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Taguchi Method by Grey Relational Analysis for Multi-Response Optimization of Innovative Rice Crackers

[1] Surapong Bangphan, [2] Suwattanarwong Phanphet*

[1] Department of Industrial Education and Technology, Faculty of Engineering, Rajamangala University of Technology Lanna, Chiang Mai, Thailand.
[2] Department of Industrial Technology, Faculty of Science and Technology Chiang Mai Rajabhat University, Chiang Mai, Thailand.

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KEYWORDS

Taguchi, Grey relational analysis, response, analysis of variance, innovative rice crackers.

ABSTRACT:
Innovative Rice Crackers were investigated. Three and five-level Taguchi's Grey relational analysis was used to study the effects of different experimental variables on an innovative cracker of moisture content of five variables. (10, 11, 12, 13, and 14 percent), temperature (25, 26, 27, 28 and 29 degrees Celsius), and speed (1460, 1470, 1480, 1490, and 1500 rpm.) were used to identify significant effects and interactions in cohort studies. A polynomial regression model was developed using experimental data. The results showed that rice cracker innovation was greatly affected by changes in rice moisture content. The most innovative rice cracker activity was achieved when it was dehusked at a humidity of 10 percent, a temperature of 26 degrees Celsius, and a speed of 1480 revolutions per minute. The starting factor setting that produces 98.9 percent of good rice is close to the rice cracker innovation activity that was produced from the experiment, which is 99.32 percent of good rice and the percentage of broken rice produced is 19.10, decreasing to 18.96, respectively. By confirming the experimental results in Grey's relational analysis at 0.074.

1. Introduction

The quality of paddy depends on many factors such as rice variety, feed rate, and distance between the rubber and the rubber barrel. and moisture content of paddy is usually controlled below 14%, but the most important factor is the type of abrasive [1]-[2]. Procurement of rice is another advantage of brown rice compared to polished or white rice. Postharvest researchers say that the recovery of brown rice is 10% higher than that of polished rice [3]. Fuel savings in rice milling can be 50-60% as the polishing and whitening process is eliminated. This is followed by shorter milling times and less labor and equipment costs. (If the mill is exclusively for brown rice) is much cheaper, since the mill does not need to install a milling machine and bleach. Increasing productivity and the milling economy is a business opportunity for brown rice [4]. Brown rice (paddy) contains bran (6–7% by weight), endosperm (E90%), and embryo (2 –3%) [5] White rice is referred to as milled, milled, or milled rice when 8 –10% of the mass (mainly the bran) is removed from brown rice [5] during milling. Brown rice is milled or rubbed to remove the bran layer. This results in high, medium, or low milling levels depending on the amount of rice bran removed [5]-[8]. Edible properties of milled rice [5]-[8] as most grains of rice do not show the structure is homogeneous from outer (surface) to inner (central) [9]. Hence, information on nutrient distribution will be of great help in understanding rice milling effects. and help improve the sensory properties of rice, while still retaining essential nutrients as much as possible [10].

This research was developed from the One Tambon One University project, Nong Phueng Subdistrict, Saraphi District, Chiang Mai Province, and Mueang Ngai Subdistrict, Chiang Dao District, Chiang Mai Province, as well as students from both institutions, including the units used in production and production test. And this time has been extended by adding a set of inverters. To optimize the speed and increase efficiency, a collaboration between the Industrial Education and Technology, Faculty of Engineering Rajamangala University of Technology Lanna and Department of Industrial Technology Faculty of Science and Technology Chiang Mai Rajabhat University. By using

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the Grey relational analysis method, the confidence was significant.

This research was in collaboration the Industrial Education and Technology, Faculty of Engineering, Rajamangala University of Technology Lanna with the Industrial Technology Department, Faculty of Science and Technology Chiang Mai Rajabhat University. Because Nong Phueng Subdistrict, Saraphi District, Chiang Mai Province, and Mueang Ngai Subdistrict, Chiang Dao District, Chiang Mai Province can better utilize the rice cracker innovation.

