# OPTIMIZATION OF INFRARED-CONVECTIVE DRYING PROCESS OF GINGER SLICES USING RESPONSE SURFACE METHOD (RSM)

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***ABSTRACT***

***Optimization of Infrared-convective drying process of Ginger was investigated using dependent variables of specific energy consumption (SEC), colour changes and rehydration ratio. Box-Behnken design was selected for design and optimization of the process. The second-order polynomial models with transformed responses were developed from experimental data to generate three dimensional response surfaces and contour plots. Experiments were performed at infrared power levels of 300, 400 and 500 W, air temperatures of 35°C, 40°C and 45°C, air velocities of 1, 2 and 3 m/s and slice thicknesses of 3mm. Based on response surface and desirability functions, the optimum conditions for Ginger drying i.e. infrared power, air velocity and air temperatures were 300 W, 2.93 m/s and 45°C for which the specific energy consumption, colour value (L value) and rehydration ratio (RR) were 80.3kJ/kg, 36.0 and 3.76, respectively.***

***KEY WORDS: Box-Behnken design, ginger, rehydartion ratio***

## INTRODUCTION

Ginger is one of the spices that is being cultivated in India for consumption as fresh vegetable and also in a dried form. Ginger is obtained from the rhizomes of *Zingiber officinale*. The ginger family is a tropical group, abundant in Indo-Malaysian region, consisting of more than 1200 plant spices in 53 genera. The world ginger production in 2012 was 2,095,056 tons (Source: FAOSTAT, 2014). India is the primary producer and consumer of ginger in the world. The ginger production of India was 570197 tons in 2012. Cochin ginger is widely considered to be one of the finest in the world, commanding a premium price, because of its lemon-like flavour, low fibre content and high moisture content (Source: FAO, 2014). In India, Ginger has numerous applications in the food, beverage and pharmaceutical industries. Fresh ginger is consumed as a vegetable. The dried products are the major form in which ginger is internationally traded. Dried ginger is used directly as a spice and also for the manufacture of products like ginger powder, ginger oil and ginger oleoresin.

Drying is the most common procedure of food preservation. Drying improves the product stability, since it reduces the moisture and microbiological activity of the foodstuff and minimizes physical and chemical alterations during storage (Hatamipour *et al.,* 2007). Drying of moist products is a complicated process involving simultaneous heat and mass transfer process.

Water is transferred by diffusion phenomenon from inside the food material to the air–food interface and from the interface to the air stream by convection. Knowledge of heat and moisture transport is crucial for process design, energy savings and product quality. Developing drying models and determining moisture transport parameters are of particular interest for efficient mass transfer analysis and reproducibility of quality-controlled products (Corzo *et al.,* 2008).

Water removal from food and agricultural materials is very energy consuming. The efficiency of drying with respect to both time and energy is an important economic consideration. Case hardening and low thermal conductivity of the material are the main factors responsible for controlling the hot air drying process (Hebbar *et al.,* 2004). In most drying operations, water is the liquid evaporated and air is the drying medium (Ozgener and Ozgener, 2006).

The increasing demand for high-quality shelf-stable dried fruits and vegetables requires the design, modeling and optimizing of the drying process with the purpose of implementing not only the final quality of the dried product but also the efficiency of the process. During drying of food and agricultural products undergo physical, chemical, structural and nutritional changes that cause quality degradation (Arslan and Özcan, 2011). Optimization has been applied in food process engineering for the efficient operation of systems and unit processes yielding a high quality product (Corzo *et al.,* 2008).

Modeling and optimizing of the process is vital important in drying technology to increase the efficiency of the drying facilities. Complex and highly nonlinear phenomena in drying process are involved (Omid *et al.,* 2009). Hence, it is difficult to quantify the complex relationships between inputs and outputs of a drying approach based on analytical methods. Response surface method (RSM) is a powerful tool for optimizing of many engineering applications probably because of its high efficiency, simplicity and comprehensive theory. It can save a lot of time and can build models accurately and quickly in an optimization design (Nazghelichi *et al.,* 2011).

