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The Optimization of a Bilih Fish Drying System Using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

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Abstract

The quality of dried Bilih fish can be determined on the basis of its water and protein content. The dried Bilih fish produced by Small Medium Enterprise (MSE) Mina Lestari has a high water content of 24% and a low protein content of 35%. These problems were addressed using a proposed parabolic-type drying machine, whose operating system is affected by drying duration, drying tray height, tray rotation, drying layer material and rack quantity and capacity. The results showed that water content decreased to 11.98% and that protein concentration increased to 64.02%. The sensitivity analysis indicated that changes in the values of quality attributes were minimally sensitive to alterations in the weights attached to water and protein content. The optimal combination of factor levels would remain consistent even under a weight of ≤0.83286 ascribed to water content, indicating that a weight ranging from 0 to 0.83286 for this substance exhibits little sensitivity to the initial decision on level factors.

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1 Introduction

Bilih fish is one of the most abundant marine products in the coastal area of Gunung Kidul, Yogyakarta in Indonesia. On the initiative of the community, UMKM (MSME) Mina Lestari was established as a manufacturer of dried Bilih fish products. To ensure product quality, the company uses traditional drying methods that take four to seven days to complete. The quality of dried Bilih fish can be determined on the basis of its water and protein content; the lower and the higher the water and protein concentrations, respectively, the greater the quality of the product. However, the dried Bilih fish produced by UMKM (MSME) Mina Lestari has a high water content of 24% and a low protein content of 35%. Fish is a source of animal protein, with fresh and dried variants providing 17% and 40% of the nutrient, respectively. The proportion of collagen in fish is also considerably lower than that found in livestock; it ranges from 3% to 5% of total protein, which is why fish is generally more tender than livestock meat (Khomsan, 2004).

To help manufacturers develop products in accordance with expected quality targets and ensure resistance against disturbance factors or robust performance in experiments, this study conducted a few experiments using a Taguchi method (Belavendram, 1995). The factors regarded as exerting effects on product quality were the duration of drying, the height and rotation of drying trays, the drying layer material used, and the quantity and capacity of racks. The quality approach introduced by Taguchi is an offline quality control method that has been widely applied in industries such as machining (Kumar & Kulkarni, 2017; Gaikwad & Jatti, 2018), chemical and carbon fibre manufacturing (Nia et al., 2019; Moralı et al., 2018; Zolgharnein & Rastgordani, 2018; Purnomo et al., 2018), construction and welding (Teimortashlu et al., 2018; Naik & Reddy, 2018), and electricity (Gohil & Puri, 2018; Ugrasen et al., 2018). The difference between the current work and previous studies is the object of investigation and the incorporation of the concept of sensitivity into the analysis. Specifically, this research is an expansion of the study conducted by Hermawan (Hermawan, 2018), featuring a combination of the technique for order preference by similarity to ideal solution (TOPSIS), full factorial experimentation, and sensitivity analysis.

Taguchi's design of experiments was used to determine the settings of the factor level design adopted in this work; that is, the influencing factors of product quality and variables that are robust to noise were identified. Taguchi's multi-response method was employed because this study involved more than one response variable, namely, water and protein concentrations. As a Taguchi approach, TOPSIS is substantially affected by the weight attributes of product quality in the determination of alternatives. This research analyzed the effects of the weighing of water and protein concentrations on the quality of dried Bilih fish products to accommodate the weighing of dynamic product quality attributes. In other words, each individual can have different perceptions of the value attached to the weight attribute of product quality as this measure can be dynamic and subjective. The optimal levels for the two response variables were based not only on experimental results but also on predictions regarding the values of the response variables of all alternative combinations of factors (Dincer, 2011; Chakraborty, 2022; Santosa & Yusuf, 2017; Santosa & Sutarna, 2016).

