International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
www.chemijournal.com
IJCS 2020; 8(3): 1958-1967
© 2020 IJCS
Received: 16-03-2020
Accepted: 18-04-2020

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Response surface optimization of quality parameters of turmeric slices in an innovative infrared assisted hybrid solar dryer

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DOI: https://doi.org/10.22271/chemi.2020.v8.i3aa.9492

Abstract

Drying of pre-treated turmeric slices was performed in an innovative infrared assisted hybrid solar dryer. The study evaluated the effect on the drying time and quality parameters (color, antioxidant activity) of the pre-treated turmeric slices by the independent parameters. Numerical optimization of process parameters for solar drying of turmeric slices was done through response surface methodology approach with Box-Behnken experimental design. Three levels of independent parameters including dryer temperature (50 to 70ºC), power of infrared (1000 to 1500 W) and drying tray to infrared source distance (11 to 35 cm) were used for the experiment. At the optimized values of dependent parameters (69.16ºC, 1500 W and 11 cm), the color variation, antioxidant activity (EC_{50} value) and drying time was 13.684, 5.131 and 307.2 min respectively.

Keywords: Solar dryer, infrared heating, turmeric slices, temperature control, pid controller, antioxidant activity

1. Introduction

Drying of agricultural produce is one of the most primitive and contemporary used preservation methods. Within the 30 per cent share of global energy use by food processing sector, drying of agricultural produce alone contributes about 20-30% (FAO, 2011; Kumar, Karim, & Joardder, 2014) [11, 20]. A minimal improvement of even 1% efficiency in such an energy intensive sector can result in 10% increase in the profit (Beedie, 1997) [8]. A large portion of unorganized food processing sector in India (42%) provides an opportunity for infusion of alternative energy sources (Eswara & Ramakrishnarao, 2013) [16]. Solar energy has an immense potential for diffusion (directly or indirectly) especially in the unorganized and small scale industrial domains. Indirectly, solar energy has also been used in food processing sector at industrial level for the reduction of carbon foot print and enhancing sustainable development (Salerno, 2008) [31]. For on-farm use for drying of foodstuffs (like vegetables, fruits, herbs, spices etc.), apart from the numerous advantages that encompass solar energy, the main disadvantage is its non-reliability due to the irregular nature of sunshine.

Turmeric (*Curcuma longa* L.) commonly known as “haldi” in India, is a valuable spice crop rich in valuable chemical components like curcuminoids. Besides the traditional use in medicines, cosmetics and flavoring foods, the advanced use of its extracted and encapsulated curcumin for sustained release and improved bioavailability for pharmaceutical purposes has also been reported (Rafiee, Nejatian, Daeihamed, & Jafari, 2018) [29]. During 2016-2017, India produced 8.6 million tons of turmeric and exported 116,500 tons valued at 12, 418 million Rupees (Spices Board India, 2018) [33]. The primary processing of turmeric involves washing and drying. Traditionally, farmers sun dry turmeric rhizomes on mud floors. Longer duration for dying (up to 12-15 days) and inferior quality of dried products are the major limitations of the open sun drying (Raza, Ali, Yusof, Nasir, & Muneer, 2018) [30]. To address this problem, an alternative solar drying method capable of reducing the moisture to safe limits within shorter time period without lowering the quality of dried products has to be introduced. (Bala & Janjai, 2009) [7].

Integrated solar drying method followed by open sun drying has been suggested to be best suited for drying of spices like ginger and turmeric as compared to fluidized bed drying and electrical oven methods (A. Borah, L. N. Sethi, S. Sarkar, & K. Hazarika, 2017a) [10].

The potential use of solar drying has led to the development of numerous variants of solar dryers like greenhouse solar dryers, indirect type solar dryers, indirect multi-shelf solar dryers, cabinet type solar dryers, tunnel type solar dryers, integral type solar dryers, mixed mode natural convection solar dryers, solar chimney dryers, back-pass and multi-pass solar dryers, low cost domestic and industrial solar dryers (Vijaya Venkata Raman, Iniyan, & Goic, 2012) [35]. To remove the constraints of intermittent nature of sunshine, all weather solar drying systems (with phase change materials) have been developed. (Agrawal & Sarviya, 2016) [5] The developed solar dryers have been used for drying of agricultural produce (Bala & Janjai, 2009) [7]. However, the temperature fluctuations inside the solar dryer and slow drying rate along with drying non-uniformity are the problems still prevalent with this energy concentrating equipment. Infrared radiation heating combined with modern automatic control system is one of the suitable auxiliary systems for temperature maintenance and heat transfer enhancement in the solar dryer (Adonis & Khan, 2008) [3]. An advanced method of hybrid solar drying comprising of auxiliary infrared radiation module (powered by electricity) controlled by a PID (Proportional Integral Derivative) controller (designed for the specific solar dryer) was developed at the Department of Post Harvest Process and Food Engineering, G B Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. The infrared radiation finds extensive use for processing foods besides its use for non-destructive quality evaluation, the difference being the wavelength range (Krishnamurthy, Khurana, Soojin, Irudayaraj, & Demirci, 2008) [19]. It lies between the visible and microwave bands of electromagnetic spectrum. The infrared radiation travels in the form of waves and is converted into sensible heat after impingement onto the food surface (Atungulu & Pan, 2010) [6]. Despite the other auxiliary heating arrangements used for solar dryers, infrared radiation is advantageous in terms of efficiency, quality end product, control over process conditions, high heat transfer coefficient etc. besides being environment friendly in nature

The present study aims at optimization of process parameters for turmeric slices in the developed solar dryer through response surface methodology (RSM) approach employing Box-Behnken experimental design (BBD).