Therefore, this study is to multi-response optimization of cracker innovation using the Design of Experiment (DOE) by the Taguchi method combined with relational analysis to generate optimum factors.

2. Experimental Procedure

Material and Method

Material

In this experiment to find efficiency, brown rice innovation machine was used to build confidence in the community by experimenting with Hom Nil rice varieties. Hom Nin rice is still popular for consumption and Hom Nin rice varieties will be tested to be stable throughout the experiment. The bown rice innovation machine, is shown in Figure 1. The rice used for the experiment was the Hom Nin rice variety. The experiment was carried out at 1 kg each time (set as a constant value throughout the experiment) with 3 control factors: moisture of paddy, temperature, speed, and 5 levels as shown in Table I.

Fig.1. The new-designed paddy husker [11]

Table 1. Doe Parameters

Parameter	Variable	Code level				
		-1	0	0	1	1
Rice of Moisture, RM	X_1	10	11	12	13	14
Rice of Temperature, RV	X_2	25	26	27	28	29
Speed, S	X_3	1460	1470	1480	1490	1500

Note:

X_1 = the unit is percentage, X_2 = degree Celsius, and X_3 = round per minute.

Method

The Taguchi Method

Taguchi's robust parametric design was used to determine the levels. That is, the parameter settings should be intentionally set so that there is minimal variation in the product response while the average value is close to the desired target. Taguchi's method is based on statistical analysis and sensitivity to determine optimal parameter settings to achieve robust performance [12]. The mean and variance are combined into a single performance measure known as the ratio. Signal-to-Noise (S/N) [12]. The innovative rice crackers are regarded as a quality characteristic with the concept of "the larger, the better". The S/N ratio is used for this type of response. It is assumed that the target S/N ratio is the maximum response value and is appropriate when listing only the acceptable limits below, which can be obtained from:

$$S/N_L = -10\log\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right) \quad (1)$$

Assuming a smaller problem type is better (response variance), the S/N ratio of the target value is assumed. The response is zero, and the appropriate value is given when detailing the upper limit tolerance. Can be obtained by:

$$S/N_S = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (2)$$

Where n is the number of measurements and y_i is the measured characteristic value. The mean response for Grey relational grade is high and the main effect plot for gray relational grade is very significant. This is because the optimal process conditions can be estimated from this plot. The dotted line is the value of the combined average

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of the S/N ratio and the average effect from the research of [13].

The study of optimum factors for hulling with rice cracker innovation by Taguchi method and Grey relational analysis.

TABLE II. L-25 (5^3) Orthogonal Array

Trial order	Variable			Response	
	X_1	X_2	X_3	PGR	BRP
1	**10**	**25**	**1460**	**98.9**	**19.10**
2	10	26	1470	96.7	19.90
3	10	27	1480	97.4	19.90
4	10	28	1490	93.1	20.20
5	10	29	1500	88.9	21.30
6	11	25	1470	79.4	26.40
7	11	26	1480	84.5	22.20
8	11	27	1490	80.3	22.90
9	11	28	1500	77.9	23.70
10	11	29	1460	85.6	20.90
11	12	25	1480	77.8	25.30
12	12	26	1490	76.8	22.50
13	12	27	1500	83.5	22.20
14	12	28	1460	87.5	20.15
15	12	29	1470	79.9	23.90
16	13	25	1490	76.6	23.50
17	13	26	1500	84.2	21.90
18	13	27	1460	85.1	19.30
19	13	28	1470	75.5	23.80
20	13	29	1480	78.6	24.40
21	14	25	1500	68.6	25.30
22	14	26	1460	77.9	20.21
23	14	27	1470	74.9	25.60
24	14	28	1480	73.8	25.90
25	14	29	1490	70.7	25.50

Note:
X_1 = the unit is percentage, X_2 = degree Celsius, and X_3 = round per minute, PRG = percentage of good rice, and BRP = broken rice percentage.

