



Original Article

Parametric Optimization of Fluidized Bed Dryer by Taguchi Method: Drying Kinetics of Ragi

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Abstract

This experimental study emphasizes on the assessment of the physicochemical properties of a long-term cereal Ragi (Eleusine coracana), using standard analytical methods. The main objective is to estimate their moisture content. The drying properties of these materials studied using a fluid bed dryer to estimate and evaluate parameters by Taguchi L9 (3x3) method. In addition, the fluid bed dryer is a proven and tested dryer to estimate the moisture rate in grains. In this regard an investigative model is necessary to gain insights into the factors influence on fluid bed dryer. This experimental investigation attentive on the influence of operating factors such as drying medium (air) air velocity, temperature, and solid holdup. Taguchi design technique with L9 (3x3) array settings was used. For the least number of experimental cycles with the required process factors, the L9 orthogonal array method was prepared the SN Ratio and Analysis of Variance (ANOVA) analysis tools. Significant control factors for moisture ratio and, necessary for designers and users of fluid bed dryers, have been identified. ANOVA was performed at a 95% confidence level and a 5% significance level. F values ($F > P$) indicate the significance level of the control factors. The solid holdup parameter with the largest percentage contribution (76.66 %), followed by the factor air velocity (21.20%), are significant parameters, while the factor temperature (2.08 %) is insignificant for Moisture ratio (MR)

Keywords: Drying Kinetics, SN ratio, Fluidized Bed Dryer, Moisture Content, ANOVA

Introduction

The drying of food grains is a crucial process in the food industry, as it significantly impacts their shelf- life, processing quality, and nutritional retention. Conventional drying methods such as tray drying and advanced drying techniques like fluidized bed drying are commonly used for moisture removal. However, the efficiency of these methods in preserving the nutritional content of food grains varies. Understanding the drying kinetics of different grains under varying conditions helps in optimizing the drying process. This study aims to compare the drying behavior and nutritional retention of Ragi under tray and fluidized bed drying conditions, providing insights into the best drying methodology for these grains. Previous studies have explored different drying methods for grains and their impact on nutritional quality. Tray dryers are widely used due to their simplicity and cost-effectiveness, but they have limitations in drying efficiency and uniformity [1]. Fluidized bed drying, on the other hand, offers faster moisture removal and better control over drying conditions. Research by [2] highlighted that higher temperatures in drying [3] processes lead to significant nutrient degradation, particularly protein and vitamin content. Studies on drying kinetics by [4] suggest that Page's model provides a more accurate representation of drying behavior than Newton's model for various grains.



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[5] Emphasized that heat and mass transfer mechanisms in different drying technologies affect final product quality. Studies by [6] indicate that fluidized bed drying enhances heat transfer rates, leading to shorter drying times compared to traditional methods. Research by [7] confirmed that optimizing drying parameters improves energy efficiency and minimizes nutrient loss. Studied the energy and exergy efficiency of drying methods and found that fluidized bed drying consumes less energy per unit of moisture removal than tray drying [8]. However, limited studies have focused on comparing these drying methods specifically for wheat and Ragi. Therefore, this research expands on previous findings by analyzing both drying kinetics and nutritional retention of these grains under different drying conditions. Despite extensive research on drying kinetics, few studies directly compare the effectiveness of tray dryers and fluidized bed dryers for wheat and Ragi. Moreover, the impact of these drying methods on key nutritional parameters such as protein, fat, and fiber has not been thoroughly examined. This study aims to bridge this gap by conducting an in-depth comparative analysis of drying kinetics and nutritional retention for the Ragi grains.

Materials and Methodology

In view of experimental investigation, experiments conducted on drying of Ragi millets with sophisticated fluid bed dryer techniques. Using the data, the factors optimization conditions examined.

2.1 Raw Materials and sample preparation

Ragi grains were sourced from the local market in Hyderabad. The initial moisture content, density, particle size, and other physio-chemical properties were determined using standard methods. The particle size, density, minimum fluidization velocity and Bed void age at minimum fluidization of selected Food grains obtained from various sources and shown in below table.

Name of Food Grain	Particle Size (mm)	Density (kg/m ³)	Minimum fluidization velocity U_{mf} (m/s)	Bed Void age at minimum fluidization velocity (ϵ_{mf})
Ragi	1.48	1140	0.89	0.42

2.2 Design of Experiments: Taguchi L₉ (3x3) array, Drying Kinetics Study in Fluidized Bed

Fluidized bed drying was performed [9] under varying conditions of air velocity (1.75 m/s, 1.80 m/s, 1.85 m/s) and drying temperatures (50°C, 60°C, 70°C). The moisture loss was monitored over time to study the drying kinetics. The drying of Ragi are conducted in fluidized bed dryer at various drying conditions of drying medium (air) air velocity, temperature, and solid holdup. During the drying, the kinetics data were analyzed and found the effect of temperature, velocity and solid holdup on drying kinetics in a fluidized bed dryer. For the discussion of obtained results, the temperature for drying of 50° C, 60° C, 70° C, the air velocities of 1.75m/s, 1.80m/s, 1.85m/s and solid holdups of 0.100 kg, 0.150 kg, 0.200 kg considered. The operating conditions for effect of temperature, effect of velocity, effect of solid holdups for Ragi given in the table 1.