RSM included a group of techniques used to establish the relationship between one or more measured responses and independent variables. RSM can be used in problems that have ingredients and/or processingconditions as variables (KiatPua *et al.,* 2010). RSM has been frequently used in the optimization of food processes (Varnalis *et al.,* 2004; Eren and Kaymak-Ertekin, 2007; Erbay and Icier, 2010; Nazghelichi *et al.,* 2011).

It is not information available about physical and thermal properties of Ginger slices and its optimization the drying process in the literature. The aim of this study was: (a) to study the effect of independent variable on the dependent variable and (b) optimization of the Ginger slices drying in an Infrared-convective dryer.

## MATERIALS AND METHODS

***Sample preparation***

The ginger rhizomes were taken out of storage chamber and were allowed to equilibrate with room temperature for 4 h before start of the experiments. The gingers were peeled manually. The peeled ginger was cut, with a sharp stainless steel knife, into slices having thickness about 3 mm. The thickness of the slices was measured with vernier caliper at three different places and average value was found to be about 3±0.4 mm.A standard hot air oven method was used to determine the moisture content of Ginger in triplicate (ASAE, 1996). The average moisture content of the samples was 78.1% (w.b).

***Experimental dryer***

The infrared-convective dryer comprised of two components i.e. a drying chamber having a tube type infrared heater and a hot air supply unit. The provisions were made in the dryer so that the infrared radiation intensity as well as air temperature could be varied by regulating the voltage through variacs. The air velocity was regulated with the help of a damper placed in the air supply line to the drying chamber. A schematic view of the experimental drier is shown in Figure 1.

The drying chamber of 400·300·300 mm was made from a plywood sheet of 8 mm thickness having a single door opening at the front. The inner sides of the chamber were covered with an aluminum foil. Two openings, one of 150 mm diameter and another of 150·150 mm were made in the two opposite short walls for entering and exiting of hot air. An infrared heater (tube type) of 1000 W having diameter of 18 mm and length of 300 mm was fitted on the top inside surface of the drying chambers. The output power of the heater could be varied by regulating the voltage through a variac. A sample tray of woven wire mesh having dimension of 300·200 mm was placed beneath the infrared heater.

The hot air supply unit was made of GI sheet having insulation of asbestos from inside. It was fitted with a finned type electrical heater of 1000 W and a axial flow blower (rated capacity 12.5 m3/min) forcing the ambient air into dryer through electrical heater. Temperature of the drying air could be regulated through a variac and the air velocity was adjusted through a damper valve in the air supply line. The air velocity inside the drying chamber was measured, close to tray, using a hot wire thermo anemometer which had the working range of 0.4–30 m/s.

***Experimental procedure***

Locally available ginger was used in the present study. The hand peeled ginger was cut, with a sharp stainless steel knife, into slices of thickness 3±0.4 mm. Three measurements were made on each slice for its thickness, using a Vernier caliper and their average values were reported. The moisture content of the ginger slices was measured by oven dry method (Rangana, 1986) and was expressed as g water/g dry matter. The initial moisture content of the ginger sample was 3.57 g water/g dry matter approximately. The dryer was run idle for about 0.5 h to achieve a steady state in respect of pre-set experimental drying conditions before each drying run. About 100 g of ginger slices after weighing were uniformly spread on the tray. Preliminary trial of drying the ginger slices, at infrared power of 600 W at 1.0 m/s air velocity and 60–70 $^{o}$C air temperatures darkened the product. The drying experiments were, therefore, carried out at infrared power 300, 400 and 500 W; lower drying air temperatures 35, 40 and 45oC and air velocities of 1.0, 2 and 3 m/s. The mass of the ginger slices was measured by a digital electronic balance throughout the drying experiment at an interval of 2 min for first half an hour and 10 min subsequently thereafter. For measuring the mass of the sample at any time during experimentation, sample along with tray was taken out of the drying chamber and weighed on the digital top pan balance and placed back into the chamber. The digital top pan balance (2000±0.01 g) was kept near to the drying unit and weight measurement process took about 10 s time. Drying time was defined as time required to reduce the moisture content of the product to 8% (dry basis), i.e. the average moisture content of a commercial dry product.

