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IMPLEMENTATION OF THE TAGUCHI METHOD WITH TRAPEZOIDAL FUZZY NUMBER IN THE TOFU PRODUCTION PROCESS

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ABSTRACT

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Indonesians consume more tofu every week, proving it is one of the country's most well-liked and potential food ingredients. Therefore, several people benefit from this positive potential as a business opportunity and improve the quality of their products as part of a market competition strategy. This study uses the Taguchi method and fuzzy logic to optimize the multi-response characteristic tofu production process. These multi-responses include water and protein content, each with the characteristics of "nominal is best" and "larger is better." In this experiment, three independent variables were varied: soybean soaking time, soybean porridge boiling time, and tofu lump pressing time. The experimental design used is the orthogonal matrix L9. This study aims to determine the optimal combination of independent variables and determine the contribution of each variable to the multi-response of water content and protein content simultaneously. The findings indicated that soaking soybeans for 4 hours, boiling soybean porridge for 70 minutes, and pressing tofu lumps for 20 minutes are the ideal settings to produce optimal multi-response simultaneously. Additionally, the duration of soybeans soaking contributed 14.74%, the duration of boiling soybean porridge contributed 29.50%, and the duration of pressing lumps of tofu contributed 38.18% to the multi-response.

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1. INTRODUCTION

Soybean commodities in Indonesia in 2021 will reach 613.3 thousand tonnes [1], while soybean imports will reach 2.5 million tons [2]. Soybean is one of the commodities used as raw material for making tempeh and tofu. The average consumption of tofu per capita in Indonesia was 0.158 kg per week in 2021. This number has increased by 3.27% compared to 2020, which was 0.153 kg of average consumption per week [3]. Increased consumption of tofu will have an impact on the high demand for tofu so that tofu processing can be used as a business field.

Tahu Berkah is a factory that produces raw tofu. As a home industry scale business, Tahu Berkah Factory has many competitors, so tofu producers try to improve the quality of their products as part of a market competition strategy. The quality of tofu can be affected by the length of the weight during the pressing process and the length of time the soybean porridge is cooked [4][5]. Therefore, a practical method is needed to overcome problems in the tofu production process by improving and controlling product and process quality. Quality control is a verification and control system of a desired product or process quality level with careful planning, use of appropriate equipment, continuous inspection, and corrective action when necessary [6].

One of the methods used to control quality and process is to use the Taguchi method. The Taguchi method was developed by Dr. Genichi Taguchi to design robust parameters used to ensure good performance in the product design stage or production process [7]. The Taguchi method is often referred to as robust design because of its ability to create strong and sturdy products from noise [8]. Taguchi uses an orthogonal matrix to determine the minimum number of trials for process parameter estimation. The orthogonal matrix is chosen based on the level of input factor processing conditions that can be controlled to perform each experiment [9]. However, the Taguchi method can only be used to optimize one response process. Optimization of more than one response at once or multi-response is by a combination of the Taguchi method and fuzzy logic [10].

Fuzzy logic is a mathematical theory of precise reasoning that allows human thought processes to be modeled in language. Fuzzy logic control allows uncertainty in processing parameter values [11]. Fuzzy logic is a mapping of an input space into an output space [12]. In fuzzy logic, the membership function is a curve that shows the mapping of data input points with membership values between 0 and 1. One way to get membership values is the function approach, including linear representation, representation of triangle curve, trapezoidal curve representation, shoulder shape curve representation, s-curve representation, and bell shape curve representation [13].

Previous research that raised the problem of setting parameters or factors in a process has been carried out [14]. Who used the Taguchi method and fuzzy logic to optimize the iron content in the magnetic separation process. In addition, [10] their research carried out multi-response recast layer optimization and surface roughness in the wire-EDM process using the Taguchi method and fuzzy logic with triangular fuzzy numbers as a membership function.