Table: 1. Operating Factors and control levels of food grains Ragi

S No	factors	Level 1	Level 2	Level 3
1	Solid holdups(kg)	0.1	0.15	0.2
2	Velocity(m/s)	1.75	1.8	1.85
3	Temperature(°C)	50	60	70

2 Results and Discussions

The operating conditions for effect of temperature, effect of velocity, effect of solid holdups for Ragi are given in the table 2. Taguchi L₉ (3x3) orthogonal codes, operating factors, control levels and Response.

Table: 2. Taguchi L₉ (3x3) orthogonal codes, operating factors, control levels and Response.

Expts No	Taguchi L ₉ (3x3) orthogonal code values			Levels			Response
	Factor A Solid Hold Kg	Factor B Velocity m/s	Factor C Temp °C	Level 1 Factor A Solid Hold Kg	Level 2 Factor B Velocity m/s	Level 3 Factor C Temp °C	Moisture Ratio MR
1	1	1	1	0.1	1.75	50	1
2	1	2	2	0.1	1.8	60	0.58
3	1	3	3	0.1	1.85	70	0.55
4	2	1	2	0.15	1.75	60	0.52

5	2	2	3	0.15	1.8	70	0.36
6	2	3	1	0.15	1.85	50	0.29
7	3	1	3	0.2	1.75	70	0.25
8	3	2	1	0.2	1.8	50	0.14
9	3	3	2	0.2	1.85	60	0.04

1.4. Analysis of the findings

Analysis of the results obtained using the Taguchi-designed L9 (3x3) cluster design was performed at a 95% confidence level using MINITAB R18 software.

1.5. Signal to noise ratio (S/N) analysis

The basic planning method in the Taguchi test converts an independent parameter into a signal-to-noise ratio, which is treated as quality properties index, the lowest variability and optimal designs are achieved using the S / N ratio [10]. Advantages of S / N ratio includes increasing the influence of premium factors, reducing interactive performance, improve quality by processing mean and variation simultaneously. The higher the S/N ratio, the more stable the quality. Based on the response variable, the higher the S/N ratio, the more suitable the value is for Moisture rate analysis. The experimental results and signal-to-noise ratios are listed in Table 3. The response table of signal-to-noise ratios for control factors such as drying medium (air) air velocity, temperature, and solid holdup generated using the Taguchi method and is listed in Table 1. The optimal factors A₃, B₃, and C₂ for fluidized bed dryer Moisture ratio were determined from Table 3 and Figure 2

Table: 3. Response Table for Signal to Noise Ratios
Smaller is better

Level	A Solid Hold Kg	B Velocity m/s	C Temp °C
1	3.308	5.907	9.276
2	8.435	10.228	12.790
3	19.026	14.635	8.703
Delta	15.718	8.727	4.087
Rank	1	2	3

