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Optimization of Gluten Free Spaghetti Products from Local Food with the Taguchi Method Approach

N K I Mayasti¹, M Ushada², and M Ainuri²

¹Development Center for Appropriate Technology, Indonesian Institute of Sciences
Subang, Indonesia

²Agricultural Technology Faculty, Gadjah Mada University, Yogyakarta

Email: indahmayasti@gmail.com

Abstract. Pasta product, especially spaghetti, is a very potential product to be developed. As the market growth, nutritious gluten-free spaghetti product is now being developed (as a response from consumer needs). The production process of gluten-free spaghetti relies on the gelation process and retrogradation mechanism which requires an extruder machine. The objectives of this research are to optimize the production of gluten-free spaghetti by combining four factors and three levels based on controlled quality. Taguchi method will be applied in this research. Taguchi data tabulation includes SNR, ANOVA, contribution percentage, multiresponse loss function, and a confirmation test. The result of this optimization research is the gluten-free spaghetti made by local flour (60 mesh) with composition of 30% mocaf, 30% corn flour, 30% rice flour, 10% soybean flour, 1.5% guar gum with confirmed quality characteristics (within confidence interval) : moisture content $9.94 \pm 0.57\%$, protein content $10.33 \pm 0.55\%$, fat content $1.11 \pm 0.67\%$, carbohydrate content $76.51 \pm 2.32\%$, cooking time 10.65 ± 0.25 minutes, cooking loss 13.00 ± 2.76 , elongation 181.35 ± 25.72 , hardness 2069.03 ± 453.07 gf, adhesiveness -32.75 ± 3.41 g.sec, color 76.51 ± 0.63 dL and sensory of taste 4.80 ± 0.16 .

1. Introduction

Taguchi method is one of the methods which applies to produce a robust product towards external noise. Robust design is intended to optimize experimental results and based on quality improvement by decreasing the additive effect [1]. Taguchi method is chosen for this study as it helps to include several factors and levels, as well as, to conclude response from factors and controls which results in optimum response. Product development with Taguchi is expected to create an optimum product with efficient time and cost.

The development of pasta product, especially spaghetti, is potentially advanced. The product has turned into a global commodity and becomes a staple food in western countries and many other countries. The total number of pasta production is increasing every year [2]. In Indonesia, the development of pasta product was previously limited to the high-class society, and nowadays, its consumption level is rising from 5% to 30% [3]. As the market growth, nutritious gluten-free spaghetti product with high protein and high fiber is now being developed as a response to the increasing criteria from the consumers [4].

Spaghetti is defined as a dry product with a massive stick-*ish* shape which has 1.4-2.5 mm diameter. It is produced through a mixture extrusion process of wheat, with or without additional ingredients and other allowed substances [5]. The availability of local Indonesian food is considered as a solution to dependency of imported wheat as the main ingredients in spaghetti production. Rice,



cassava, and corn were the three most produced crops in Indonesia in 2016. The total number of rice production is 79,354,767 ton, the total of cassava production is 20,260,675 ton, and corn production is 23,578,413 ton [6]. The challenge in developing non-wheat spaghetti from a local product is the characteristics of the ingredients which must be gluten-free and low protein content.

The production of gluten-free spaghetti requires different process from the conventional spaghetti since the non-wheat spaghetti does not have gluten protein which has elastic characteristic on the mixture. Without the modification process, the mixture of gluten-free spaghetti will be very easily ruined. Gluten-free spaghetti counts on the gelation process of starch and the retrogradation process to form sturdy tissue structure. Therefore, extrusion system through extruder machine is required. Through the extrusion process with high compression and enough shear stress, the flour will rupture, in which most of the starch will be detached from the granola flour and will experience gelation [7]. Afifah and Ratnawati developed curly noodles made by mocaf (modified cassava) flour, rice flour, and corn flour through extrusion technique [8]. The curly noodles resulted in 10.6-14.3% cooking loss, 276-374% elongation, 4.09%-5.58% protein content. The resulted non-wheat noodles have lower protein content compared to spaghetti product. The protein content of the spaghetti can be increased through adding soybean flour as the source of protein.