2 Materials and Methods

Research object

The case for investigation was UMKM (MSME) Mina Lestari UKM, which is involved in fish drying in Gunung Kidul, Yogyakarta. Samples of the dried fish products were tested in a laboratory. This study was aimed at determining significant influencing factors of the quality of dried Bilih fish products on the basis of water and protein content. The combination of factor levels that produce the highest quality products was ascertained by looking into the effects of the weights attached to product quality attributes.

Experimental design

An experimental design clearly delineates each step/action involved in an experiment so that information related to or necessary to solve a problem being studied can be collected (Sudjana, 1994). Such a design is intended to enable researchers to derive as much data as possible on issues of interest at minimum costs. There are two types of experimental designs, namely, the conventional type and Taguchi's version. Genichi Taguchi designed an experiment, with the aims of identifying the factors that influence responses and interactions under a minimum number of experiments and determining the best factor level with certain criteria as optimal parameters. Taguchi's strategy for minimizing the number of experiments is illustrated in Table 1, which presents an example experiment wherein seven factors and two levels are applied.

Table 1
Full factorial experiment

			A1								A2							
			B1				B2				B1				B2			
			C1		C2		C1		C2		C1		C2		C1		C2	
			D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2
E1	F1	G1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
		G2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	F2	G1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
		G2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
E2	F1	G1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
		G2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	F2	G1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
		G2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2
1/16 fractional factorial experiment

			A1								A2							
			B1				B2				B1				B2			
			C1		C2		C1		C2		C1		C2		C1		C2	
			D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2
E1	F1	G1	■															
		G2														■		
	F2	G1												■				
		G2							■									
E2	F1	G1								■								
		G2											■					
	F2	G1													■			
		G2		■														

A comparison of Tables 1 and 2 shows that in the latter, 27 = 128 combinations of factor levels are needed, whereas in the former, the number of experiments is reduced, with only eight combinations of factor levels required.

Signal-To-Noise Ratio and Quality Lost

The S/N ratio is a logarithm of a quadratic loss function and is used to evaluate the quality of a product. Several types of S/N ratios are available (Belavendram, 1995):

- Smaller the better (ST

$$S/N\_STB = -10 Log\left[\frac{1}{n} \sum_{i=n}^{n} yi^2 \right] \quad (1)$$

where n is the number of tests in a trial, and yi denotes the response value from the ith sample for a particular type of experiment.

- Larger the better (LTB)

$$S/N\_LTB = -Log\left[{}^{1}/_{n}\sum_{i=n}^{n}{}^{1}/_{yi^2}\right] \quad (2)$$

- Nominal the better (NTB)

$$S/N\_NTB = 10\,log\left[\frac{\mu^2}{\sigma^2}\right] \quad (3)$$

where:

$$\sigma^2 = \frac{\sum\left(y_i - \bar{y}\right)^2}{n-1}.$$

The quality loss (Lij) in each trial, as determined on the basis of the characteristics of quality, is expressed as follows:

- STB

$$L_{ij} = k\frac{1}{n_i}\sum_{k=1}^{n_i} y^2{}_{ijk} \quad (4)$$

- LTB

$$L_{ij} = k\frac{1}{n_i}\sum_{k=1}^{n_i}\frac{1}{y^2{}_{ijk}} \quad (5)$$

- NTB

$$L_{ij} = k\frac{1}{n_i}\sum_{k=1}^{n_i}\left(y_{ijk} - m\right)^2 \quad (6)$$

Where: yijk = data on the ith response, jth trial, kth replicate
m = target value
ni = replication for the ith response
k = coefficient of quality loss

TOPSIS

An experimental The Taguchi method is classified into single- and multi-response approaches. The single-response method involves one response variable, thereby enabling the immediate derivation of the optimal combination of response variables. The multi-response approach entails the use of more than one response variable, and if each of these variables presents different combinations of factor levels, further handling is required to obtain the optimal combination of factors necessary for improving the quality of each response variable. The specific technique applicable to solving multi-response problems is TOPSIS (Tong & Su, 1996), which is based on the concept that the best-chosen alternative not only has the shortest distance from the positive ideal solution but also has the longest distance from the negative ideal solution (Hwang et al., 1981). The procedure for carrying out TOPSIS is described as follows.