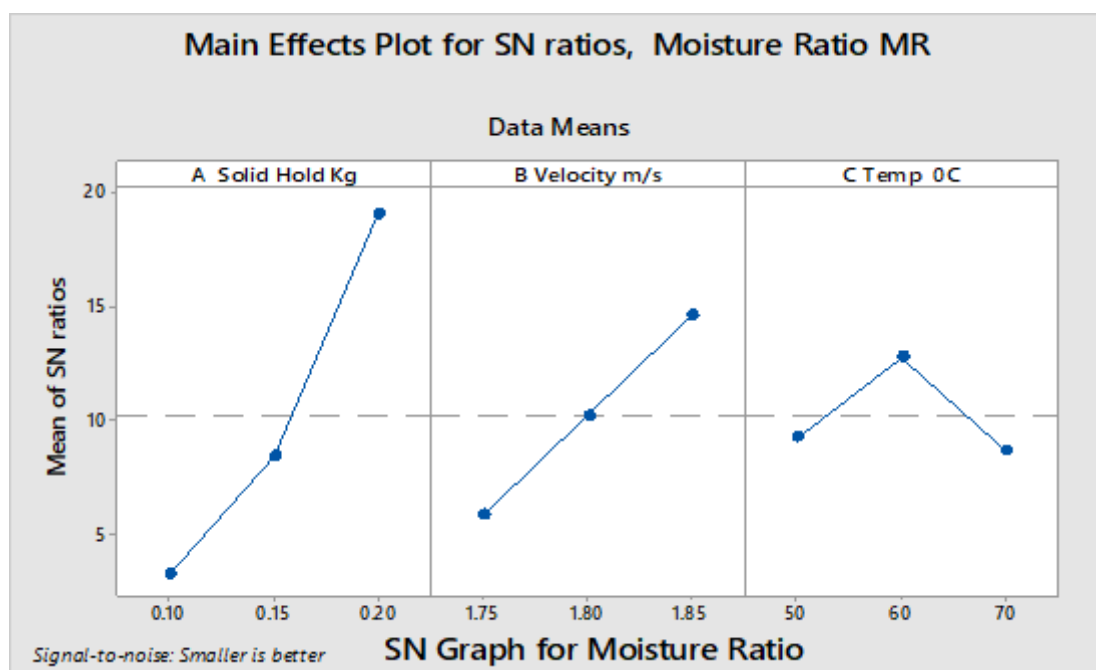


Figure.1. SN Graph for Moisture ratio

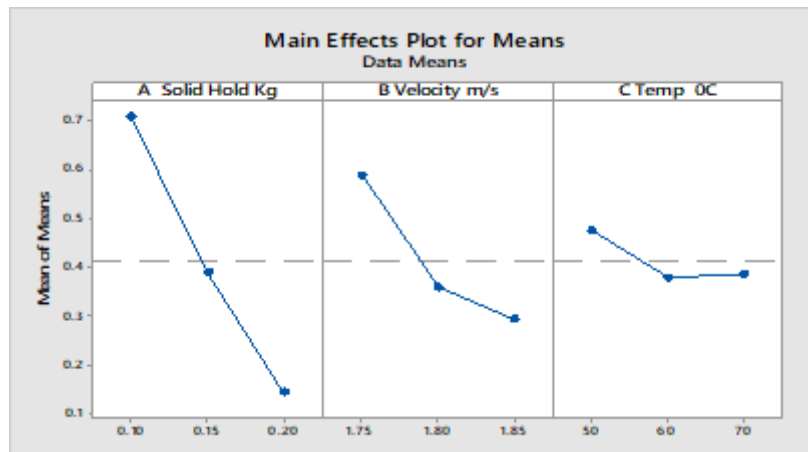


Figure.2. Main Effective plot for means of MR (Moisture Ratio)

Table: 4. Response Table for Means

Level	A Solid Hold up Kg	B Air Velocity m/s	C Temp 0C
1	0.7100	0.5900	0.4767
2	0.3900	0.3600	0.3800
3	0.1433	0.2933	0.3867
Delta	0.5667	0.2967	0.0967
Rank	1	2	3

Table: 5. Taguchi L₉ (3x3) orthogonal array, control parameters, SN ratio of MR and Mean

A Solid Hold Kg	B Velocity m/s	C Temp 0C	Moisture Ratio(MR)	SN Ratio of MR	MEAN
0.1	1.75	50	1	0	1
0.1	1.8	60	0.58	4.7314	0.58
0.1	1.85	70	0.55	5.1927	0.55
0.15	1.75	60	0.52	5.6799	0.52
0.15	1.8	70	0.36	8.8739	0.36
0.15	1.85	50	0.29	10.752	0.29
0.2	1.75	70	0.25	12.0412	0.25
0.2	1.8	50	0.14	17.0774	0.14
0.2	1.85	60	0.04	27.9588	0.04
Average			0.4144444	10.2564	

The figure 1, shows the S/N graph for finding the optimal parameters using the corresponding table 3 and table 4. According to Figure 1 and figure 2, for the S/N ratios, the improved combination of optimal parameters determined for factor A, Solid Hold up, level 3, 0.20 Kg, (S/N = 19.026), factor B Air Velocity, level 3, 1.85 m/s (S/N = 14.635), and factor C Temperature, level 2, 60⁰ C (S/N = 12.790). The analysis of the S/N ratio showed the way to choose the optimal factor level based on the minimum variation around the target and also on the average value closest to the target. [11] The average S/N ratio 10.2564 of moisture ratio (MR) obtained from Table 5 and the graph of the S/N ratio for the smaller is better given in Figure 2. In the present study “the smaller the better” standard characteristics applied. For “smaller the better” quality feature, the S/N ratio (K) is expressed by the equation (1)

$$K = -10 \log_{10} (1/MSRD) \quad (1)$$

$$MSRD = \sigma^2 + (m_{avg} - m_0)^2 \quad (2)$$

Where σ^2 is the variance, the m_{avg} is the data mean, and m_0 is the target value, which in this case is zero. The evaluation of the experimental data carried out using the Minitab-R18 program. The graphical value of the S/N ratio is used to determine the optimal factor level [12]. The corresponding effect of this factor is estimated for ANOVA. The data required for ANOVA are given by the equation 3.