Response surface method was applied to study the effects of infrared power air velocity and air temperatureon the dependent variable (specific energy consumption, color and Rehydartion ratio). In this experimental design, three coded levels for each variable were selected: -1, 0 and +1 corresponded to the low level, mid-level and high level of each independent variable, respectively. The independent variables and representative coded and un-coded levels are given in Table 1.

The Design Expert software (Version 8.0.7.1) was used forexperimental design matrix, data analysis and optimization procedure. First step in RSM is to find a suitable approximation for the true functional relationship between response and the set of independent variables (Montgomery, 2001).

***Specific Energy Consumption***

The drying of food material, a process of togetherly heat and mass transfer, needs considerable energy amounts. The specific energy consumption was calculated for infrared-convective drying processes, accounting the total energy supplied to dry ginger rhizomes from initial moisture content of about 3.57 kg water/kg dry matter to a final moisture content about 0.08 kg water/kg dry matter. An energy meter was put between the electrical supply point and the drying unit to record the energy consumption during the drying process. The specific energy consumption for the process was calculated using equation 1.

Specific energy intake in infrared-convective drying process, HIR was as given under by (Sharma and Prasad, 2006).

$$HIR = \frac{\text{Total energy supplied in the drying process}}{\text{Amount of water removed during drying}},\ \text{kJ/kg} \quad ..1$$

***Colour measurement***

The color of ginger rhizomes was determined by using Hunter Lab. The color was measured in terms of Hunter L, a, and b values. Hunter L represents the lightness or darkness of the object and it is measured on a scale of 0 to 100. ‘L’ values of 100 represent white and L of 0 represents black. Hunter ‘a’ values represents redness or greenness. A Hunter ‘b’ value represents yellowness or blueness. The samples were ground using a grinder and whole samples were used for color measurements. For each sample, three replications of the color test were performed.

***Rehydration ratio***

Rehydration assays for the dehydrated ginger slices were carried out by immersing the dried samples in water. Approximately 10 g dried sample was put in 50 ml of distilled water in a 100 ml beaker kept in a hot water bath to maintain a water temperature of 35 $^{o}$C for 5 h (Kim and Toledo, 1987). The water of the beaker was drained and sample removed. The surface moisture from the sample was removed by wiping off the surface with a tissue paper gently. The sample was weighed again. The rehydration ratio was estimated from the ratio of weight of rehydrated sample to weight of dried sample.

## RESULTS AND DISCUSSION

### *Response surface analysis*

The experimental data describe the effects of infrared power, air temperature and velocity on the specific energy consumption, color changes and Rehydration ratio of the dried Ginger slices. Results of different runs of drying experiments are shown in Table 2.

### *Specific energy consumption*

Specific energy requirements for drying Ginger slices were determined using Equation (1).Table 2 shows that maximum value of SEC (106.02kJ/kg) was calculated at infrared power of 300 W,air temperature of 35°C and air velocity of 2 m/s. Also, minimum value of SEC (46.09 kJ/kg) were calculated at infrared power of 400 W,temperature of 45°C, air velocity of 1 m/s. Also according to Table 5, the infrared power, air temperature and velocity, interaction effect of air temperature and velocity, quadratic value of air temperature and quadratic values of air velocity and infrared power had significant effect on SEC. Figure 2 indicates that with increasing air velocity, SEC increased. Due to the reduction of water vapor in surface of the samples, increase in drying rate and subsequently decrease in drying time, the lowest energy consumption was obtained at lowest air velocities. Similar results have been reported in drying of paddy (Khoshtaghaza *et al.*, 2007).

### *Colour*

The first judgment of a foods quality is more often dependent on its various appearance characteristics, such as its color, surface structure and shape. Color, in particular, is an important sensory attribute (Varnalis *et al.*, 2004).