Experimental design by Taguchi method, in this experiment, three factors affecting the husking process of innovative crackers and brown rice were examined, each of which had 5 levels of *L*-25 (5^3). A second iteration was performed to confirm the results to determine the efficacy. Therefore, the experiment was run equal to 25 cycles and the total iterations were 25 cycles. The determined factor is shown in Table II. The *L*-25(5^3) orthogonal array sequence was used in this study [13].

The Grey Relational Generation

The first step is to create a Grey relation. The experimental results are normalized to a range between 0 and 1 due to different units of measurement. Data preprocessing converts the original sequence into a set of comparable sequences. Normalization of experimental data for each quality trait follows the type of performance response. Therefore, normalized data processing for smaller the better, can be expressed as: [14].

$$x_i^*(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{3}$$

Processing standard data for the percentage of good rice, and broken rice corresponding to a larger the better criterion can be expressed as:

$$x_i(k) = \frac{y_i(k) - \min\ y_i(k)}{\max y_i(k) - \min y_i(k)} \tag{4}$$

Where i = 1, 2, 3, ..., *m*, *m* is the number of trials in the Taguchi orthogonal array. In the present work, an orthogonal array *L*-25 is chosen, then *m* = 25 *k* = 1, 2, ..., *n*, *n* are the number of quality characteristics or process responses. at the percentage of good rice, and broken rice in the current job selected, then *n* = 1 [13].

Min $y_i(k)$ is the minimum value of $y_i(k)$ for the k response, y_i max(k) is the maximum value of $y_i(k)$ for the k^{th} response, $x_i(k)$ is the Grey relational generation. The normal value of the material removal rate was calculated by equations (3), (4), respectively [13].

Grey Relational Coefficient and Grey Relational Grade

The second step was to calculate the Grey relational coefficient based on the normalized experimental data to show the relationship between the desired experimental data and the actual data. The average Grey relative coefficients correspond to each operating characteristic. For this reason, the optimal combination of process parameters was evaluated considering the maximum Grey relative grade using the Taguchi method, as standard the Grey relational coefficient can be calculated using the following equation: [13].

$$\xi_i(k) = \frac{\Delta_{\min} + \varsigma\,\Delta_{\max}}{\Delta_{0i}(k) + \varsigma\Delta_{\max}} \tag{5}$$

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$$\Delta_{0i}(k) = \|x_0(k) - x_i(k)\|, \tag{6}$$

$$\Delta_{\max} = \max_{\forall j \in i} \max_{\forall k} \|x_0(k) - x_i(k)\|, \tag{7}$$

$$\Delta_{\min} = \min_{\forall j \in i} \min_{\forall k} \|x_0(k) - x_i(k)\|, \tag{8}$$

Where

$\Delta_{0i} = \|x_0(k) - x_i(k)\|$ is difference of the absolute value between $x_0(k)$ *and* $x_i(k), x_0(k)$ is the reference sequence of the k^{th} quality characteristics [13].

$\Delta_{\min}$ *and* $\Delta_{\max}$ These are the minimum and maximum absolute differences of all comparison sequences, respectively [13].

ζ is the discrimination coefficient $0 \le \zeta \le 1$. The purpose is to reduce the effect of Δ_{max} when it is too large, thereby amplifying the important distinction of the relativistic coefficient, in the present case $\zeta = 0{,}5$ was used due to its moderate heterogeneity and good effect stability [13].

Grey relational coefficient of each behavior. The relative grade of Grey can be calculated as follows:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i\,(k), \tag{9}$$

Where, γ_i = 1, 2, 3 ... 9, (L-25 orthogonal array chosen), $\xi_i(k)$ is the Grey relational coefficient of the k^{th} response in experiment i^{th}, and n is the number of responses. Response the optimum level of the process parameter is the one with the highest Grey relative grade [13].

The process parameter, which can be displayed as a mean response table. From the average answer table. Higher average grade values were selected as the optimal parametric combination for multiple responses [16].