First, the performance rating of each Ai alternative in each Ci criterion is normalized using Xij = Lij thus:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} xij^2}} \text{, i=1,2,...,m dan j=1,2,....,n} \quad (7)$$

The ideal solutions of positive A+ and negative A– can be given on the basis of normalized rating vii:
Vij = Wj rij, i = 1,2,..., m dan j=1,2,...., n

Then, the following calculation is conducted:

$$\begin{aligned} A^+ &= \{(\max V_{ij} \mid j \in J), (\min v_{ij} \mid j \in J') \mid i = 1,2,\ldots,m\} \\ &= \{V_1{}^+, V_2{}^+, \ldots, V_j{}^+, \ldots, V_n{}^+\} \\ A^- &= \{(\min v_{ij} \mid j \in J), (\max v_{ij} \mid j \in J') \mid i = 1,2,\ldots,m\} \\ &= \{V_1{}^-, V_2{}^-, \ldots, V_j{}^-, \ldots, V_n{}^-\} \end{aligned} \quad (8)$$

The distance between alternative Ai and the ideal positive solution is determined, after which the following equations are performed:

$$\begin{aligned} S_i{}^+ &= \sqrt{\sum_{j=1}^{n} \left(v_{ij} - V_j{}^+\right)^2}, i = 1,2,\ldots,m \\ S_i{}^- &= \sqrt{\sum_{j=1}^{n} \left(v_{ij} - V_j{}^-\right)^2}, i = 1,2,\ldots,m \end{aligned} \quad (9)$$

The preference value for each alternative (Ci*) is obtained in the following manner:

$$C_i{}^* = \frac{S_i{}^-}{S_i{}^* + S_i{}^-} \quad (10)$$

where i=1,2,3,,m. The largest Ci* value points to the best alternative.

3 Results and Discussions

Experimental Planning

To acquire the information necessary in implementing the experiments, the following planning steps were carried out:

1) The characteristics of product quality relevant to this research were determined. A fish dryer was designed to improve the traditional drying system, the facilities and time at which drying is executed and the quality of dried fish products. The response variables used in this regard were water content (expressed in percentage), to which the criterion STB was imposed, and protein content (also expressed in percentage), to which the criterion LTB was applied.
2) The influencing factors of product quality were identified and selected. The factors thought to have an effect on product quality were drying duration, tray height, tray rotation, drying layer material, rack quantity, tool capacity, and the combination of drying duration and tool capacity. The control factor level was determined

on the basis of (Riansyah et al., 2013; Sulistyo & Hardanto, 2010; Tambosoe et al., 2010; Kustoyo, 2011; Mukkun & Dana, 2016 Setyoko & Atmanto, 2013), and the results of the discussion. The control factors and interactions that affect fish quality are presented in Table 3.

Table 3
Control factors

No.	Control factor	Code	Level 1	Level 2
1	Drying time	A	6 hours	12 hours
2	Tray height	B	10 cm	20 cm
3	Tray rotation	C	16 rpm	20 rpm
4	Drying layer material	D	Glass	Aluminium foil
5	Rack quantity	E	3 racks	5 racks
6	Tool capacity	F	3 kg	5 kg
7	A × F interaction	G	-	-

Water and protein concentrations were identified via experiments carried out using the L8 inner array. The data derived are shown in Table 4.