Table 2 showed the value of color changes in different experiments. Maximum (37.08) and minimum (26.50) value of color changes were obtained at air temperature of 45 $^{o}$C and 40 $^{o}$C, respectively. Air temperature had significant effect on color changes, so that the color change was increased with increasing air temperature. Air velocity and Infrared power had not significant effect on color changes. Color changes may be due to browning reactions which happen during drying process (Arslan and Özcan, 2011). At high temperatures the enzymatic and non-enzymatic reaction, superficial burns and blacking of the samples increases. So in this condition, the color change increased. In most cases, at high temperatures the pigment degradation is higher. Similar results have been reported in dehydration characteristics of garlic (Sacilik and Unal, 2005), tarragon (Arabhosseini *et al.*, 2007) and stone apple slices (Rayaguru and Routray, 2012). Figure 3, 4 and 5 showed that the L-value of color changes (white level) in the ginger powder at infrared power of 300, 400 and 500 W.

### *Rehydration ratio*

The rehydration ratio was considered as one of the important quality attribute for the dried slices in the present study. The rehydration ratio values of dried ginger slices were estimated as discussed in earlier sections, using standard procedure. It varied between 3.16 and 3.77, under different drying conditions.

### *Process optimization*

A relatively straightforward approach to optimize several responses that work well when only a few process variables are is to overlay the contour plots for each response (graphic method). Often a lot of trial and error is needed to specify which parameters to hold constant and what levels to select to achieve the best view of the surface. A popular procedure is to formulate and solve the problem as a constrained optimization problem (nonlinear programming methods). Mathematical techniques are used in this method (Corzo *et al.*, 2008). Optimum conditions for Infrared-convective drying of ginger slices were determined to obtain minimum SEC, color maximum color and maximum rehydration ratio. Second order polynomial models achieved in this study were utilized for each response in order to determine the specified optimum conditions. The desired goals for each factor and response are shown in Table 6.

The constraints were set such that the selected variables (Power, Temp and Velocity) would be minimum from economical point of view for the most important product attribute and close to the optimum for the others. The main criteria for constraints optimization were maximum possible L-value, rehydration ratio and minimum possible specific energy consumption as most important quality attribute. Also, in order to optimize the process parameters for infrared convective drying process by a graphical multi-responses optimization technique which determine the workable optimum conditions for the infrared convective drying of ginger slices. The contour plots for all responses were superimposed and regions that best satisfy all the constraints were selected as optimum conditions .The optimized values for process parameters i.e. infrared power, air velocity and air temperatures were 300 W, 2.93 m/s and 45$^{o}$C for which the specific energy consumption, colour value (L- value) and rehydration ratio (RR) were 80.3 kJ/kg, 36.0 and 3.76 respectively.

## CONCLUSION

From the study, it can be concluded that increasing air velocity led to the increase specific energy consumption. The specific energy consumption varied from 46.09 to 106.02 kJ/kg.. The air temperature had significant effect on color changes. The highest (37.08)and lowest (26.50) values of color changes were obtained at air temperatures of 45°C and 40°C, respectively. Box-Behnken design was applied for optimization the process. The infrared power of 300 W air temperature of 45°C, air velocity of 2.93 m/s was proposed as the optimum independent variable. The optimum value SEC, color and rehydration ratio changes for the drying process was obtained as80.3 kJ/kg, 36.0 and 3.76 respectively.