The next step was an analysis of variance (ANOVA) to judge the key parameters affecting multiple responses at a 95% confidence level and provide important information about the experimental data. ANOVA analysis is useful in determining the percentage of contribution to identifying effects response. The *P*-value (the sum of squared deviations about the large mean) is subdivided into individual parameter values and errors [15]. The *P*-value (probability of significance) is generally calculated based on the *F*-value or ratio. If the value is less than 0.05, degrees of freedom (*DF*) must be used to assess the mean squared (*M*S), and measure the availability of independent data to assess the sum of squares (*SS*) in the Deviation ANOVA analysis. [16]

After the optimal combination of process parameters has been found, the predicted value of the Grey relative grade for the appropriate level can be obtained as follows.

$$\hat{\gamma} = \gamma_m + \sum_{i=1}^{0} \left(\bar{\gamma} - \gamma_m\right), \tag{10}$$

Where γ_m is the total Grey average relative grade $\bar{\gamma}_i$ is the average Grey average grade at the optimal level of each parameter and 0 is the number of significant process parameters [17].

The multi-objective optimization problem is converted to a single-function objective optimization problem using Grey-scale relational analysis. Maximum Grey using the Taguchi method. According to the research of [13]

3. Results and Discussion

When hulling the brown rice with an innovative rice cracker in which the material of three rubber balls the new-designed paddy husker (Diameter of the rubber ball hull 2.5 inches), which the three rubbers will have different speeds. All three will rotate toward each other. The efficiency of percent good rice and percentage broke rice under the design conditions were tested of 25 experiments, and the weight and timing values were measured. Hulling times were recorded over time. The relationship between moisture, temperature, and speed. The speed is 1460 rpm, the second factor is 10 percent moisture and the third factor is temperature 25 percent, the highest good rice is 98.9 % and the minimum broken rice is 19.10 %.

The experimental data were normalized for both percentage good rice and percentage broke rice using Equation (3) and presented in Table III, referred to as the Grey relational shown in Table III.

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TABLE III. Grey relational generation values

Trial order	PGR	BRP
Ideal sequence	1	1
1	0.000	0.000
2	0.073	0.110
3	0.050	0.110
4	0.191	0.151
5	0.330	0.301
6	0.644	1.000
7	0.475	0.425
8	0.614	0.521
9	0.693	0.630
10	0.439	0.247
11	0.696	0.849
12	0.729	0.466
13	0.508	0.425
14	0.376	0.144
15	0.627	0.658
16	0.736	0.603
17	0.485	0.384
18	0.455	0.027
19	0.772	0.644
20	0.670	0.726
21	1.000	0.849
22	0.693	0.152
23	0.792	0.890
24	0.828	0.932
25	0.931	0.877

The Grey relational coefficient was calculated using Equation (4) shown in Table III. The value of the difference coefficient is considered to be 0.5 because equal weighting is given to the quality characteristics, both results are shown in Table IV, by using Equation (9) from the results of the Grey relational coefficient. GRG results are shown in Table IV.

TABLE IV. Grey relational coefficient and Grey relational grade values

Trial order	Evaluation of Δ_{0i}		GRC		GRG	Rank
	PGR	BRP	PGR	BRP		
1	**1.000**	**1.000**	**0.333**	**0.333**	**0.667**	**1**
2	0.927	0.890	0.350	0.360	0.632	3
3	0.950	0.890	0.345	0.360	0.636	2
4	0.809	0.849	0.382	0.371	0.603	4
5	0.670	0.699	0.427	0.417	0.553	7
6	0.356	0.000	0.584	1.000	0.485	14
7	0.525	0.575	0.488	0.465	0.513	11
8	0.386	0.479	0.564	0.510	0.485	13
9	0.307	0.370	0.620	0.575	0.468	20
10	0.561	0.753	0.471	0.399	0.546	8
11	0.304	0.151	0.622	0.768	0.461	24
12	0.271	0.534	0.649	0.483	0.484	15
13	0.492	0.575	0.504	0.465	0.509	12
14	0.624	0.856	0.445	0.369	0.573	6
15	0.373	0.342	0.573	0.593	0.470	17
16	0.264	0.397	0.654	0.557	0.468	19
17	0.515	0.616	0.493	0.448	0.518	10
18	0.545	0.973	0.479	0.340	0.584	5
19	0.228	0.356	0.687	0.584	0.464	22
20	0.330	0.274	0.602	0.646	0.463	23
21	0.000	0.151	1.000	0.768	0.480	16
22	0.307	0.848	0.620	0.371	0.536	9
23	0.208	0.110	0.706	0.820	0.461	25
24	0.172	0.068	0.744	0.880	0.466	21
25	0.069	0.123	0.878	0.802	0.468	18