This research applies Taguchi method in the optimization process of gluten-free spaghetti production combination of four factors and three levels. The research started with control factors and levels, and the quality response characteristics of spaghetti. The degree of freedom will be calculated, and the orthogonal matrix will be selected. Taguchi data tabulation includes the average calculation, SNR, impact factors, ANOVA, contribution percentage and multi-response loss function to get the optimal combination based on the intended characteristics quality [1]. Thus, the objective of this optimization research is to obtain the optimal combination factors and levels based on the intended characteristics quality.

2. Materials and Methods

2.1. Materials and Tools

Materials used in this research is the ingredients used in the process of spaghetti production which are mocaf (modified cassava flour) from Cimanggu cassava fermented with starter mocaf; rice flour Ciherang varieties, P21 hybrid corn, and local soybean flour. Each flour was made with 40, 60, and 80 mesh smoothness index. The tools used in the process of spaghetti production are extruder machine, cabinet dryer, fan scale, gas stove, steaming pan, spoon, scissors, stainless table, and sealer. Physical analytic tools are texture analyzer for elongation, hardness, and adhesiveness analysis, and physical analytic tools for *cooking loss* are *colorimeter* 3nH to test the color, chemical analytic tools such as moisture content by using gravimeter method, protein content by using Kjeldahl method, ash content by using ash method, fat content by using soxhlet, and carbohydrate content by using difference method.

2.2. Place and Time Research Conduct

The research was conducted from January to May 2018 in Pilot Plant of Non-Wheat Product, Laboratorium of Food Chemistry, Laboratorium of Instrumentation, PPTTG LIPI, West Java, Subang; PT. Saraswanti, Bogor dan Analysis Services, Agricultural Technology Faculty, Gadjah Mada University, Yogyakarta.

2.3. Experiment design with Orthogonal-Taguchi Matrix

a. Factors and levels of measurement

Table 1. Factors and levels of experiment

Smoothness Index of the Flour (A)	Mocaf Flour: Corn Flour (B)	Rice flour: soybean flour (C)	Guar gum (D)
40 mesh	40% : 20%	35% : 5%	1 %
60 mesh	35% : 25%	30% : 10%	1.5 %
80 mesh	30% : 30%	25% : 15%	2 %

b. Degree of freedom calculation and orthogonal matrix selection

- Degree of freedom = $4 \times (3 - 1) = 8$
- Selection of orthogonal matrix 3 levels: $L_9(3^4)$, $L_{27}(3^{13})$, $L_{81}(3^{40})$
- Orthogonal Standard Matrix selected is $L_9(3^4)$ because of its degree of freedom is 8, similar to degree of freedom in the experiment.

c. Plotting factors and levels in accordance with the standard orthogonal matrix.

Table 2. Research design

Concept	Smoothness index of the flour	Mocaf flour: corn flour (%)	Rice flour: soybean flour (%)	Guar gum (%)
1	40	35 : 25	35 : 5	1
2	40	30 : 30	30 : 10	1.5
3	40	25 : 35	25 : 15	2
4	60	35 : 25	30 : 10	1.5
5	60	30 : 30	25 : 15	1
6	60	25 : 35	35 : 5	1.5
7	80	35 : 25	25 : 15	1.5
8	80	30 : 30	35 : 5	2
9	80	25 : 35	: 10	1

2.4. Gluten-free spaghetti preparation

Gluten-free spaghetti was prepared using the extruder machine with 16 die-designed holes and 2mm diameter, the temperature at 60 °C, and spinning speed at 40 rpm. All the ingredients are measured as mentioned in Table 2. Then, they were mixed with dough mixer and steamed in steaming pan for 30 minutes, before the mixture was placed in the extruder machine.

2.5. Analyses of gluten-free spaghetti

2.5.1 Chemical analysis. The analysis of moisture content was done by using SNI 01-2891-1992, related to an analysis method for food and beverage. Protein content is measured according to the Dumas combustion method by using DuMaster Buchi D-480, Switzerland, ash content and fat content with soxhlet, and carbohydrate content were analyzed through *by difference* method [9].