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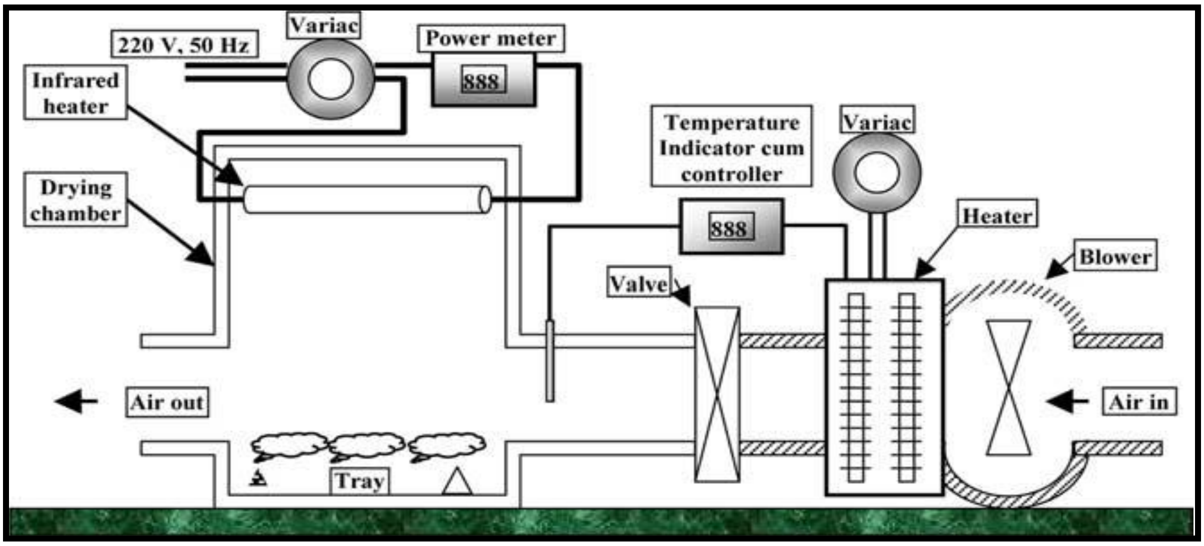


*Fig. 1: Schematic view of experimental infrared drying setup.*

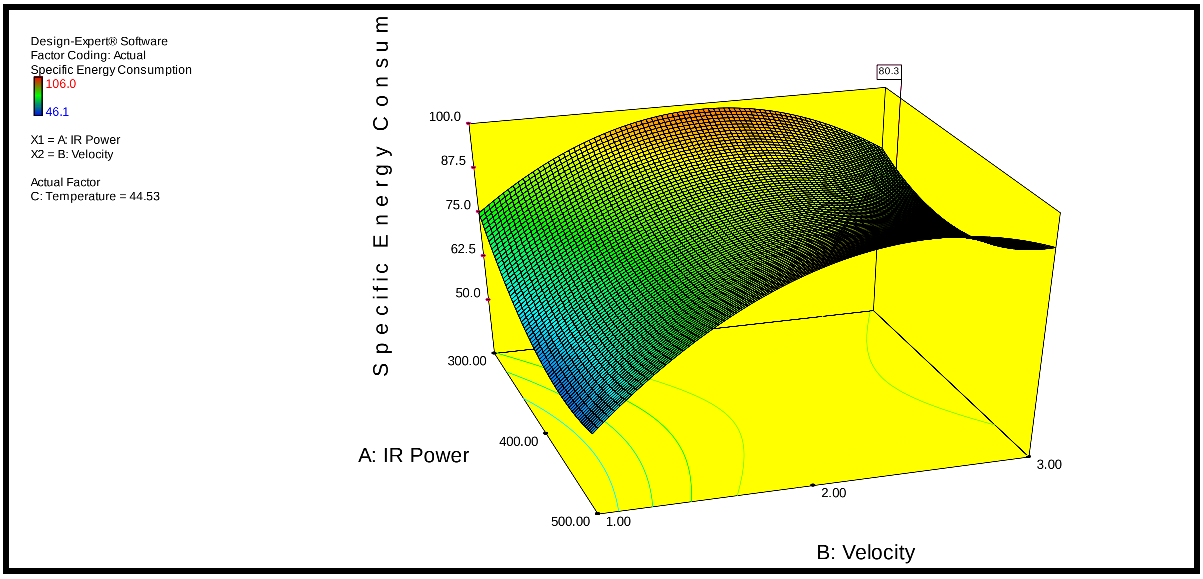


*Fig. 2: Interaction effect of Infrared power and air velocity on SEC for drying of Ginger Slices samples*