In this study, the Taguchi method and fuzzy logic will be focused on the tofu production process with multi-response characteristics that will be used, namely water content and protein content. The aim of the research was to determine the optimal combination of independent variables and to determine the contribution of each independent variable to the multi-response characteristics of water content and protein content simultaneously. The software used in this research is the Minitab and Python programs. The Minitab program was used to create the Taguchi experimental design in the form of an orthogonal matrix to calculate the S/N ratio and ANOVA, while the Python program was used to analyze fuzzy logic, namely in the form of fuzzification, making fuzzy rules, defuzzification and making illustrations of fuzzy rules from the results of defuzzification.

2. RESEARCH METHODS

2.1 Research Tools and Materials

The raw materials used for making tofu in this study were imported soybeans (US soybeans) obtained from PT. Gerbang Cahaya Utama. In addition, vinegar is also used as a coagulant. The tools used in this study were grinding machines, buckets, furnaces, filter cloths, pans, fine cloths, moldboards, pressure tools, and knives.

2.2 Experimental Design

Factors that influence the quality of tofu consist of four main factors, namely human factors in the form of pressing, stirring, lack of vinegar solution; method factors in the form of no standard pressing, boiling time of soybean juice and boiling time in the tofu process when it is yellowed; material factors such as the type of soybean, vinegar solution, cloudy and smelly water; mechanical factors in the form of steam engine damage [15][16]. In this study, the determination of independent variables in the tofu production process was based on considerations of time and costs to be incurred. This study used three independent variables, namely soybean soaking time, soybean porridge boiling time, and tofu lump pressing time. The range of factor levels is based on the company's allowable range, operator experience, and considerations from PPC (Production Planning and Control) [17]. The setting of the independent variables and the level of the independent variables can be seen in Table 1.

Table 1. Independent Variable

Symbol	Factor	Level 1	Level 2	Level 3
A	Soaking time of soybeans	2 hours	3 hours	4 hours
B	Soybean porridge boiling time	50 minutes	60 minutes	70 minutes
C	Tofu lump pressing time	15 minutes	20 minutes	25 minutes

Table 1 shows the three independent variables used in the experiment, where each independent variable has three levels of regulation.

Before choosing the orthogonal matrix to be used, first, calculate the degrees of freedom. Degrees of freedom are calculated using Equation (1) [18].

$$\boldsymbol{N_{Taguchi}} = \mathbf{1} + \boldsymbol{NV}(\boldsymbol{L} - \mathbf{1}) \tag{1}$$

with
NV : number of independent variables
L : number of levels

In this study, there are three independent variables and three levels, so the experiments to be carried out. ($N_{Taguchi}$) = 1+3(3-1) =8. This means that the number of experiments that must be carried out is at least 8. In the Minitab program, the orthogonal matrix L_9 satisfies the requirements for the experimental design. The orthogonal matrix L_9 is shown in Table 2.

Table 2. Column Factor

Experiments Number	Column A	Column B	Column C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 2 shows the orthogonal matrix $L_9(3^3)$. A, soaking time of soybeans; B, time of boiling soybean porridge; C, time of pressing tofu lumps.

2.3 Analysis Method

The analytical method used in this study is the Taguchi method and fuzzy logic. The stages of analysis in research are as follows:

1. Calculate the S/N ratio for each response

The deviation of quality characteristics from the target value is measured by the S/N ratio [19]. There are three types of signal-to-noise ratio: higher is better, nominal is better, and lower is better. In signal-to-noise ratio, a signal is related to the actual expected value, while noise is related to unwanted factors in the measured orthogonal array [20]. The formula for calculating the S/N ratio for each quality characteristic uses Equation (2), Equation (3), and Equation (6) [21].

a. Lower is better

$$S/N = -10Log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{2}\right) \tag{2}$$

with

y_i : i-th observation value, i=1,2…n
n : number of repetitions of an experiment

b. Nominal is better

$$S/N = 10Log\left(\frac{\bar{y}^2}{s^2}\right) \tag{3}$$

with

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(y_i - \bar{y})^2 \tag{4}$$

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i^{2} \tag{5}$$

c. Higher is better

$$S/N = -10Log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^{2}}\right) \tag{6}$$

with
y_i : i-th observation value, i=1,2…n
n : number of repetitions of an experiment

2. Fuzzification

Fuzzification is converting the S/N ratio obtained by the Taguchi method into fuzzy numbers using membership functions by mapping fuzzy input to fuzzy output using fuzzy rules. Fuzzy rules are made to control output variables with human thinking mechanisms that are grouped based on IF-THEN rule boundaries [22].