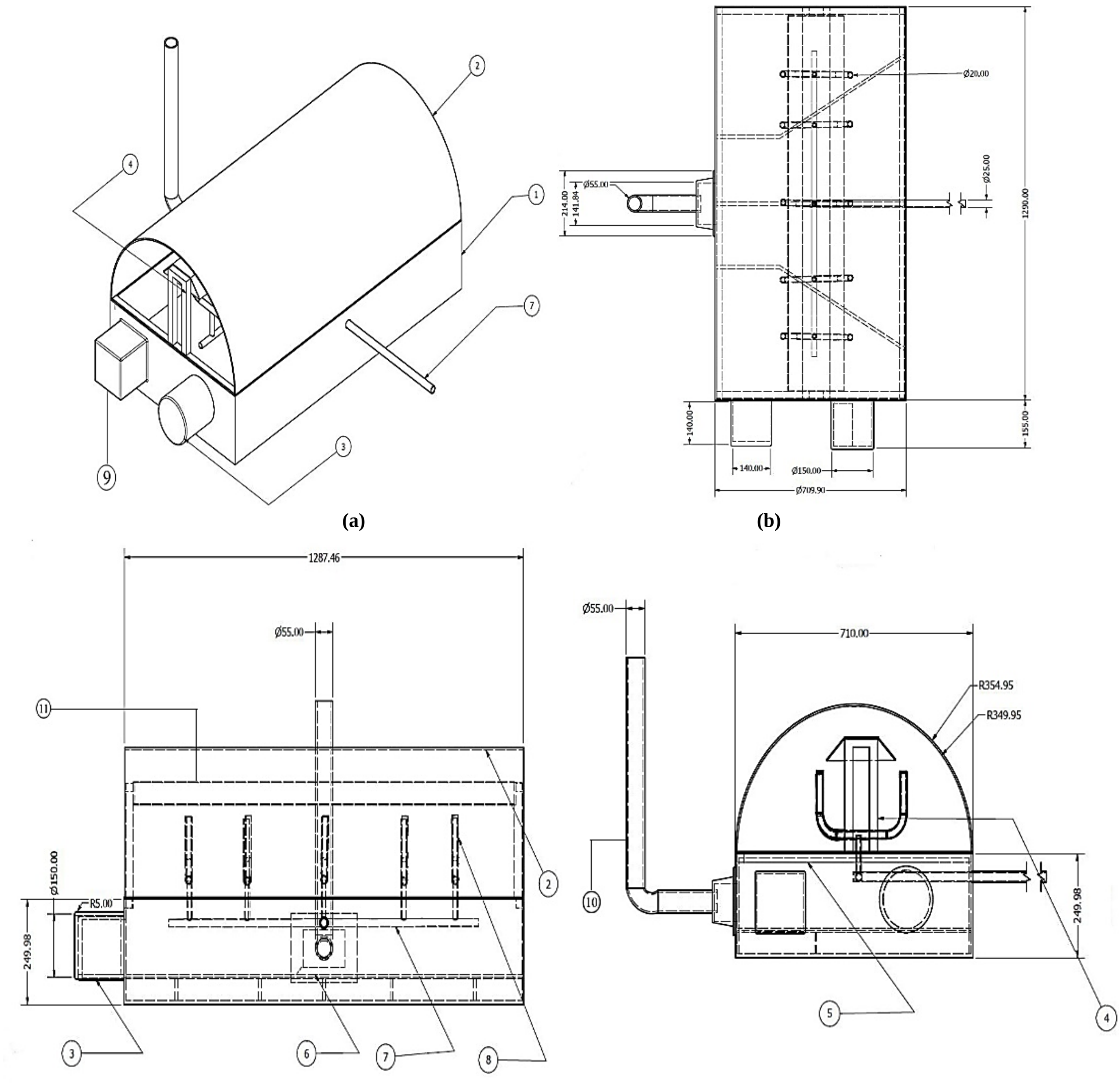
2. Materials and methods

2.1. Raw material preparation

Freshly harvested turmeric rhizomes (*Curcuma Longa* L.) popularly known in India as “haldi” were procured from Kota bagh, Haldwani, Uttarakhand, India to ensure uniformity of raw material. The storage of raw material prior to drying was done at ambient temperature. After washing cleaning rhizomes, the pre-treatment was applied. This boiling of turmeric in 0.1 % sodium bicarbonate solution for 30-45 min, after which their texture became soft (Lokhande, Kale, Sahoo, & Ranveer, 2013) [23]. This was followed by uniform manual slicing of turmeric of 5 mm diameter size. The slices samples were then weighed to a predetermined quantity and loaded onto the drying tray outside the dryer. After maintaining the solar dryer temperature to a specific point, the loaded tray was put into the drying chamber. For drying calculations, three aluminum sample pans with attached rods extended through the solar dryer bottom were loaded with same sample size. The weight of the sample trays was taken after a fixed time interval by placing the weighing balance below the solar dryer bottom with extension rods of sample trays on it.

2.2. Drying equipment, instrumentation and operation

The drying of pre-treated and sliced turmeric was done in the developed temperature controlled solar dryer illustrated in Figures 1 and 2. The dryer works primarily on natural convection mechanism with some modifications. The dryer has a single infrared (IR) heating tube installed along the length of the dryer, emitting wavelength in the medium wavelength range suitable for absorption of biological materials and resulting in molecular vibrations and subsequently efficient drying (Das & Das, 2010) [13]. The infrared assembly was fabricated by Ace Heat Tech (Infrared Heating Systems), Thane, Mumbai, India on the specific requirements. It consisted of IR tube in stainless steel module with power rating of 1500W/230V. The infrared radiations emitted were in the medium wavelength range. In order to study the effect of infrared position on the drying of food material. The provision for infrared height adjustment of the infrared was also made. Along with the infrared unit, a complete temperature control system tuned to match the infrared unit was also designed by the aforementioned company. Besides IR heating tube, the



(a) (b)

(c) (d)

Fig 1: Engineering Drawing of Newly Developed Hybrid Solar Dryer. (a) Isometric View, (b) Top-View, (c) Left Side View, (d) Front View.