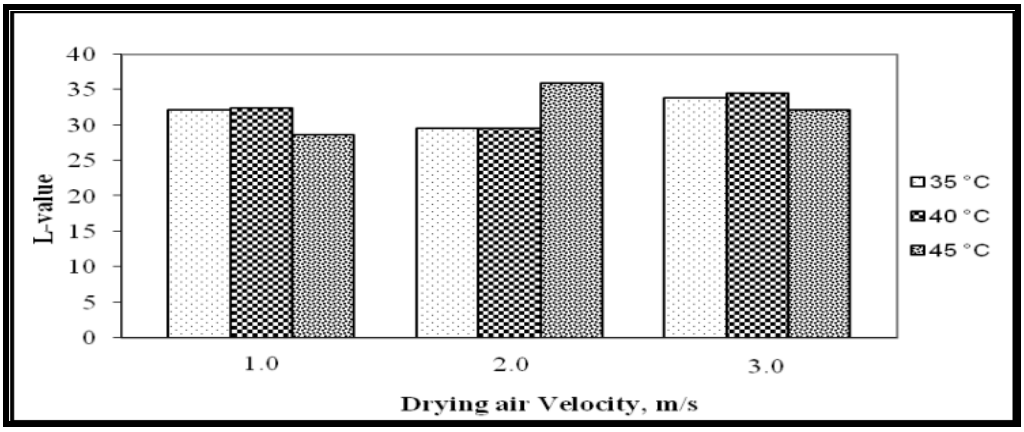


*Fig. 3: Colour (L-value) of ginger powder made from ginger slices dried at IR power of 300 W*

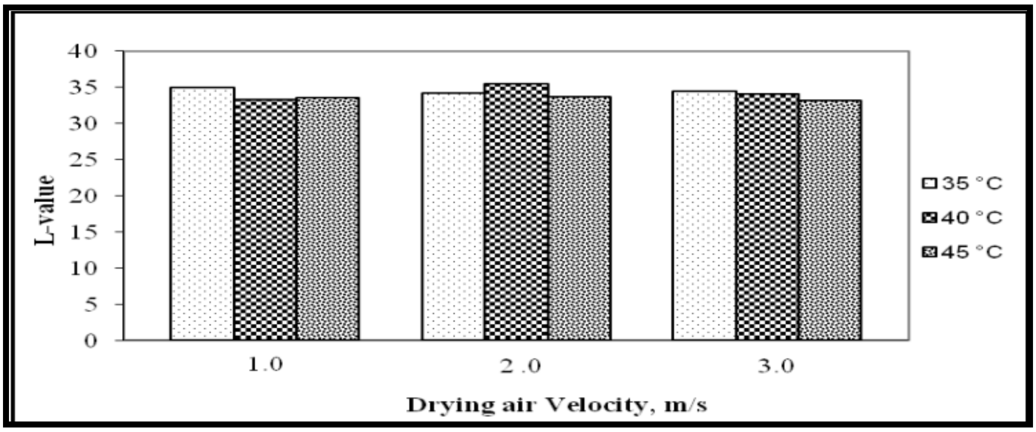


*Fig. 4: Colour (L-value) of ginger powder made from ginger slices dried at IR power of 400 W*