3. Defuzzification

Defuzzification is the step of converting fuzzy values into fuzzy inference values or fuzzy reasoning grades (FRG), namely by mapping fuzzy sets to strict sets. Central of Area (CoA) is a widely used defuzzification method that calculates the area under a membership function that is scaled to the limit of the output variable and returns a sharp value. Defuzzification is calculated using Equation (7) [23].

$$CoA = \frac{\sum_{j=1}^{n}\mu_A(z_j)z_j}{\sum_{j=1}^{n}\mu_A(z_j)} \tag{7}$$

with
CoA : center of area
$\mu_A(z_j)$: membership degree

4. Analysis of variance (ANOVA)

The Taguchi method uses ANOVA to determine independent factors or variables that have a significant effect on multiple responses. The ANOVA table consists of the sum of squares, degrees of freedom, the sum of squares mean, F-value, P-value, and the percentage contribution of each independent variable. Percent contribution is a function of the sum of the squares of each factor that has a significant effect [11].

3. RESULTS AND DISCUSSION

The experimental results are the values obtained from testing the water and protein content based on the Taguchi design with the L_9 orthogonal matrix shown in Table 3.

Table 3. Experimental Result Data

Combination	Factor			Water Content (%)		Protein Content (%)	
	A	B	C	R1	R2	R1	R2
1	1	1	1	82.0456	81.9226	6.36	6.41
2	2	2	2	79.8992	80.0189	10.21	10.11
3	3	3	3	75.2333	75.1625	5.71	5.76
4	1	1	3	83.5012	83.6255	7.31	6.16
5	2	2	1	75.9881	76.2341	8.03	8.06
6	3	3	2	81.9287	83.0117	6.68	6.96
7	1	1	2	74.2819	74.1302	7.76	7.66
8	2	2	3	82.4201	82.5391	8.01	7.91
9	3	3	1	84.0301	83.9776	6.98	7.01

Based on Table 3, data on water content and protein content were replicated twice to avoid the influence of uncontrollable disturbance factors.

The value of the S/N ratio used for the water content response is "nominal is better" and for protein content is "higher is better" so the S/N ratio value for each response is obtained as shown in Table 4.

Table 4. S/N Ratio Data

Combination	S/N Ratio	
	Water Content (%)	Protein Content (%)
1	59.4868	16.1030
2	59.5058	20.1376
3	63.5337	15.1704
4	59.5612	16.4717
5	52.8206	18.1105
6	62.9019	16.7889
7	56.7994	17.7405
8	59.8263	18.0177
9	67.0931	16.8957

Based on Table 4, the highest S/N ratio for water content is in combination 9 with a value of 67.0931 and the lowest S/N ratio is in combination 5 with a value of 52.8206, while the highest S/N ratio value for protein content is in combination 2 with a value of 20,1376 and the lowest S/N ratio is found in combination 3 with a value of 15.1704.

After the S/N ratio is obtained, then do the fuzzification stage. In this study, the S/N ratio of each response was used as an input variable with a trapezoidal membership function grouped uniformly into three classes, namely low (L), medium (M), and high (H).