The value of the GRG, the impact of individual process parameters at different levels are plotted and shown in Fig. 2, and the relative average gray grade is shown in Table V. The optimal parametric combinations are selected based on higher relative Grey average values from Table V. Higher values of the Grey relative grade indicate a stronger affinity with the reference sequence and better performance. Therefore, the optimal setting for various responses becomes M_1-T_1-S_2, e.g., moisture 10 %, temperature 25 °C and speed 1460 rpm, respectively. The higher value of the relative Grey average grade (Fig. 2) gave the highest value of percentage of good rice and the lowest percentage of broken rice. The difference in the average GRG maximum and minimum for the exfoliation parameter was 0.1359 for moisture, 0.0365 for temperature and 0.0796 for velocity, respectively (Table V). This result indicates that moisture has the greatest effect on response, variety compared with the temperature and speed of shelling. The process parameter priority in various responses is Moisture > Velocity > Temperature.

TABLE V. Main effects on mean Grey relational grade

Factor	Mean Grey relational grade					Max-Min	Rank
	L1	L2	L3	L4	L5		
M	**0.6182**	0.4995	0.4997	0.4994	0.4823	0.1359	1
T	0.5122	**0.5368**	0.5351	0.5147	0.5002	0.0365	3
S	**0.5813**	0.5024	0.5080	0.5017	0.5056	0.0796	2

Total mean Grey relational grade = 0.51981

Note: M = Moisture, T = Temperature, and S = Speed

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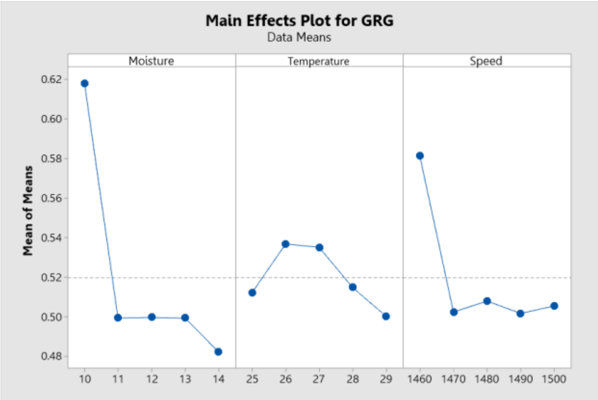

Fig.2. Main effect plot of Grey relational grade

A table of analysis of variance (ANOVA) was prepared on the basis shown in Table VI. From the ANOVA table, moisture and velocity were found as parameters. Significant processes affecting multiple responses as p values were less than 0.05 at the 95% confidence level, temperature did not show any significance.

TABLE VI. Results of ANOVA on Grey relational grade

Source	*DF*	*Adj SS*	*Adj MS*	*F*	*P*	Remarks
Moisture	4	0.061589	0.015397	34.27	0.000	*Significant*
Temperature	4	0.004932	0.001233	2.74	0.078	*Insignificant*
Speed	4	0.023757	0.005939	13.22	0.000	*Significant*
Error	12	0.005392	0.000449			
Total	24	0.095669				

S	*R-sq*	*R-sq(adj)*	*R-sq(pred)*
0.0211966	94.36%	88.73%	75.54%

The predicted GRG can be obtained using Equation (10). The Grey relational grade at the optimum setting becomes 0.741, which is close to the predicted value, that is, 0.672. From the confirmation run shown in Table VII, it was found that the Grey relational grades of the two responses, i.e., percentage of good rice and percentage of broken rice, were significantly improved. (0.074) via setting the optimal parameter combination.