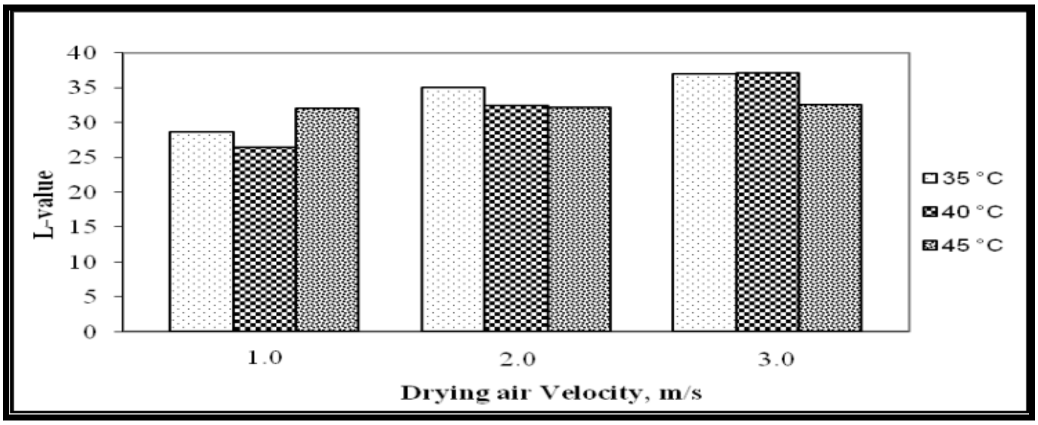


*Fig. 5: Colour (L-value) of ginger powder made from ginger slices dried at IR power of 500 W*

**Table 1: The independent variables and representative coded and un-coded levels**

| Independent Variables | Symbol | Coded Values | | |
|---|---|---|---|---|
| | | **-1** | **0** | **1** |
| Infrared power | X1 | 300 | 400 | 500 |
| Air temperature/°C | X2 | 35 | 40 | 45 |
| Air velocity/m s-1 | X3 | 1 | 2 | 3 |

**Table 2: Box-Behnken design and experimental data obtained for the response variables**

| Number | Infrared Power (Watt) | Air Velocity (m/s) | Air Temperature/°C | Lvalue | RR | SEC(kJ/kg) |
|---|---|---|---|---|---|---|
| 1 | 400 | 2 | 40 | 35.48 | 3.27 | 82.97 |
| 2 | 300 | 2 | 45 | 35.96 | 3.33 | 101.41 |
| 3 | 300 | 2 | 35 | 29.60 | 3.17 | 106.02 |
| 4 | 300 | 3 | 40 | 34.54 | 3.48 | 73.75 |
| 5 | 500 | 2 | 45 | 32.20 | 3.33 | 96.80 |
| 6 | 400 | 1 | 45 | 33.60 | 3.33 | 46.09 |
| 7 | 300 | 1 | 40 | 32.42 | 3.28 | 87.58 |
| 8 | 400 | 2 | 40 | 35.48 | 3.27 | 82.97 |
| 9 | 400 | 2 | 40 | 35.48 | 3.27 | 82.97 |
| 10 | 400 | 2 | 40 | 35.48 | 3.27 | 82.97 |
| 11 | 500 | 2 | 35 | 35.04 | 3.31 | 82.97 |
| 12 | 400 | 3 | 45 | 33.18 | 3.77 | 82.97 |
| 13 | 400 | 2 | 40 | 35.48 | 3.27 | 82.97 |
| 14 | 500 | 1 | 40 | 26.50 | 3.33 | 59.92 |
| 15 | 400 | 1 | 35 | 35.01 | 3.61 | 59.92 |
| 16 | 500 | 3 | 45 | 37.08 | 3.36 | 73.75 |
| 17 | 400 | 3 | 35 | 34.50 | 3.12 | 82.97 |

**Table 3: Analysis of variance (ANOVA) table of colour (L-Value) for Dried Ginger slices using Quadratic Model**

| Source | Sum of Squares | df | MeanSquare | F-Value | p-value Prob> F |
|---|---|---|---|---|---|
| Model | 56.8108 | 6 | 9.468467 | 1.812634 | 0.1936 non-significant |
| A-IR Power | 0.36125 | 1 | 0.36125 | 0.069157 | 0.7979 |
| B-Temperature | 0.078013 | 1 | 0.078013 | 0.014935 | 0.9052 |
| C-Velocity | 17.31661 | 1 | 17.31661 | 3.315075 | 0.0987 |
| AB | 21.16 | 1 | 21.16 | 4.05085 | 0.0719 |
| AC | 17.8929 | 1 | 17.8929 | 3.425399 | 0.0939 |
| BC | 0.002025 | 1 | 0.002025 | 0.000388 | 0.9847 |
| Residual | 52.23595 | 10 | 5.223595 | | |
| Lack of Fit | 52.23595 | 6 | 8.705992 | | |
| Pure Error | 0 | 4 | 0 | | |
| Cor Total | 109.0468 | 16 | | | |