The membership function of the S/N ratio of water content based on the trapezoidal curve is as follows:

$$\mu_{Low}(x) = \begin{cases} 0; & x \geq 59.45685 \\ 1; & 52.8206 \leq x \leq 53.8206 \\ \dfrac{59.45685 - x}{59.45685 - 53.8206}; & 53.8206 \leq x \leq 59.45685 \end{cases}$$

$$\mu_{Medium}(x) = \begin{cases} 0; & x \leq 53.8206 \; or \; x \geq 66.0931 \\ \dfrac{x - 53.8206}{59.45685 - 53.8206}; & 53.8206 \leq x \leq 59.45685 \\ 1; & 59.45685 \leq x \leq 60.45685 \\ \dfrac{66.0931 - x}{66.0931 - 60,45685}; & 60.45685 \leq x \leq 66.0931 \end{cases}$$

$$\mu_{High}(x) = \begin{cases} 0; & x \leq 60.45685 \\ \frac{x - 60.45685}{66.0941 - 60.45685}; & 60.45685 \leq x \leq 66.0931 \\ 1; & 60.45685 \leq x \leq 67.0931 \end{cases}$$

The shape of the membership function for the S/N ratio of water content can be seen in **Figure 1**

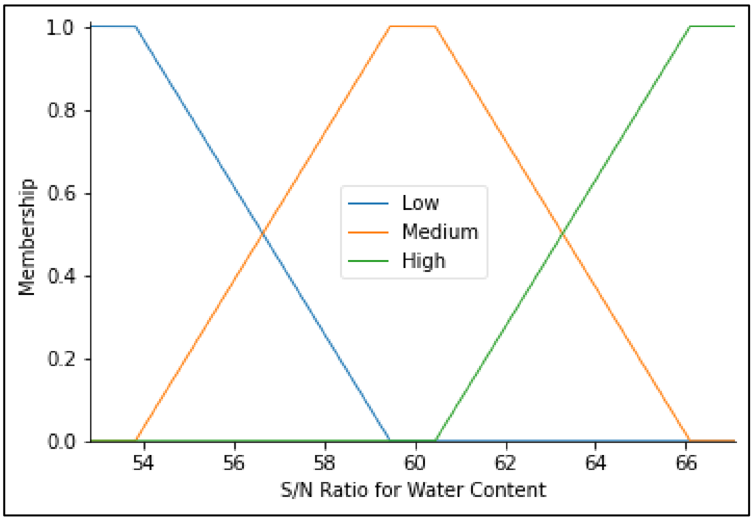

Figure 1. Membership function for S/N ratio of water content

Figure 1 shows the S/N ratio of water content in the low category is in the range of values between 52.8206 – 59.45685, the medium category is in the range of values between 53.8206 – 66.0931 and the high category is in the range of values between 60.45685 – 67.0931. If the x value is on the intersecting line between the values 53.8206 − 59.45685 or is on the intersecting line between the values 60.45685 − 66.0931, then the membership value taken is the most dominant.

The membership function of the S/N ratio of protein content based on the trapezoidal curve is as follows:

$$\mu_{Low}(x) = \begin{cases} 0; & x \geq 17.1540 \\ 1; & 15.1704 \leq x \leq 16.1704 \\ \dfrac{17.1540 - x}{17.1540 - 16.1704}; & 16.1704 \leq x \leq 17.1540 \end{cases}$$

$$\mu_{Medium}(x) = \begin{cases} 0; & x \leq 16.1704 \; or \; x \geq 19.1376 \\ \dfrac{x - 16.1704}{17.1540 - 16.1704}; & 16.1704 \leq x \leq 17.1540 \\ 1; & 17.1704 \leq x \leq 19.1376 \\ \dfrac{19.1376 - x}{19.1376 - 18.1540}; & 18.1540 \leq x \leq 19.1376 \end{cases}$$

$$\mu_{High}(x) = \begin{cases} 0; & x \leq 18.1540 \\ \dfrac{x - 19.1376}{19.1376 - 18.1540}; & 18.1540 \leq x \leq 19.1376 \\ 1; & 19.1376 \leq x \leq 20.1376 \end{cases}$$

The shape of the membership function for the S/N ratio of protein content can be seen in **Figure 2**.