From the above analysis the parameters were optimized and the maximum value of the percentage of good rice was found, and the lowest percentage of broken rice in dehusked through Grey relational analysis according to Taguchi's approach.

TABLE VII. Confirmation Experiment

Level	Initial factor setting	Optimal cracking factors	
		prediction	experiment
	M1-T1-S1	M1-T2-S3	M1-T2-S3
PRG	98.90	-	99.32
BRP	19.10	-	18.96
Grey relational grade	0.667	0.672	0.741

Improvement in GRG = 0.074

Mathematical model

A multiple regression model was developed for both the responses, i.e., percent f of good rice and percentage of broken rice at 95% confidence level, considering moisture (*M*), temperature (*T*), and velocity (*S*) as parameters, input the adequacy of the model is checked by evaluating the determination coefficient (R^2). The greater the value of R^2, e.g. The greater the significance of the model. From the experimental results. The second-order mathematical model for the percentage of good and minimum of broken rice is shown in Equations 3, 4, 5 and 9 with R^2 values respectively.

Second order model

$$
\begin{aligned}
GRG = {} & 0.51979 + 0.09837\ Moisture\_10 - 0.02032\ Moisture\_11 \\
& - 0.02012\ Moisture\_12 \\
& - 0.02042\ Moisture\_13 - 0.03751\ Moisture\_14 \\
& - 0.00760\ Temperature\_25 \\
& + 0.01696\ Temperature\_26 + 0.01526\ Temperature\_27 \\
& - 0.00507\ Temperature\_28 \\
& - 0.01955\ Temperature\_29 + 0.06149\ Speed\_1460 \\
& - 0.01736\ Speed\_1470 - 0.01181\ Speed\_1480 \\
& - 0.01809\ Speed\_1490 - 0.01422\ Speed\_1500
\end{aligned}
$$

$R^2 = 94.36\%$

4. Conclusion

This paper presents The Grey-based Taguchi method that has been applied to various behaviors of shelling operations.

Multi-response optimization of the shelling process was used to obtain an optimal parameter combination that yielded the maximum percentage of broken rice (BRP) versus the minimum percentage of good rice (PGR). Grey relational, according to Taguchi's method, directly combines several quality characteristics into a single performance characteristic known as the Grey relational grade. The optimal combination of the process parameters

The use of the Taguchi method greatly reduced the number of trials. *L*-25(5^3) Taguchi orthogonal arrays, signal-to-noise (*S*/*N*) ratio, and analysis of variance (ANOVA) were used to optimize the cracking parameters based on gray-scale correlation grades. Based on the analysis of the optimal combination for the newly designed paddy shelling, (Diameter of rubber ball hull 2.5 inches) Percentage of good rice percentage of broken rice Several performance characteristics were *M*-level 1, *T*-level 2, and *S*-level 3: humidity M = 10 percent, temperature T = 26 °C and speed S = 1480 rpm.

ANOVA indicates the percentage contribution of humidity, temperature, and velocity influencing many operating characteristics. Based on the percentage contribution of the ANOVA, velocity, and temperature are two parameters that have a strong influence on the relative grade of Grey, and moisture is the most powerful factor in performance.

Grey relational analysis assists in the rice milling process. It can give confidence in rice milling machine innovation as well, for example, the percentage of broken rice decreases, and the percentage of good rice increases. This will give the community the confidence to apply it in real life.

And this research has been transferred to the community according to the One Tambon One University project under BCG that has been extended in the third phase. Between the municipality of Nong Phueng Subdistrict, Saraphi District, Chiang Mai Province, and Muang Ngai Subdistrict Municipality Chiang Dao District Chiang Mai Province to some villages with agricultural products, that is, rice production. This is to encourage the community to consume more brown rice.

Rice is part of the lives of people and animals. Water, especially part of the yield of rice husks and bran, can be used as feed for aquatic animals, making aquatic animals grow faster and stronger. Therefore, in this research, the products obtained are not only for the general public to consume. The remainder can also be effectively used for aquatic animals in both ways.

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