Part Number	Description
1	Drying Chamber
2	Polycarbonate Dome Cover
3	Variac
4	Height Adjustment mechanism
5	Angle Iron for holding Drying Tray
6	Mechanism for air exhaustion
7	Air Inlet and inside horizontal inlet air pipe
8	Uniform air distribution
9	Temperature control unit (PID)
10	Chimney
11	Infrared Module

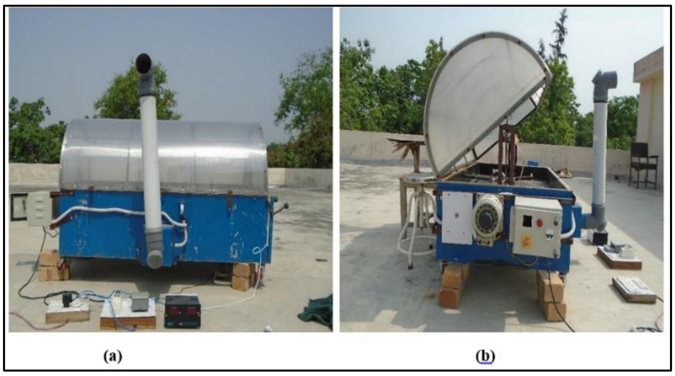


Fig 2: Newly developed solar dryer. **(a)** Front Side, **(b)** Left side

Temperature control assembly comprised of K-type thermocouple, PID control panel assembly. The thermocouple was put in close contact with turmeric slices for sensing the temperature of the product. To alter the power of IR heating tubes, a variac was also provided.

The inside temperature of the solar dryer was raised to the desired temperature, before putting the drying material, by feeding the temperature into the temperature control system. The heating inside the solar dryer occurred due to the greenhouse effect produced by the double layer ultra violet protected polycarbonate dome along with the supplementation by the auxiliary infrared heating module. The sliced turmeric was then placed in a thin layer on the tray of solar dryer. During the course of operation any deviation in temperature inside the dryer was sensed by the thermocouple in contact with food material and sent to the PID controller to which it was attached. Based on the preset and present temperature deviation, the PID controller sent an output in the form of duration of infrared being switched on. The moist air was carried out by an exhaust fan attached to the base of the solar dryer and dispatching it through an optimized chimney. For initial moisture content determination conventional hot air oven method was employed. The drying aimed to reduce the moisture content to safe value (7-10 %). After drying, the material was packed in polyethylene bags, and prior to analysis was ground by a hammer mill.

2.3. Experimental Design, Statistical Analysis

The design of experiments was done using Box Behnken Design (BBD) response surface methodology (RSM) with three variables, having three levels each as listed in the **Table 1**. The constant parameters in the experiment included loading density (2 kg/m^2), chimney height (1.1 m) and inlet air flow rate (1.7 m/s) The dependent variables or the responses for which the dried turmeric was then evaluated include color, antioxidant activity and curcumin content.

The model development was done using regression analysis and the optimization was done using response surface methodology in Design expert V 9.0.Complete second order model as given in Eq. 1 was fitted to the data and the model adequacy was tested using R^2 (coefficient of multiple determination) and fisher's F-test. The parametric effect on various responses was done through the interpretation of developed models. Regarding three independent variables a second order response function has the following general form-

$$Y = \beta_0 + \sum_{i=1}^{4} \beta_i X_i + \sum_{i=1}^{3} \sum_{j=i+1}^{4} \beta_{ij} X_i X_j + \sum_{i=1}^{4} \beta_{ii} X_i^2 \qquad (2.1)$$

Where,

β_0, β_i, β_{ij} are constants
X_i, X_j are variables (coded)

Table 1: List of independent parameters in coded and actual form for BBD RSM design

Independent variable	Symbol	Code	Coded level		
			-1	**0**	**+1**
Solar Dryer Temperature (℃)	T_{sol}	X_1	50	60	70
Infrared Power (W)	P_{inf}	X_2	1000	1250	1500
Height of infrared from drying tray (cm)	D_{im}	X_3	11	23	35

Multiple regression analysis was used to analyze the experimental data in order to develop response functions and obtain variable parameters optimized corresponding to best outputs. The values of model coefficients and related statistics in terms of lack of fit and P-value were obtained through the program.

2.4. Quality analysis

2.4.1. Colour

The colour of the ground (to ensure uniformity) turmeric was determined using digital camera and subsequent analysis using Adobe Photoshop CS 5 software. The photograph of all the dried samples were taken in triplicate. The standard procedure was used (Yam & Papadakis, 2004) [36]. The colour difference between the fresh and dried samples was calculated using the following formula (Gnanasekharan, Shewfelt, & Chinnan, 2006) [18].

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \qquad (2.2)$$

Where, ΔE = color difference between the fresh and dried sample.

L_0^*, a_0^*, b_0^* are the values for fresh turmeric sample calculated from the same equation as that for L^*, a^* and b^* respectively.

2.4.2. Antioxidant activity

The antioxidant activity of the fresh and dried turmeric sample was determined using l,l-Diphenyl-2-picrylhydrazyl (DPPH) free-radical scavenging assay (Yan & Asmah, 2010) [37]. The absorbance of the prepared extracts and standard was taken at 517 nm. Following formula was used for conversion of absorbance to radical scavenging activity (%)

$$Scavenging\ activity\ (\%) = 1 - \frac{Absorbance\ (sample)}{Absorbance\ (control)} \qquad (2.3)$$

The radical scavenging activity (%) was plotted against the concentration of the samples and from that EC_{50} value was obtained. EC_{50} value refers to the half maximal effective concentration. Lesser the EC_{50} value more is the antioxidant activity.

2.5. Optimization of the drying process

The numerical optimization of the process for the quality parameters and drying time was done through a multivariate response method (Abano, Ma, & Qu, 2014) [1]. In the present study, the goal for the independent parameters was within the range of levels. However, in the case of the response variables, the goal was minimum values for color variation and maximum values for antioxidant activity and curcumin content.