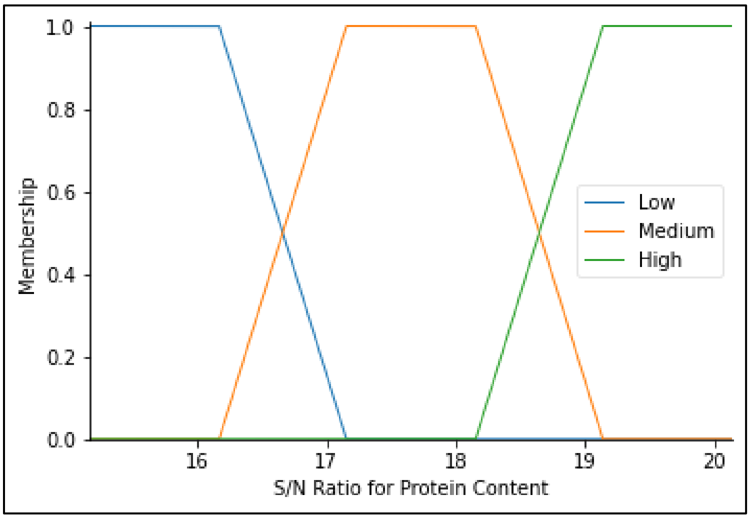

Figure 2. Membership function for S/N ratio of protein content

Figure 2 shows the S/N ratio of protein content in the low category is in the range of values between 15.1704 – 17.1540, the medium category is in the range of values between 16.1704 – 19.1376 and the high category is in the range of values between 18.1540 – 20.1376. If the x value is on the intersecting line between the values 16.1704 −17.1540 or is on the intersecting line between the values 18.1540 − 19.1376, then the membership value taken is the most dominant.

This study uses fuzzy reasoning grade (FRG) as an output variable with the membership function used, namely the trapezoidal shape which is grouped into five fuzzy classes, namely very low (VL), low (L), medium (M), high (H), and very high (VH).

The membership function of the FRG based on the trapezoidal curve is as follows:

$$\mu_{VL}(x) = \begin{cases} 0; & x \geq 0.2 \\ 1; & 0 \leq x \leq 0.06 \\ \dfrac{0.2 - x}{0.2 - 0.05}; & 0.05 \leq x \leq 0.2 \end{cases}$$

$$\mu_{L}(x) = \begin{cases} 0; & x \leq 0.05 \text{ or } x \geq 0.45 \\ \dfrac{x - 0.05}{0.2 - 0.05}; & 0.05 \leq x \leq 0.2 \\ 1; & 0.2 \leq x \leq 0.3 \\ \dfrac{0.45 - x}{0.45 - 0.3}; & 0.3 \leq x \leq 0.45 \end{cases}$$

$$\mu_{M}(x) = \begin{cases} 0; & x \leq 0.3 \text{ or } x \geq 0.7 \\ \dfrac{x - 0.3}{0.45 - 0.3}; & 0.3 \leq x \leq 0.45 \\ 1; & 0.45 \leq x \leq 0.55 \\ \dfrac{0.7 - x}{0.7 - 0.55}; & 0.55 \leq x \leq 0.7 \end{cases}$$

$$\mu_{H}(x) = \begin{cases} 0; & x \leq 0.55 \text{ or } x \geq 0.95 \\ \dfrac{x - 0.55}{0.7 - 0.55}; & 0.55 \leq x \leq 0.7 \\ 1; & 0.7 \leq x \leq 0.8 \\ \dfrac{0.95 - x}{0.95 - 0.8}; & 0.8 \leq x \leq 0.95 \end{cases}$$

$$\mu_{VH}(x) = \begin{cases} 0; & x \leq 0.8 \\ \dfrac{x - 0.8}{0.95 - 0.8}; & 0.8 \leq x \leq 0.95 \\ 1; & 0.95 \leq x \leq 1 \end{cases}$$

The shape of the membership function of the FRG can be seen in **Figure 3**.