2.5.2 Cooking quality analysis. Cooking quality analysis includes analyzing cooking time, cooking weight and cooking loss [10]. Cooking time analysis is started with cutting 5 gram of dried spaghetti for 4-5 cm long and cooked in 200 ml boiled water in closed beaker glass. Every 30 seconds, the sample is taken and pressed with two transparent glass up to a certain period which shows that sample is well-cooked. Cooking weight and cooking loss analysis were done by cutting 1 gram of dried spaghetti for 3-5 cm long and cooked based on the determined cooking time of each sample. The sample was then filtered by monyl T13 and washed with distilled water. The sample was filtered for one minute and put on scale to measure the cooking weight. The calculation formula in cooking weight can be seen in the equation formula (1). The cooking loss is counted based on the residual solid dissolved by the boiled water which is drained by oven in 105 °C temperature until it reaches its constant weight. The cooking loss formulation can be seen in the equation formula (2).

$$\text{Cooking weight (\%)} = \frac{W_1 - W_2 \times (1 - M)}{W_2 \times (1 - M)} \times 100\% \quad (1)$$

$$\text{Cooking loss (\%)} = \frac{W_3}{W_2 \times (1 - M)} \times 100\% \quad (2)$$

Explanation =

W_1 = sample weight after being cooked; W_2 = sample weight before being cooked

W_3 = weight of dry solid dissolved during cooking process; M = moisture content sample

2.5.3 Profile Texture Analysis. Profile texture analysis includes elongation, hardness and adhesiveness are analyzed through texture analyzer (TAXt-Plus, Stable Micro Systems, Surrey, UK). A strand of spaghetti which has been cooked based on the cooking time was drained for 2 minutes at room temperature. Texture analysis is based on Stable Micro System with several modifications [11]. Elongation of cooked spaghetti is measured with spaghetti tensile grips (A/SPR) rig pretest 1 mm/s, test speed 3 mm/s, post-test speed 10 mm/s and initial distance slaps 2 cm. Solidity and adhesiveness analysis is done by placing the strands of spaghetti on the metal plate under the probe. Experiment test with cylinder P/36R probe on mode trigger type, auto 0.5 g; pre-test speed 2 mm/s, test speed 2 mm/s; post-test speed 10 mm/s and strain 95 %. Each analysis was repeated for 5 times.

2.5.4 Sensory test of taste. Sensory test using hedonic scale is a test conducted to 30 panelists to find out the level of taste recipient of the product. The panelist scores are as follow: 1 (very bad); 2 (bad); 3 (quite bad); 4 (neutral); 5 (not very bad); 6 (good); 7 (very good).

2.6. Taguchi data calculation

a) Calculation of the average of every experiment

b) Value calculation of SNR per experiment

Larger the better

$$\eta = -10 \log \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right) \quad (3)$$

Nominal the best

$$\eta = 10 \log_{10} \left[\frac{\mu^2}{\sigma^2} \right] \quad (4)$$

$$\mu = \frac{1}{n} \sum_{i=1}^n y_i^2 \quad (5)$$

$$\sigma^2 = \frac{1}{n-1} \sum_{i=1}^n (y_i - \mu)^2 \quad (6)$$

Smaller the better

$$\eta = -10 \log \left(\frac{1}{n} \sum_{i=1}^n y_i^2 \right) \quad (7)$$

Explanation:

η = SNR value of every experiment; n = the number of repetition in every experiment

y = value of every experiment; μ = the average of each experiment; σ^2 = deviation of every experiment

c) The ANOVA average value calculation

d) ANOVA calculation of SNR value (the same method to calculate the average of ANOVA)

e) Calculation of Multi Response Loss Function

i) Calculate loss function

Larger the better

$$L_{ij} = \frac{k}{n} \sum_{p=1}^n \frac{1}{y_{ijp}^2} \quad (8)$$

Smaller the better

$$L_{ij} = \frac{k}{n} \sum_{p=1}^n (y_{ijp}^2) \quad (9)$$

Nominal the best

$$L_{ij} = \frac{k}{n} \sum_{p=1}^n (y_{ijp} - m) \quad (10)$$

Explanation:

L_{ij} = loss function ; k = coefficient loss; n = number of data repetition;

y_{ijp} = result of experiment ; m = intended value

ii) Calculate normalization

$$N_{ij} = \frac{L_{ij}}{\bar{L}_{ij}} \quad (11)$$

Explanation:

N_{ij} = normalization; $\bar{L}_{ij}$ = the average loss function

iii) Calculate of loss function

$$TL_j = \sum_{i=1}^r w_i x N_{ij} \quad (12)$$

Explanation:

TL_j = total loss function; w_i = total variable response

iv) Transformation to SNR

$$\eta = -10 \log(TL_j) \quad (13)$$

Creating factor effect table

v) Optimization of level combination and optimal factor

f) Confidence interval calculation (confirmation test)

i) Estimation of average optimal condition

$\mu_{\text{prediction}}$ = sum of the average from optimum factor level + y

ii) Confidence interval calculation

$$Cl_{mean} = \pm \sqrt{F_{\alpha;v_1;v_2} x MS_e x \frac{1}{neff}} \quad (14)$$

$$neff = \frac{\text{number of experimental} \times \text{replication}}{\text{number of degree of freedom} \text{ degree of freedom for measuring the mean}} \quad (15)$$

Explanation:

CI = confidence interval ; $F_{\alpha; v_1; v_2}$ = F-ratio from table ; α = Risk, confidence level = 1–risk ; v_1 = degree of freedom numerator; v_2 = degree of freedom denominator; Mse = the average of sum of squares polled error

iii) Average confirmation experiment

Average value calculation

$$\mu = \frac{1}{n} \sum_{i=1}^n y_i \quad (16)$$

Confidence interval calculation

$$Cl_{mean} = \pm \sqrt{F_{\alpha;v_1;v_2} x MS_e x \left(\frac{1}{neff} + \frac{1}{r} \right)}$$

Explanation: r = The number of observation used to calculate the average

3. Result and Discussion

3.1. Characteristics of the Spaghetti Quality

Table 3 presents the characteristics of the spaghetti response quality.

Table 3. Characteristic determination

Spaghetti Quality	Characteristic	Spaghetti Quality	Characteristic
Moisture content	Smaller the better	Elongation	Nominal the best
Protein content	Nominal the best	Hardness	Nominal the best
Fat level	Nominal the best	Adhesiveness	Nominal the best
Carbohydrate	Higher the better	Color	Nominal the best
Cooking time	Smaller the better	Sensory of taste	Higher the better
Cooking loss	Nominal the best		

The quality response of moisture content in this study is smaller the better. The amount of moisture content affects the shelf life of the product. The low water content of spaghetti products shows the product has good quality

3.2. Data tabulation and interpretation

This scientific paper illustrates data tabulation in one of the quality characteristics of the gluten-free spaghetti, in this case, is the moisture content.

3.2.1. The average calculation and SNR of moisture content

The average of moisture content from 9 concepts of gluten-free spaghetti product is around 9.54% to 10.77%. Based on significant difference test, the highest average of moisture content is concept 1 which has 10.77% differentiation compared to the lowest average of moisture content in product 7 with 9.54%.

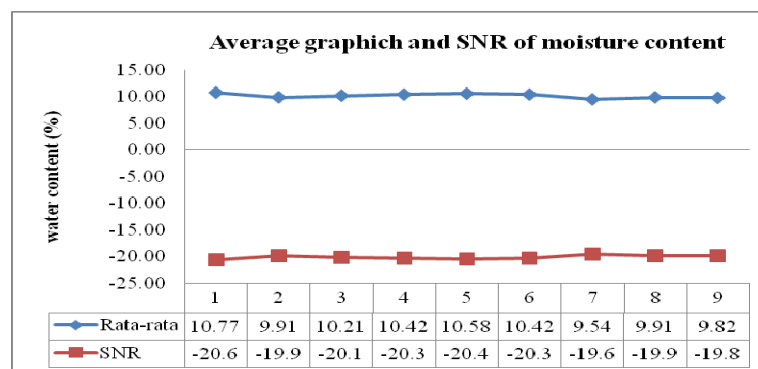


Figure 1. Average graphics and SNR of moisture content

Gluten-free spaghetti in concept 1 is made from 35% of mocaf (modified cassava flour), 25% of corn flour, 35% of rice flour, 5% of soybean flour, and 1% of guar gum. The whole flours are used to produce spaghetti concept 1 with the level of smoothness index of 80 mesh. From SNR graphic response of moisture content with smaller the better quality characteristic from 9 concepts ranged from -19.85 – (-20.65). The SNR highest value of smaller the better moisture content is 7, and the lowest is 1. This proves that the combination factor level of concept 7 has the biggest effect on the variety of moisture content response and must be controlled to meet the expected quality.

3.2.2. The average response of moisture content

Besides the average calculation and SNR of moisture content, the calculation of factor effect and SNR were also conducted to identify the effect level from factor towards the average of observed quality. The average effect of every level from each factor has resulted from the calculation of the average quality value from the contained product concept. The average effect of level from each factor then subtracted with the highest score with the lowest score to find the deviation as the average effect value from the factor level. The calculation of factor effect from the moisture content is as illustrated in Table 4.