3. Results and discussion

The experiments were carried out during the month of March and April), during which the ambient air temperature, relative humidity of air and solar radiation ranged between 29-42ºC, 10-42% and 141-966 W/m^2, respectively. The relative humidity inside the solar dryer ranged between 8-28 %. The solar dryer temperature had a rise of about 10-15 ºC than ambient temperature without using auxiliary infrared heating system. Moreover the solar radiation data was also taken on regular basis for subsequent use. Preliminary investigations revealed that the designed auxiliary infrared heating system was capable of raising the initial temperature of the solar dryer in about less than 15 min in case of required higher temperature (70°C), and the time duration was even lower for low temperature (50°C). Also it was found that the temperature at the corner of the solar dryer was almost same as that at the center, thereby ensuring uniformity in drying.

The effect of independent parameters on the drying time and the quality parameters of the turmeric slices of all the experiments carried out during the drying were analyzed and the relevant data is given in Table 2. In order to develop a full second order model for the aforementioned drying parameters and evaluate the model adequacy and statistical significance, regression analysis and analysis of variance was used. The result of the regression analysis and analysis of variance for the experiments is shown in Table 3 and Table 4 respectively.

Table 2: Box-Behnken Design for three factors and the experimental results for solar drying of Turmeric

Exp.	**Actual Values (Coded values)**			**Experimental value of responses**		
	(X_1)	**(X_2)**	**(X_3)**	**Drying Time (min)**	**Colour Variation (Δ E)**	**EC_{50} Value (gl^{-})**
1	60 (0)	1500 (1)	11 (-1)	390	10.340**	5.90
2	60 (0)	1000 (-1)	35 (1)	425	20.391	6.56
3	50 (-1)	1000 (-1)	23 (0)	500*	34.676	8.58**
4	60 (0)	1000 (-1)	11 (-1)	415	18.370	6.33
5	70 (1)	1500 (1)	23 (0)	300**	15.091	5.12
6	60 (0)	1250 (0)	23 (0)	400	16.107	6.20
7	70 (1)	1000 (-1)	23 (0)	335	26.811	5.40
8	60 (0)	1250 (0)	23 (0)	400	16.250	6.12
9	60 (0)	1250 (0)	23 (0)	420	16.130	6.01
10	70 (1)	1250 (0)	11 (-1)	315	21.323	5.10*
11	70 (1)	1250 (0)	35 (1)	325	23.668	5.24
12	50 (-1)	1250 (0)	35 (1)	475	34.994*	7.33
13	50 (-1)	1500 (1)	23 (0)	460	28.005	7.03
14	60 (0)	1250 (0)	23 (0)	420	16.160	6.10
15	50 (-1)	1250 (0)	11 (-1)	475	28.450	7.38
16	60 (0)	1250 (0)	23 (0)	400	19.500	6.50
17	60 (0)	1500 (1)	35 (1)	390	11.477	6.30

* Minimum value, ** Maximum value

Table 3: Regression analysis for the drying time and quality parameters of turmeric slices

Source	**Drying time**	**Antioxidant activity (EC_{50} value)**	**Colour (ΔE)**
	Coeff.	**Coeff.**	**Coeff.**
Model	406.67*	6.19*	16.83*
X_1	-79.38*	-1.18*	-4.90*
X_2	-16.88*	-0.31**	-4.42*
X_3	2.50	0.90	1.51**
X_1X_2	1.25	0.32**	-1.26
X_1X_3	2.5	0.048	-1.05
X_2X_3	-2.5	0.042	-0.22
X_1^2	-8.54**	0.17	10.64*
X_2^2	-0.87	0.18	-1.32
X_3^2	-2.13	-0.090	-0.36
R^2	99.00	96.93	98.40
F-value	77.04	24.54	47.70
LOF	NS	NS	NS

*, **, *** Significant at 1, 5 and 10 % level of significance respectively

Table 4: Analysis of variance (Annova)

Source	**F- Value of responses**		
	Drying time	**Antioxidant activity (EC_{50})**	**Color Variation**
Model	77.04*	24.535*	47.701*
Linear	229.44*	69.540*	61.227*
Quadratic	1.38**	1.663	80.939*
Interactive	0.24	2.396**	1.833
LOF	0.17(NS)	1.97(NS)	1.35(NS)

*, **, *** Significant at 1, 5 and 10 % level of significance respectively

3.1. Effect of the dependent parameters on the drying time and quality characteristics of turmeric slices

The adequacy of the model to predict the response was good as shown in Table 3 ($F_{cal} < F_{Tab}$). The model has high significance (P<0.01) for all the responses. However the interactive terms were not significant at any level of significance, except in case of antioxidant activity.

3.1.1 Drying Time

The linear and quadratic terms for the drying time were found to be significant at 1 and 5% level of significance while the interactive terms were not significant at any level of significance. Also, the R^2 value of 0.99 (Table 2) shows that 99% of the data's were explained by the given model. The further verification of model suitability was done by the probability plot of drying time residuals (Fig. 3) and the experimental and predicted drying time plot (Fig. 3). There is no problem with the severity and normality of the outliers in the drying time experimental data, as both the plots lie along the straight line. The response surface plots for drying time, are shown in Fig. 3.3a-c. The drying time of turmeric was carefully observed during the experiments from initial to final moisture content (ranging from 548.93 – 481.39 % (db) to 10.50 - 8.80 % (db). The final moisture content attained was considered to be safe as recorded in literature (Prasad, Vijay, Tiwari, & Sorayan, 2006) [28]. From the experimental data shown in Table 2, the minimum drying time observed during the present investigation was 300 min for experiment run 5, while the maximum drying time of 500 min was observed in experiment run 3. The drying time was very less as compared to the earlier open sun and solar drying of turmeric (Borah, Hazarika, & Khayer, 2015; Borah *et al*., 2017a; Prasad *et al*., 2006) [10, 9, 28]. The response surface plots (Fig. 5) shows that with an increase in solar dryer temperature and infrared power, the drying time for turmeric slices to reach the final moisture content was reduced. The trend is obvious as at elevated drying temperature and infrared power (I. Doymaz, Kıpçak, & Pişkin, 2014) [15]**.** The effect of the distance between the infrared source and food material is insignificant which is against the general trend observed (Abe & Afzal, 1997) [2]. This could be attributed to the fact of less distance range selected between the infrared and food material, constrained by the dryer size.

