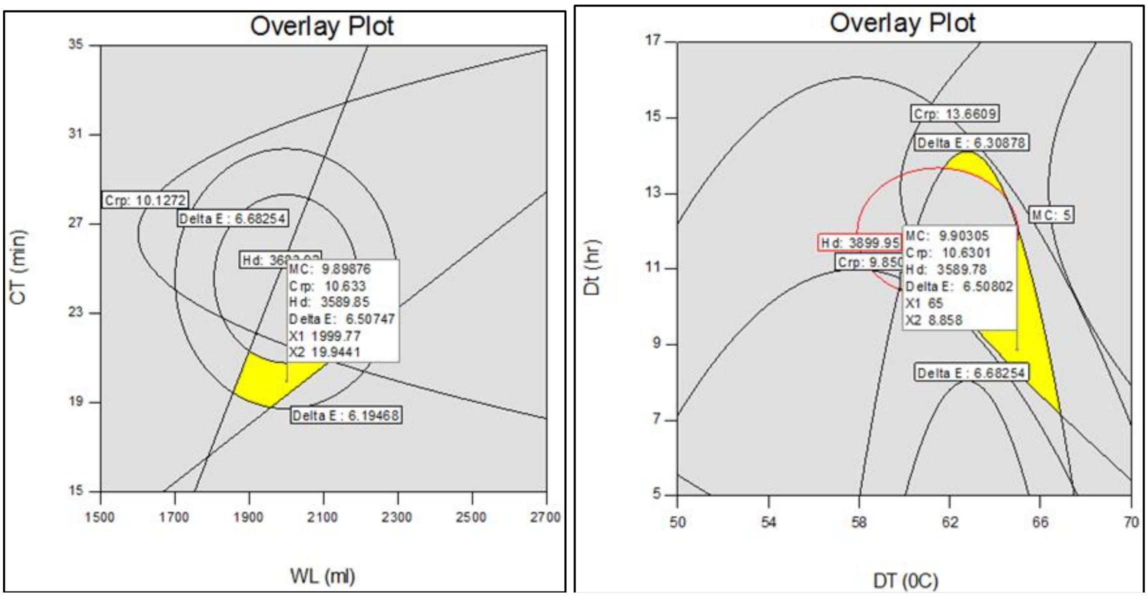


Fig 5: Superimposed contours of MC, Crp, Hd and ΔE at different levels of process parameters

Conclusions

The optimization technique of CCRD and RSM were used in design of experiments and optimization successfully. The fineness modulus of flour was 0.674 with particle size of 0.166 mm is suitable for *Kharodi* preparation. The optimized values of process parameters for *Kharodi* preparation were found as water level 1979.92 ml, cooking time 20 min, drying temperature 64.99 ^{0}C and drying time 8.79 h. The optimum values of quality attributes of the tray dried *Kharodi* prepared at optimum process parameters were: 9.93% (DB) moisture content, 10.59+ve peaks crispiness, 3591.23 g hardness and 6.52 colour difference.

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