Table 4
Measurements of water and protein content

Trial	Control factor							Water content (%)				Protein content (%)			
	A	B	C	D	E	F	G								
	Column number							Replication				Replication			
	1	2	3	4	5	6	7	1	2	3	4	1	2	3	4
1	1	1	1	1	1	1	1	10.32	10.49	10.56	10.63	46.36	45.47	45.19	45.19
2	1	1	1	2	2	2	2	19.08	18.96	19.08	18.87	60.40	61.54	60.40	60.40
3	1	2	2	1	1	2	2	9.21	9.22	8.84	8.99	58.93	57.90	55.67	57.9
4	1	2	2	2	2	1	1	8.84	8.48	9.02	8.91	55.78	55.78	56.03	55.78
5	2	1	2	1	2	1	2	19.37	19.55	19.32	19.35	52.07	51.49	52.00	51.73
6	2	1	2	2	1	2	1	12.02	12.22	12.14	11.89	59.36	58.76	58.29	58.76
7	2	2	1	1	2	2	1	15.04	14.55	14.61	14.53	60.67	60.58	60.16	60.58
8	2	2	1	2	1	1	2	15.04	18.18	18.33	12.14	46.53	47.92	46.7	47.99

Data Processing

With the experimental data as bases, the following steps were carried out to determine the combination of level factors that produce the optimal quality of dried Bilih fish:

Signal-to-Noise Ratio and Factor Effects

The S/N ratio of water content was determined with reference to the objective function of STB, whilst the S/N ratio of protein content was ascertained on the basis of the objective function of LTB. The SNR values are listed in Table 5.

Table 5
SNR values

Trial	Control factor							SNR	
	A	B	C	D	E	F	G	Water content	Protein content
1	1	1	1	1	1	1	1	–20.4243	33.1688
2	1	1	1	2	2	2	2	–25.5740	35.6608

Trial	Control factor							SNR	
	A	B	C	D	E	F	G	Water content	Protein content
3	1	2	2	1	1	2	2	–19.1487	35.2028
4	1	2	2	2	2	1	1	–18.9043	34.9392
5	2	1	2	1	2	1	2	–25.7550	34.2901
6	2	1	2	2	1	2	1	–21.6328	35.3859
7	2	2	1	1	2	2	1	–23.3369	35.6346
8	2	2	1	2	1	1	2	–24.1501	33.4918

Signal-to-Noise Ratio and Factor Effects

Uncovering the effect of each factor was intended to determine the formulation that produces the best combination of factor levels for each of the response variables.

a) Water Content

As indicated in Table 6, the best combination of factor levels for water content was A1, B2, C2, D1, E1, F1, G1.

Table 6
Effect of each water concentration

Level	Control factor						
	A	B	C	D	E	F	G
Level 1	–21.012	–23.3465	–23.3713	–22.1662	–21.3390	–22.3084	–21.0746
Level 2	–23.718	–21.3850	–21.3602	–22.5653	–23.3925	–22.4231	–23.6570
Difference	2.7059	1.9616	2.0111	0.3991	2.0536	0.1147	2.5824
Ranking	1	5	4	6	3	7	2

b) Protein Content

Table 7 shows that the best combination of factor levels for protein concentration was A1, B2, C2, D2, E2, F2, G1. Given the difference in optimal combinations between the response variables, a multi-response analysis is needed. Control factors A, G and E, C was assumed to exert a significant effect on water content, whereas the factors posited to have a significant influence over protein levels were F, E, C and D. The level that presented the lowest cost was taken for the non-significant influencing factors. The influencing factors of both water and protein concentrations were A, C, D, E, F and G—a result that highlighted the need to analyze 26 alternative combinations and slices. The orthogonal 26 array was unavailable, so we used the orthogonal L8 27 array, which featured 64 alternatives (Table 8).