The duration of drying in our study was significantly less as compared to the other studies on solar drying of turmeric even as at same or nearly same temperature (Borah *et al*., 2015; Borah *et al*., 2017a; Prasad *et al*., 2006) [10, 9, 28] or for drying of other similar moisture content food materials (Bala & Janjai, 2009) [7]. The acceleration of the drying process resulting in drying time reduction can be attributed to the fact, that during the fluctuations in inside temperature of solar dryer, the infrared heating system is switched on which directly impinges radiation on the food material, thereby resulting in increased heat transfer into the product and mass transfer out of the product (Nindo & Mwithiga, 2010) [24].

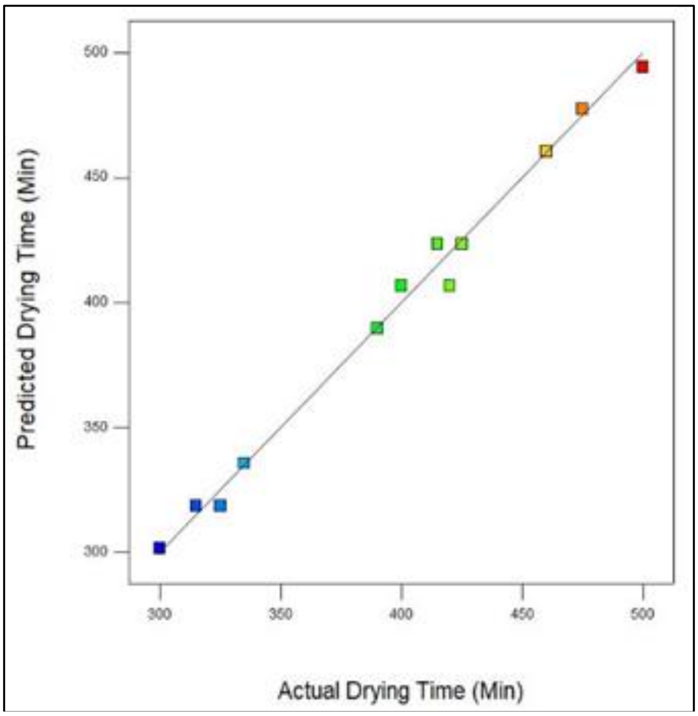


Fig. 3. Probability plot of drying time residuals

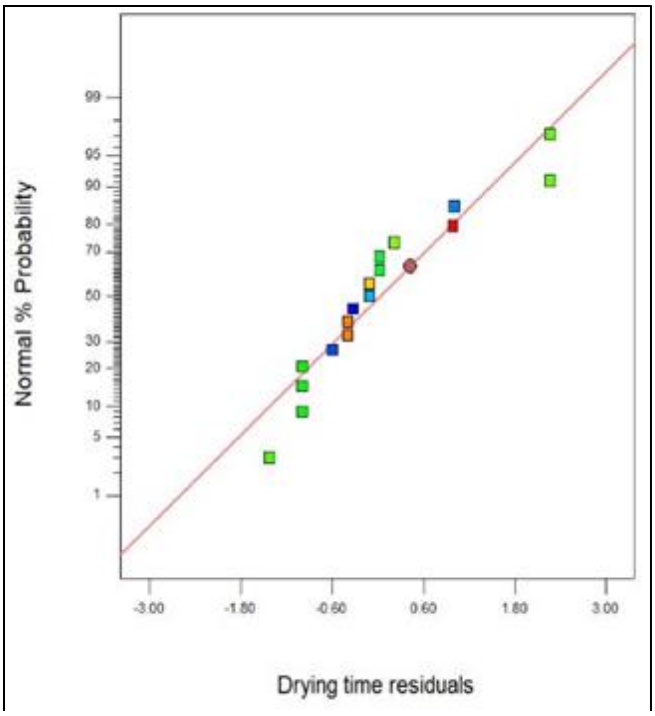


Fig. 4. Experimental and predicted drying time plot

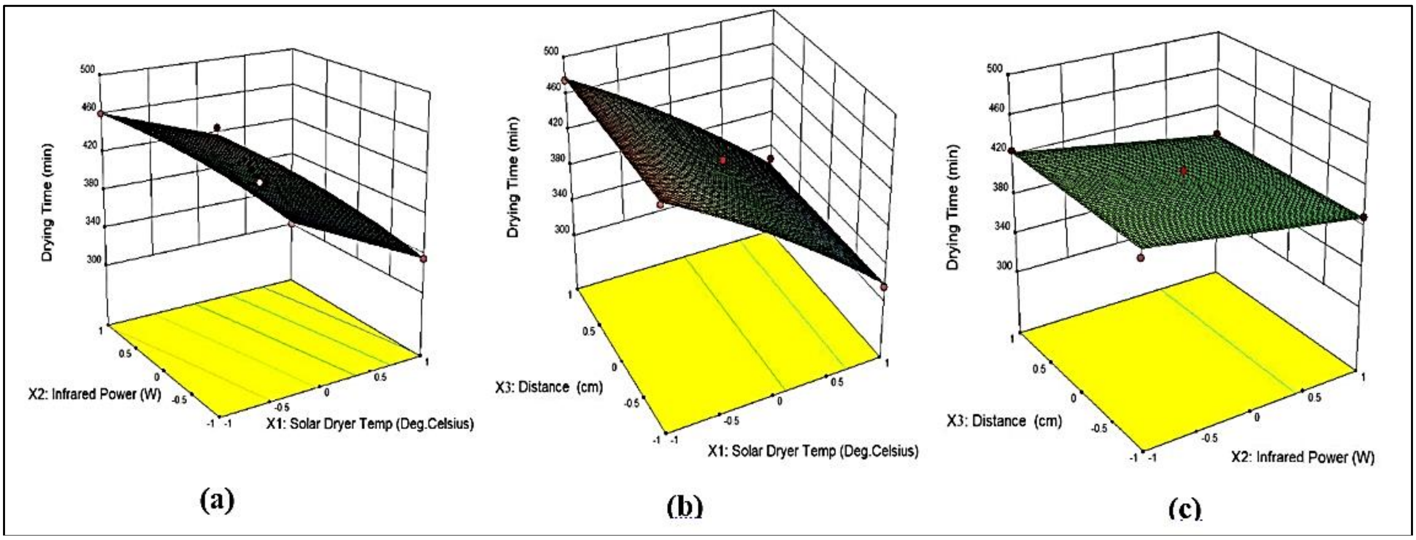


Fig 5: The effects of **(a)** Infrared Power and Solar dryer Temperature, **(b)** Distance and Solar dryer Temperature, **(c)** Distance and Infrared Power on Response Surface Plots of drying time

3.1.2 Antioxidant activity

The antioxidant activity is presented in the form of EC_{50} values as shown in Table 2. Lesser the EC_{50} value, more is the antioxidant potential. For the experiments 3 and 10, the maximum and minimum values of 8.58 and 5.10 respectively, were observed. The results showed the antioxidant activity in accordance as reported by (Cousins, Adelberg, Chen, & Rieck, 2007; Nisar *et al*., 2015) [12, 25]