$$P_s = \sum_{y=1}^N (ky - \bar{K})^2 \quad (3)$$

Where P_s is the summation of squares, N is number of findings and $\bar{K}$ is the overall mean of S/N Ratio.

$$PP_j = \sum_{y=i}^J (K_{ji} - \bar{K})^2 \quad (4)$$

Where PP_j is sum of square deviation of j^{th} factor, i is level of i^{th} factor.

$$PP_j = \frac{PP_j}{f_j} \quad (5)$$

Where U_j , f_j are variance and degrees of freedom respectively of j^{th} parameter.

$$F_j = U_j / U_e \quad (6)$$

$$F_j = \frac{U_j}{U_e} \quad (6)$$

Where F_j is the F-statistic of the j^{th} factor and U_e is the variance of error. If the degrees of freedom of the error become zero, it is not possible to calculate the F-statistic and the ANOVA analysis of variance. In this case, it is possible to predict and verify improvements in observed values using a combination of factor levels. As shown in equation (7).

$$K_{pred} = \bar{K} + (\bar{K}_i - \bar{K}) + (\bar{B}_j - \bar{K}) + (\bar{C}_y - \bar{K}) \quad (7)$$

Where K_{pred} is the predicted signal-to-noise ratio of the response, $\bar{K}$ is the sum of the experimental means, $(\bar{A}_i)$, $(\bar{B}_j)$ and $(\bar{C}_y)$ are the mean responses for factors A, B and C, at levels i , j and y , respectively ($i, j, y = 1, 2, 3$). Non-significant factors and interactions are generally omitted from Equation 7.

2. Variance Evaluation

It shows the influence of the dependent variables and also determines the percentage contribution of these dependent variables to the response variable. ANOVA analysis was performed [13] in this study with a 95% confidence level and a significance level of 5%. The F-values ($F > P$) indicate the significance of the control factors. Table 6 gives the percentage contribution of the parameters to the response variables (MR) using ANOVA. The ANOVA table therefore shows the significance of each parameter. Based on the ANOVA for moisture ratio (Table 6), the f-value concluded that moisture ratio mainly influenced by the factor –A (Solid holdup). The choice of experimental parametric factors and their corresponding levels, analysis of variance (ANOVA), controls the experimental results to determine the effect of each parameter against the objective function. General Linear Model: Moisture Ratio (MR) versus A Solid ... Temp °C shown in table 6.

3. Identification of Response Variables

The performance factors (Solid holdup, air velocity, and temperature) significantly influence the response. The variable is identified by the percentage contribution of each parameter. Factor A – Solid holdup parameters with a higher percentage contribution of 76.66%, followed by factor B – Air velocity with 21.20%, are significant parameters for the moisture ratio is most prominent effective property of a moisture ratio for fluidized bed dryer, it plays main role in the quality of the drying of Ragi grains. The applications of fluidized bed dryers have been applied in industrial applications as well as other applications like Agro industry, food processing industry, etc.

Table: 6. Analysis of Variance for Transformed Response

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
A Solid Hold Kg	2	0.341474	76.66%	0.341474	0.170737	1131.66*	0.001
B Air Velocity m/s	2	0.094440	21.20%	0.094440	0.047220	312.98*	0.003
C Temp °C	2	0.009245	2.08%	0.009245	0.004623	30.64	0.032
Error	2	0.000302	0.07%	0.000302	0.000151		
Total	8	0.445460	100.00%				

*significance at 95% confidence Level

4. Conclusions

Analysis of the experiment conducted using the Taguchi L9 (3x3) orthogonal method. A study of the signal-to-noise ratio with respect to the moisture ratio, which is generally considered "the smaller the better", shows that important parameters play a significant role in the design of a successful fluid bed dryer. The discussion concerns the optimization of moisture ratio parameters. The construction of an efficient fluidized bed dryer technique was investigated for different factors, such as solid holdup at 0.20 kg, with a 76.66% significant contribution, Air Velocity



at 1.85 m/s with 21.20% contribution and the temperature at 60⁰ C with 2.08% contribution is insignificant. The significance of the parameters determined at the 95% confidence level using ANOVA. This effective property of a moisture ratio for fluidized bed dryer, it plays main role in the quality of the drying of Ragi grains. The applications of fluidized bed dryers have been applied in industrial applications as well as other applications like Agro industry, food processing industry, etc. This modeling process can be further improved by using non-traditional optimization methods such as neural networks and genetic algorithms.

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