Table 4. The calculation of factor effect from the moisture content

	A	B	C	D
Level 1	10.30	10.24	10.37	10.39
Level 2	10.47	10.13	10.05	9.96
Level 3	9.76	10.15	10.11	10.18
Deviation	0.72	0.11	0.31	0.43
Ranking	1	4	3	2

From the average of factor effect calculation of moisture content, it shows that the order of factors ranking which has the highest number of deviation in a row is factor A, D, C, B, while the combination of factor level which resulting average response of smaller the better moisture content can be seen in Figure 2.

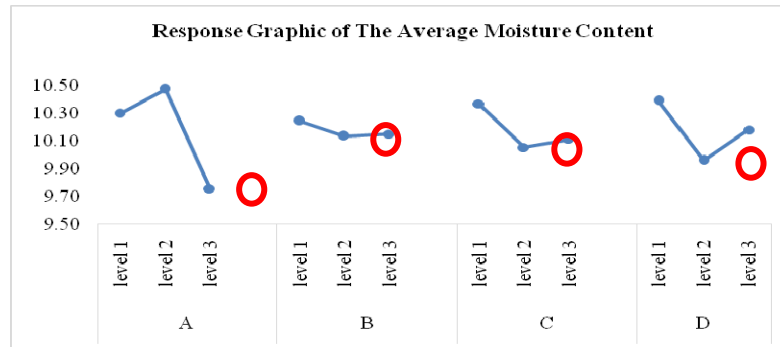


Figure 2. Response Graphic of the Average Moisture Content

From the graph of the average response of moisture content, it is known that factor A level 3 is the most influencing factor and level to the average for the moisture content response variable because it produces the lowest average moisture content response. The fineness of 80 mesh flour can be used to control the mean for the moisture content response variable if desired the lower, the better. The best combination of factors and levels to control the average response is A3, B2, C2, D2.

3.2.3. Effect of SNR moisture content

SNR effect is used to determine the effect of factors on noise. SNR effect of each level of each factor is obtained by calculating the SNR value of the quality of the product concept in which there is a combination of these levels. The SNR effect level of each factor is obtained from the highest value difference with the lowest value. From these values obtained a rating of experimental factors to the noise of each quality parameter. From the calculation of SNR factor effect of moisture content, it is known that the factor rank of the largest SNR difference is A, D, C, B, whereas the combination of factor level which produces SNR response of smaller the better moisture content can be seen in Figure 3.

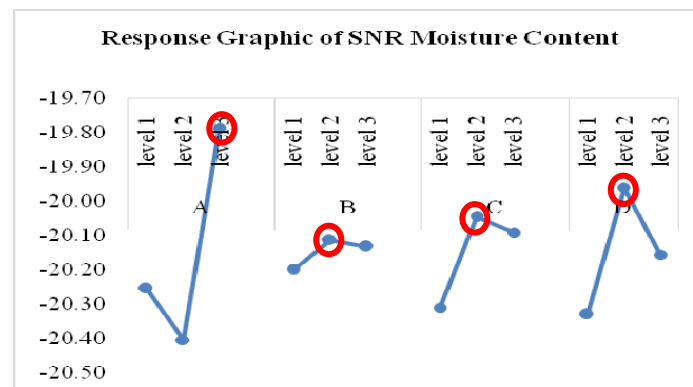


Figure 3. Response Graphic of SNR Moisture Content

From the graph of SNR response, it is known that factor A has the largest SNR response. Factor A is the most influential on the variation (noise) for the moisture content response variable. These factors should be controlled to reduce variations in the moisture content of gluten-free spaghetti products. The combinations of levels of the factors that produce the highest moisture content SNR response are A3, B2, C2, D2.

3.2.4. ANOVA of the average and SNR of Moisture Content

From the mean and SNR factor effect analysis, it is known that the A factor has the highest rank on the moisture content of spaghetti, followed by other factors. The average ANOVA calculation of moisture

content shows that not all experimental factors affect the average water content of gluten-free spaghetti. Only factor A effect with F ratio 7.89, greater than F table (0.05%) 3.55. Factor A contributes 32.39% to the quality characteristics of gluten-free spaghetti moisture content. The other factor has an F ratio lower than F table. This is because of the smaller the starch particles; the starch granules will be more ruptured. Amylose that has come out of the starch granule (but is still trapped in a flour granule) can spread throughout the dough and form a strong matrix structure through hydrogen bonds when retrograde [12].