**Table 4: Analysis of variance (ANOVA) table of Rehydartion ratio for Dried Ginger slices using Quadratic Model**

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob> F |
|---|---|---|---|---|---|
| Model | 0.364669 | 9 | 0.040519 | 14.30676 | 0.0010 significant |
| A-IR Power | 0.000613 | 1 | 0.000613 | 0.216267 | 0.6560 |
| B-Temperature | 0.037813 | 1 | 0.037813 | 13.3512 | 0.0081 |
| C-Velocity | 0.00405 | 1 | 0.00405 | 1.430013 | 0.2707 |
| AB | 0.0049 | 1 | 0.0049 | 1.730139 | 0.2298 |
| AC | 0.007225 | 1 | 0.007225 | 2.551072 | 0.1543 |
| BC | 0.216225 | 1 | 0.216225 | 76.34678 | < 0.0001 |
| A^2 | 0.006737 | 1 | 0.006737 | 2.378708 | 0.1669 |
| B^2 | 0.012737 | 1 | 0.012737 | 4.497246 | 0.0717 |
| C^2 | 0.073921 | 1 | 0.073921 | 26.10075 | 0.0014 |
| Residual | 0.019825 | 7 | 0.002832 | | |
| Lack of Fit | 0.019825 | 3 | 0.006608 | | |
| Pure Error | 0 | 4 | 0 | | |
| Cor Total | 0.384494 | 16 | | | |

**Table 5: Analysis of variance (ANOVA) table SEC for Dried Ginger slices Using Quadratic Model**

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob> F |
|---|---|---|---|---|---|
| Model | 3059.29299 | 9 | 339.9214434 | 4.618085035 | 0.0280 significant |
| A-IR Power | 382.4506813 | 1 | 382.4506813 | 5.195876289 | 0.0567 |
| B-Temperature | 2.655907509 | 1 | 2.655907509 | 0.036082474 | 0.8547 |
| C-Velocity | 448.848369 | 1 | 448.848369 | 6.097938144 | 0.0429 |
| AB | 84.98904028 | 1 | 84.98904028 | 1.154639175 | 0.3182 |
| AC | 191.2253406 | 1 | 191.2253406 | 2.597938144 | 0.1510 |
| BC | 47.80633516 | 1 | 47.80633516 | 0.649484536 | 0.4468 |
| A^2 | 403.9775106 | 1 | 403.9775106 | 5.488334238 | 0.0516 |
| B^2 | 68.49445681 | 1 | 68.49445681 | 0.93054802 | 0.3669 |
| C^2 | 1522.254356 | 1 | 1522.254356 | 20.68095496 | 0.0026 |
| Residual | 515.2460567 | 7 | 73.60657953 | | |
| Lack of Fit | 515.2460567 | 3 | 171.7486856 | | |
| Pure Error | 0 | 4 | 0 | | |
| Cor Total | 3574.539047 | 16 | | | |

**Table 6 : Process optimization of Dried Ginger slices**

| Parameter | Goal | Lower limit | Upper limit |
|---|---|---|---|
| **Infrared Power (W)** | Minimize | 300 | 500 |
| **Velocity (m/s)** | Minimize | 1.00 | 3.00 |
| **Temperature (oC)** | Minimize | 35.0 | 45.0 |
| **Specific energy consumption** | Minimize | 46.06 | 106.02 |
| **L-value** | Maximize | 26.50 | 37.08 |
| **Rehydration ratio** | Maximize | 3.16 | 3.77 |

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