Table 7
Effect of each protein concentration

Level	Control factor						
	A	B	C	D	E	F	G
Level 1	34.7429	34.6264	34.4890	34.5741	34.3123	33.9725	34.7821
Level 2	34.7006	34.8171	34.9545	34.8694	35.1312	35.4710	34.6614
Difference	0.0423	0.1907	0.4655	0.2954	0.8189	1.4985	0.1208
Rank	7	5	3	4	2	1	6

Table 8
64 alternative combinations of factor levels

			A1								A2							
			B1				B2				B1				B2			
			C1		C2		C1		C2		C1		C2		C1		C2	
			D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2	D1	D2
E1	F1	G1	1	2	3	4					33	34	35	36				
		G2	5	6	7	8					37	38	39	40				
	F2	G1	9	10	11	12					41	42	43	44				
		G2	13	14	15	16					45	46	47	48				
E2	F1	G1	17	18	19	20					49	50	51	52				
		G2	21	22	23	24					53	54	55	56				
	F2	G1	25	26	27	28					57	58	59	60				
		G2	29	30	31	32					61	62	63	64				

Prediction of the Values of Response Variables

The results in Tables 4 and 8 were determined using multiple linear regression. These findings served as bases in the prediction of water and protein content (Tables 9 and 10).

Table 9
Multiple linear regression model of water content

Replication	Regression model
1	Y = 3.7300 + 3.5050 A – 3.1650 B – 2.5100 C + 0.2600 D + 3.9350 E + 0.4450 F + 4.1200 G
2	Y = 3.5575 + 4.3375 A – 2.6975 B – 3.1775 C + 1.0075 D + 2.8575 E – 0.4375 F + 5.0425 G
3	Y = 3.7050 + 4.2250 A – 2.5750 B – 3.3150 C + 1.3100 D + 3.0400 E – 0.6400 F + 4.8100 G
4	Y = 5.5625 + 2.6275 A – 4.0425 B – 1.7575 C – 0.4225 D + 4.5025 E + 0.8125 F + 3.3475 G

Table 10
Multiple linear regression model of protein content

Replication	Regression model
1	Y = 29.055 – 0.710 A + 0.930 B + 3.045 C + 1.010 D + 4.435 E + 9.655 F – 1.060 G
2	Y = 26.550 – 0.485 A + 1.230 B + 2.105 C + 2.140 D + 4.835 E + 9.530 F – 0.435 G
3	Y = 26.960 – 0.035 A + 0.670 B + 2.385 C +2.100 D + 5.685 E + 8.650 F – 1.225 G
4	Y = 25.988 – 0.052 A + 1.543 B + 2.502 C + 1.883 D + 4.663 E + 9.238 F – 0.572 G

Determination of Optimal Factor Levels using TOPSIS

The optimal conditions for obtaining suitable water and protein concentrations were ascertained from different combinations of factor levels, thus requiring analysis to optimize these conditions simultaneously. For this purpose, Taguchi's multi-response method with TOPSIS procedure was used. The steps are described below.

1) The relative importance of each response was converted into a fuzzy number. In this case, protein content was more important than water content, so the scale applied to the latter was 'medium' and that applied to the former was 'high'. The scale was expressed as a crips score, which is the measurement with the smallest number or the simplest score to convert.
2) The scale for conversion into a fuzzy number was selected, and the fuzzy number was converted into a crips score through the fuzzy scoring method. The weighing of water (w1) and protein (w2) content proceeded as follows:

$$W_1=\frac{0,583}{0,75+0,583}=0,43736 \qquad W_2=\frac{0,75}{0,75+0,583}=0,56264$$