Owing to the statistical analysis shows that the proposed model was adequate, possessing significant fit and with very satisfactory values of R^2 for antioxidant activity (EC_{50}). The R^2 (coefficient of determination) value for the antioxidant activity (EC_{50}) was 96.93%, which implies that the model could account for 96.93% data. The probability plot of antioxidant activity residuals (Fig. 6) and the experimental and predicted drying time plot (Fig. 7) further verified the model suitability**.** For antioxidant activity, the linear terms were found to be significant at 1 and 5% level of significance while the only one interactive term was significant at 5% level of significance. The response surface plots for drying time, are shown in Fig. 8. From the plots, it can be seen, that, with increase in solar drying temperature and infrared power, the EC_{50} value of dried material is decreased, resulting in higher antioxidant activity. This may be attributed to the fact, that at higher temperatures, the duration of infrared source used for maintaining the temperature inside the solar dryer is high. The results followed the reports of higher antioxidant activity in pea hulls under infrared radiation as reported (İ. Doymaz, Karasu, & Baslar, 2016; S.-C. Lee *et al*., 2006) [14]. The is due the fact that infrared radiation have capability to cleave covalent bonds and liberate antioxidants such as flavonoids, carotene, tannin, ascorbate, flavoprotein or polyphenols from repeating polymers (Niwa, Kanoh, Kasama, & Negishi, 1988) [26]. (S. C. Lee *et al*., 2003) [22] showed that simple heat treatments could not cleave covalently bound phenolic compounds from rice hulls but infrared radiation treatments could do that. In the present investigation, a synergistic effect of reduced drying time as well as infrared radiation power, was observed, resulting in enhancement of antioxidant activity.