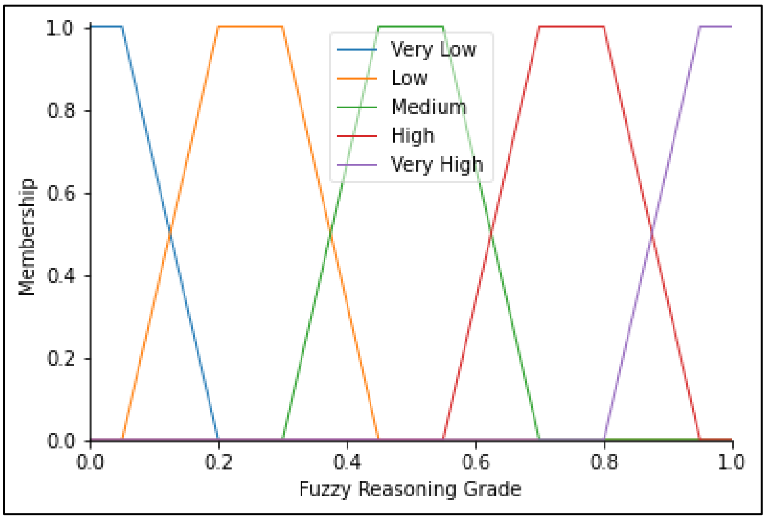

Figure 3. Membership function for FRG

Figure 3 shows that the very low FRG value is in the range of values between 0 – 0.2, the low category is in the range of values between 0.05 – 0.45, the moderate category is in the range of values between 0.3 – 0.7, the category high is in the range of values between 0.55 – 0.95 and the very high category is in the range of values between 0.8 − 1. If the value x is at the intersection of the values between 0.05−0.2 or is on the intersection between values 0.3−0.45 or is on the secant line between 0.55−0.65 or is on the secant line between 0.8−0.95, then the membership value taken is the most dominant value.

The fuzzy rules are made using the S/N ratio value of each response variable as the input value and the fuzzy reasoning grade (FRG) as the output variable. The fuzzy rules in this study are shown in **Table 5**.

Table 5. Fuzzy Rules

		Protein Content		
		Low (L)	**Medium (M)**	**High (H)**
Water Content	**Low (L)**	VL	L	M
	Medium (M)	L	M	H
		Protein Content		
		Low (L)	**Medium (M)**	**High (H)**
Water Content	**High(H)**	M	H	VH

Based on the fuzzy rules in **Table 5**, rule 1 namely, if the water content is low (L) and the protein content is low (L), then the FRG is very low (VL). As for rule 2, namely, if the water content is low (L) and the protein content is medium (M), then the FRG is low (L), and so on until rule 9, namely, if the water content is high (H) and the protein content is high (H), then FRG is very high (VH).

The results of the defuzzification process in the form of FRG values which are a response to water content and protein content simultaneously can be seen in **Table 6**.

Table 6. Fuzzy Reasoning Grade

Combination	**S/N Ratio**		**FRG**
	Water Content (%)	**Protein Content (%)**	
1	59.4868	16.1030	0.2500
2	59.5058	20.1376	0.7500
3	63.5337	15.1704	0.3850
4	59.5612	16.4717	0.3321
5	52.8206	18.1105	0.2500

Combination	S/N Ratio		FRG
	Water Content (%)	Protein Content (%)	
6	62.9019	16.7889	0.5109
7	56.7994	17.7405	0.3812
8	59.8263	18.0177	0.5000
9	67.0931	16.8957	0.6782

Based on Table 6, it is known that the highest FRG value is found in combination 2, which is equal to 0.7500. While the lowest FRG value is found in combination 1 and combination 5, which is equal to 0,2500.

The average value of the fuzzy reasoning grade (FRG) at each level of the independent variables can be seen in Table 7.

Table 7. Average FRG Value

Level	Independent Variable		
	A	B	C
1	0.4617	0.3211	0.4203
2	0.3643	0.5000	0.5867
3	0.5198	0.5247	0.3387
Delta	0.1555	0.2036	0.2840
Rank	3	2	1
Average	0,4468		

Based on Table 7, rank 1 is in the long pressing time of tofu lumps (C) with a delta value = 0,2840, rank 2 is in the soybean porridge boiling time variable (B) with a delta value = 0.2036 and rank 3 is in the old variable soaking soybeans (A) with a delta value = 0.1555.