3.2.5. Loss Function of Moisture Content

Because the response observed in this study is more than one (multi-response), the approach used is loss function. The loss function is a function of loss due to the quality produced. Taguchi adopts a loss function for the optimization process. Calculation of loss function of moisture content can be seen in table 5.

Table 5. Calculation of loss function for moisture content

Concept	Lij	Nij	Wi	Wi x Nij
1	116.07	1.12	0.08	0.0932
2	98.42	0.95	0.08	0.0790
3	104.37	1.01	0.08	0.0838
4	108.61	1.05	0.08	0.0872
5	111.96	1.08	0.08	0.0899
6	108.73	1.05	0.08	0.0873
7	91.12	0.88	0.08	0.0732
8	98.21	0.95	0.08	0.0789
9	96.64	0.93	0.08	0.0776

Calculation of loss function is continued for all the characteristics of the quality of gluten-free spaghetti (protein content, fat content, carbohydrate content, cooking time, cooking loss, elongation, hardness, adhesiveness, color, and sensory of taste).

3.3 Multiresponse Loss Function Calculation

Every optimized characteristic has a different value. Therefore, in order to equalize, it needs to be normalized on each characteristic and weighted. Calculation of total loss function is then transformed in a multiresponse signal to noise ratio. Calculation of multiresponse loss function can be seen in table 6.

Table 6. Calculation of multiresponse loss function

Concept	TLj	Hj	Concept	TLj	Hj
1	1.206	-0.813	6	0.724	1.403
2	0.861	0.650	7	1.041	-0.175
3	1.968	-2.941	8	0.883	0.543
4	0.758	1.203	9	0.731	1.362
5	0.858	0.665			

3.4 Optimum selection of the optimum combination of factors and levels

Based on the calculation of the effect of the multi-factor response on the quality characteristics of gluten-free spaghetti products, among others moisture content, protein content, fat content, carbohydrate content, cooking time, cooking loss, elongation, hardness, adhesiveness, color, and sensory taste were obtained optimum combination A2, B2, C2, D2 which can be seen in figure 4.

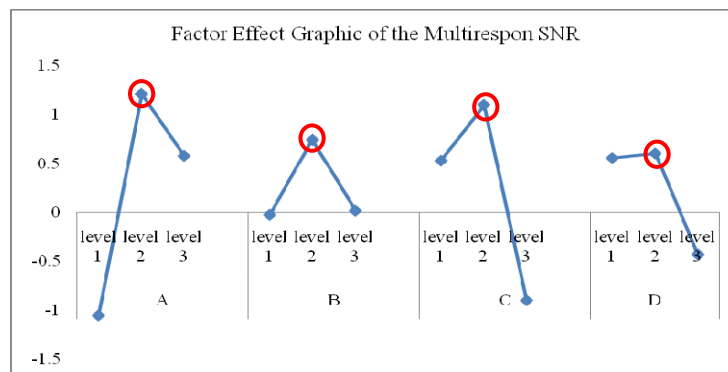


Figure 4. Factor Effect Graphic of the Multirespon SNR

3.5 Confirmation test

The confirmation test is based on reassessing product quality. Confirmation test is to find out how far the selected product can get the product with the best quality attributes. From the confirmation experiment, it is known that the optimum product selected has been in the confidence interval and has confirmed its quality.

4. Conclusion

In conclusion, we have shown that the optimum gluten-free spaghetti products made from 60 mesh local flour with a composition of 30% mocaf flour, 30% corn flour, 30% rice flour, 10% soybean flour, guar gum 1.5% with quality characteristics have been confirmed within its confidence interval. Quality analysis of this product has moisture content $9.94 \pm 0.57\%$, protein content $10.33 \pm 0.55\%$, fat content $1.11 \pm 0.67\%$, carbohydrate content $76.51 \pm 2.32\%$, cooking time 10.65 ± 0.25 minutes, cooking loss 13.00 ± 2.76 , elongation 181.35 ± 25.72 , hardness 2069.03 ± 453.07 gf, adhesiveness -32.75 ± 3.41 g.sec, color 76.51 ± 0.63 dL and sensory score of taste 4.80 ± 0.16 . This research is expected to produce alternative spaghetti products from local Indonesian food

5. Acknowledgment

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