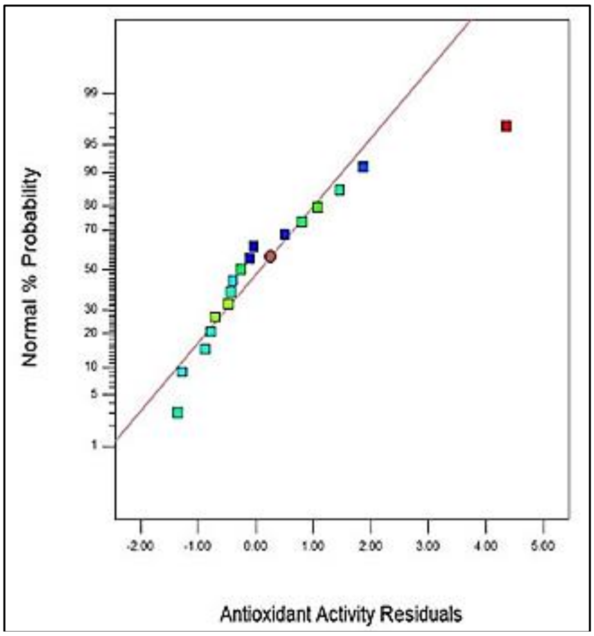


Fig 6: Probability plot of Antioxidant residuals

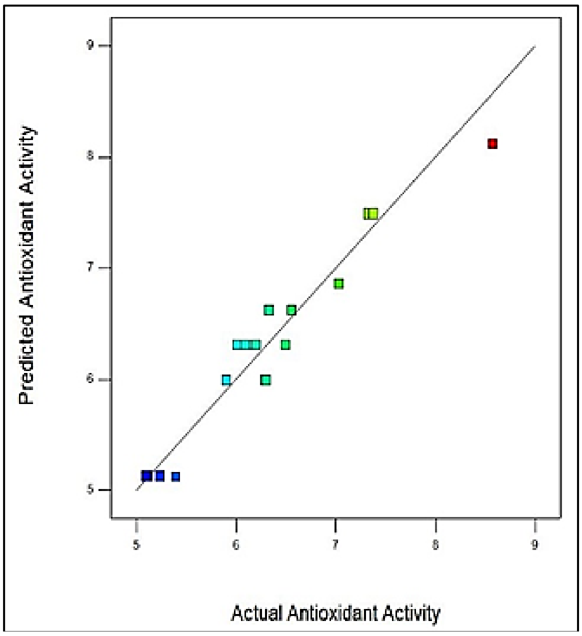


Fig 7: Experimental and predicted antioxidant activity plot

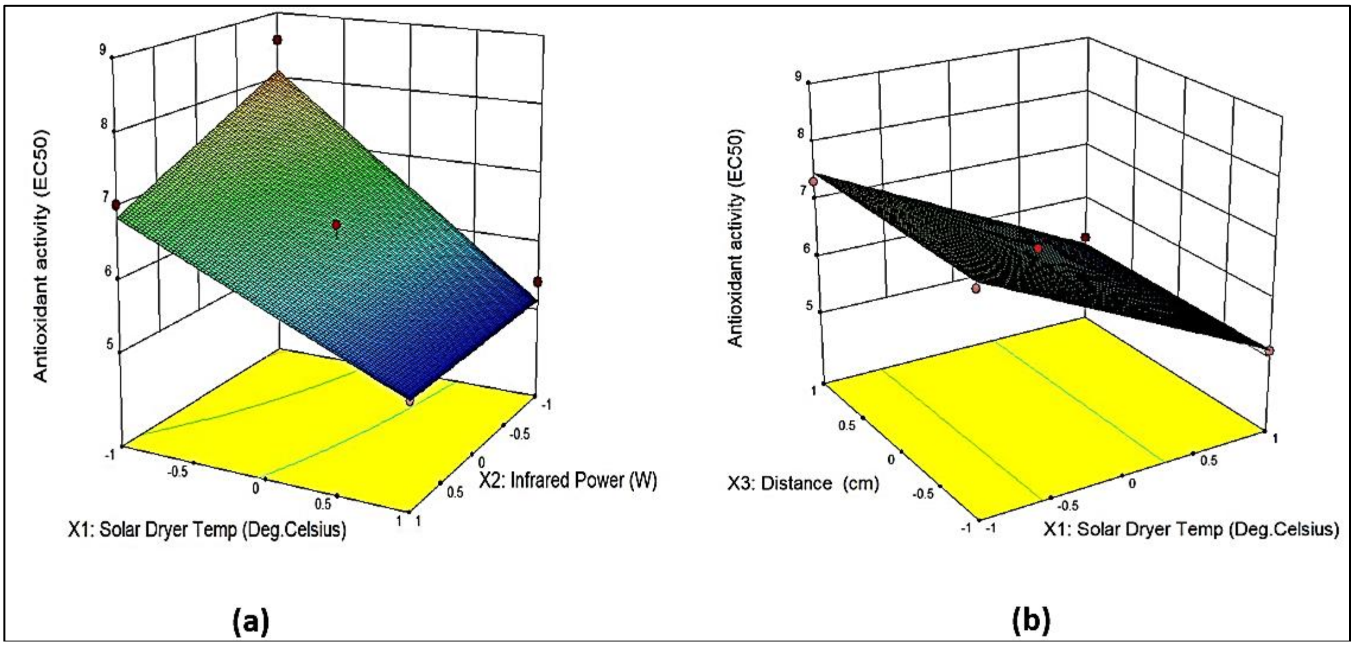


Fig 8: The effects of **(a)** Infrared Power and Solar dryer Temperature, **(b)** Distance and Solar dryer Temperature on Response Surface Plots of antioxidant activity

3.1.4 Color variation

The results of colour variation (ΔE) are shown in Table 2. The color variation (ΔE) ranged from 10.34 to 34.99. The results were in comparable with the studies conducted on solar drying of turmeric (Pradeep, Ravi, Naidu, & Prakash, 2016) [27] and better in the study conducted on various drying methods of turmeric (A. Borah, L.N. Sethi, S. Sarkar, & K. Hazarika, 2017b) [11], but were more on average, as compared to color variation obtained in mechanical drying of turmeric slices (Singh, Arora, & Kumar, 2010) [32]. The maximum variation was observed in experimental run 12, while the minimum variation was observed in experimental run 1.

Based on the multiple regression and the subsequent statistical analysis of the obtained model fitting the color variation response parameter (ΔE), it was observed that the o R^2 (0.984) for color variation (ΔE). The R^2 (coefficient of determination) value for the color variation (ΔE) was 98.40%, which implies that the model could account for 98.40% data. The probability plot of color variation (ΔE) residuals (Fig. 3.7) and the experimental and predicted color variation plot (Fig. 9) further verified the model suitability. For color variation (ΔE), except the interactive terms, the linear and quadratic terms were found to be significant at 1 and 5% level of significance The response surface plots for drying time, are shown in Fig. 10.

As the solar dryer temperature increased, the color variation decreased reaching a minimum value ahead of the center point. From there onwards, the variation started to increase till the end. The possible explanation of this result could be that at higher temperatures some of the color attributing pigments other than curcumin, sensitive to temperature might be destroyed, increasing the color variation. However, at lower temperatures, the duration of drying being high, subjects the coloring pigments to thermal stress, thereby reducing the color of dried product. The intensity of infrared power shows a significant effect in reducing the color variation as shown in Fig. 3.9. The figure clearly shows, that with increase in infrared power intensity, the color variation is reduced. Similar results for color variation for solely infrared drying of turmeric were found (Taşkın & İzli, 2019) [34]. This proved the dried quality product was comparable to the solely infrared drying which is considered to be the best low cost technique for quality retention (Krishnamurthy *et al*., 2008) [19]. The effect of height of infrared source on the color variation was almost negligible. The reason behind this might be the shorter distance between food material and auxiliary heat source.

3.2. Process optimization

The process optimization was done using Design Expert 9.0, with the goal of minimizing the drying time, color variation and the antioxidant activity (EC_{50} value). The criteria set for the optimization of different parameters and the obtained optimized values are shown in Table 5.