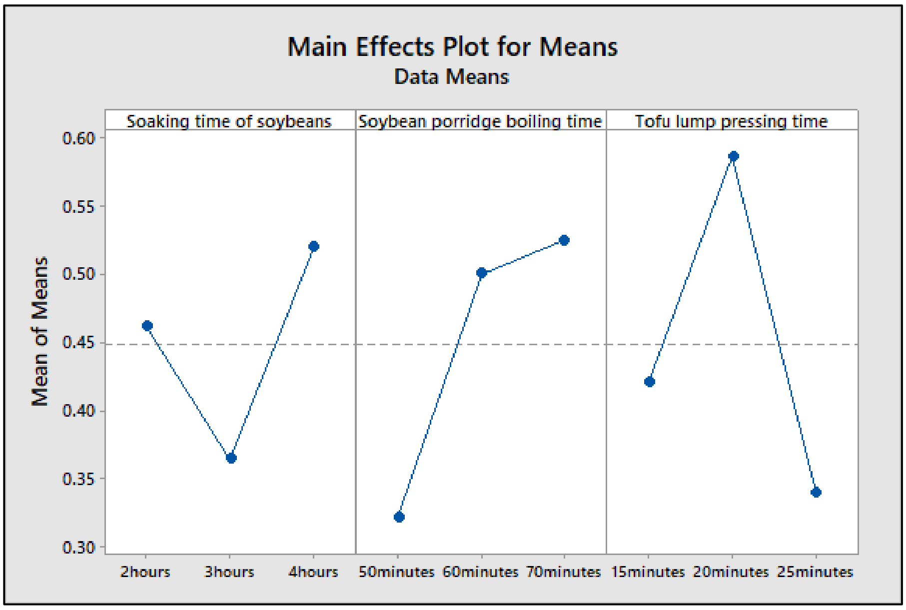

Figure 4. Graph of average multi-response FRG each level of independent variable

Based on Figure 4, the optimal level of combination of independent variables for the simultaneous multi-response of water content and protein content is obtained, namely soaking soybeans for 4 hours, boiling soybean porridge for 70 minutes, and pressing tofu lumps for 20 minutes.

To determine the effect of each independent variable on multi-response, an analysis of variance (ANOVA) was performed as shown in Table 8.

Table 8. ANOVA Table

Source	DF	Seq SS	Adj SS	Adj MS	F-value	P-value	Contribution (%)
A	2	0.0370	0.0370	0.0185	0.84	0.544	14.74
B	2	0.0741	0.0741	0.0370	1.68	0.374	29.50
C	2	0.0959	0.0959	0.0479	2.17	0.315	38.18
Error	2	0.0442	0.0442	0.0221			17.58
Total	8	0.2511					100

Based on Table 8, the soaking time of soybean seeds, the duration of boiling soybean porridge, and the duration of pressing have no significant effect, this can be seen from the P-value > α = 0.05. The independent variables that have the largest contribution to the total variance of the FRG are the pressing time of 38.18%, the boiling time of 29.50% and the smallest soaking time, which is equal to 14.74%. The error contribution is 17.58%, this shows that there is contribution from noise factors or other factors that cannot be examined.

4. CONCLUSIONS

Based on the experimental results, the process optimization and analysis that has been carried out, it is obtained that the optimal combination of independent variables for the simultaneous multi-response of water content and protein content in the tofu production process, namely, soaking time of soybeans for 4 hours, boiling time for soybean porridge for 70 minutes and the time of pressing the lumps of tofu is 20 minutes. The contribution of the independent variables to optimize the water content and protein content in tofu production simultaneously, namely, soybean soaking time was 14.74%, soybean porridge boiling time was 29.50%. Tofu lump pressing time was 38.18%.

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