3) Loss functions were calculated on the basis of their respective quality characteristics. Under the conditions examined in this work, the average water content was 24%. The factor levels for comparison in determining optimal conditions were A1, B1, C1, D1, E1, F1 and G1 at an average water content of 10.50%. The optimal combination of factor levels for water content was A1, B2, C2, D1, E1, F1, G1. Given that factor B exerted no significant effect on factor level, it was selected because it presented low cost; that is, level 1 resulted in an average water content of 7.81%. This would increase the quality of fish as the original average water content of 10.50% would decrease to 7.81% or 2.69%. These values would increase costs to IDR 2.000 so that k = 2.000/0.02692 = 2,763,919.79. The average protein content under the current conditions was 35%. The factor levels for comparison in determining optimal conditions were A1, B1, C1, D1, E1, F1 and G1 at an average protein content of 45.55%. The optimal combination determined was A1, B2, C2, D2, E2, F2, G1. Similar to the situation for water content, factor B did not have a significant effect on factor level. It was thus chosen for the low cost it presented, namely, level 1. This combination yielded an average protein content of 64.02%, indicating an increase in the quality of fish as the original average content of 45.55% would rise to 64.02% or increase by 18.47%.
4) These values would increase costs to IDR 8000.00 so that k = 8000,00/0,18472 = 234,507.21 The TOPSIS value for each trial was determined. Such values were obtained using equations (7) to (10) and the regression results in Tables 9 and 10. The findings are provided in Table 11.

Table 11
TOPSIS values

Trial	TOPSIS	Trial	TOPSIS	Trial	TOPSIS	Trial	TOPSIS
1	0.1858	17	0.5287	33	0.1546	49	0.5035
2	0.3189	18	0.6265	34	0.2881	50	0.6037
3	0.3736	19	0.6636	35	0.3483	51	0.6461
4	0.4947	20	0.7417	36	0.4726	52	0.7260
5	0.1252	21	0.4702	37	0.0824	53	0.4378
6	0.2457	22	0.5754	38	0.2015	54	0.5431
7	0.3093	23	0.6204	39	0.2770	55	0.5962
8	0.4386	24	0.7041	40	0.4113	56	0.6796
9	0.7444	25	0.9022	41	0.7304	57	0.8817
10	0.8108	26	0.9424	42	0.7979	58	0.9130
11	0.8345	27	0.9631	43	0.8240	59	0.9483
12	0.8882	28	0.9896	44	0.8788	60	0.9661
13	0.7080	29	0.8653	45	0.6875	61	0.8181
14	0.7787	30	0.8979	46	0.7571	62	0.8369
15	0.8063	31	0.9357	47	0.7925	62	0.8989
16	0.8636	32	0.9573	48	0.8492	64	0.9088

As reflected in Table 11, the optimal conditions were obtained in the 28th trial at a combination of factor levels of A1, B1, C2, D2, E2, F2, G1. Under this combination, the drying system ran for 7 hours of drying time, with a B1 tray height of 10 cm, a tray rotation of 20 rpm, aluminium foil as the drying layer material, 5 racks and a rack capacity of 5 kg. This combination produced an average water content of 11.98%, denoting a decrease by 12.02% (24% – 11.98%) and an average protein content of 64.02%, pointing to an increase by 29.02% (64.02% – 35%). Because the characteristics of water content quality is reflected by STB and those of protein content quality is denoted by LTB, the optimal conditions demonstrated a relatively high increase in the quality of both concentrations.

Sensitivity Analysis

The combination of factor levels that produced the optimal response above was obtained under 0.437359 as the weight attribute of water content and 0.562641 as the weight attribute of protein concentration. The sensitivity analysis showed that changes in the quality values of quality attributes exhibited little sensitivity to alterations in the weighing of water and protein concentrations. The optimal combination of factor levels would remain consistent at a water content weight ≤0.83286. This means that if the weight attached to water content ranges from 0 to 0.83286, this substance would be insensitive to the original decision.

4 Conclusion

The results derived in this work can be summarised as follows:

1) The combination of factor levels that produced the optimum quality of dried Bilih fish was A1, B1, C2, D2, E2, F2, G1, in which the system worked for 7 hours of drying time at a tray height of 10 cm, a tray rotation of 20 rpm, aluminium foil as the drying layer material, 5 racks and a rack capacity of 5 kg.
2) This optimal combination increased the quality of dried Bilih fish as it produced an average water content of 11.98% and an average protein content of 64.02%.

Conflict of interest statement
The authors declared that they have no competing interests.

Statement of authorship
The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

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