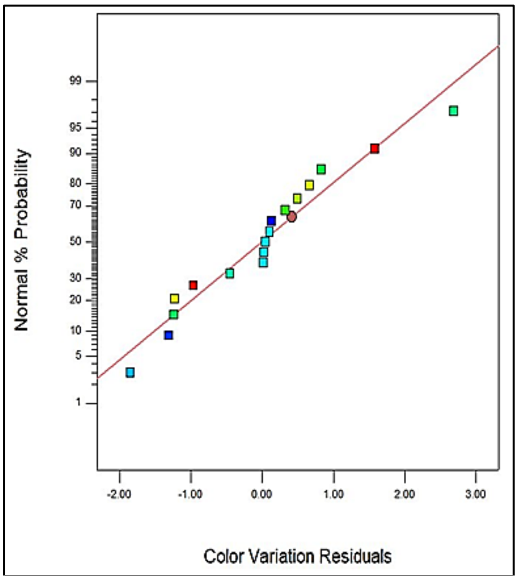


Fig 9: Probability plot of Color variation residuals

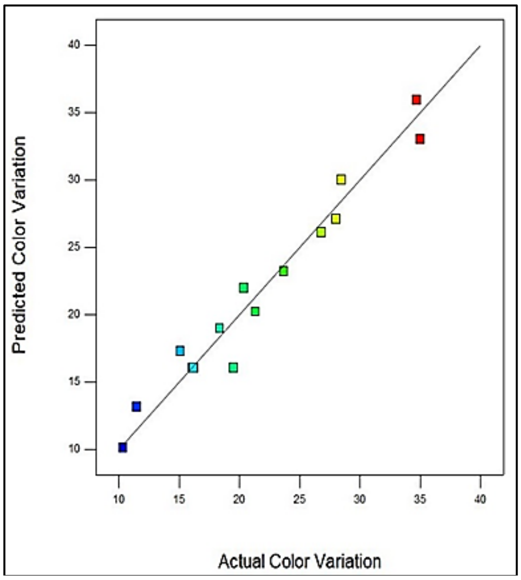


Fig 10: Experimental and predicted color variation plot

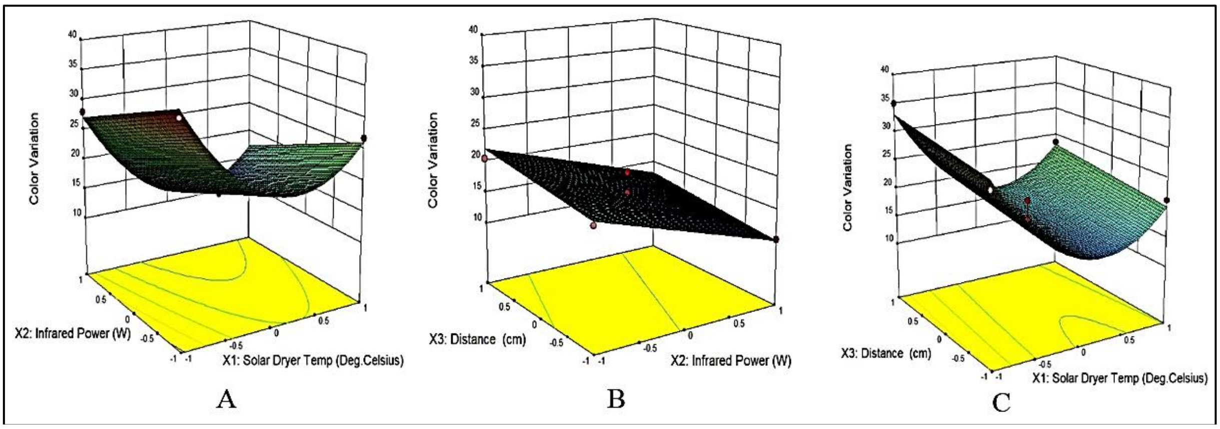


Fig 11: The effects of **(a)** Infrared Power and Solar dryer Temperature, **(b)** Distance and Infrared Power, **(c)** Distance and Solar dryer Temperature on Response Surface Plots of Color Variation

Table 5: Constraints and optimized values for dependent and independent variables for drying of turmeric slices

Parameter	Goal	Lower Limit	Upper Limit	Predicted	Experimental (mean ±std)
Solar Dryer Temperature (°C)	In Range	50	70	69.16	69
Infrared Power (W)	In Range	1000	1500	1500	1500
Distance between Infrared Source and Material (cm)	In Range	11	35	11	11
Drying Time (min)	Minimize	300	500	307.24	310±5
Antioxidant activity (EC_{50}-gl^{-1})	Minimize	5.10	8.58	5.027	5.50±0.1
Colour Variation (ΔE)	Minimize	10.340	34.994	13.684	14.01±0.2

4. Conclusion and future prospects

The developed solar dyer was a novel concept for maintaining the temperature inside the dryer very precisely and quickly. Besides reducing the drying time for turmeric, it resulted in a better quality dried product, better than the conventional turmeric drying methods and comparable to the advanced infrared drying method. Since the sunshine fluctuations vary from season to season, before commercialization for on farm drying, the drying process needs to be standardized for different seasons. Moreover, it can be tested for drying of temperature sensitive medicinal and aromatic plants. The drying process being a complex mechanism supplemented by our combined infrared assisted solar dryer mechanism, needs a more holistic modeling approach like artificial neural network (Aghbashlo, Hosseinpour, & Mujumdar, 2015) [4]. The future scope lies in making the drier electricity free through the use of photovoltaic cell for providing power to the infrared module, for enabling it to be used at farms having no electric power. Moreover it can be built and tested for largescale drying.

5. Acknowledgements

The research was funded by World Bank sponsored Project, TEQIP-II, GPBUAT, Pantnagar, India and is a part of my Thesis work entitled “Developmental Modification and Performance Evaluation of Solar Poly Tunnel Drier for Drying of Herbs and Spices” available at http://krishikosh.egranth.ac.in/handle/1/5810059328. Special thanks to my dear friends Er. Shazman Nabi, Er. Qayoom Siddiqui and Er. Ayon Tarafdar for helping me throughout the research. The authors are familiar with the submission of this research article and bear no conflict of interest.

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