RSM-based optimization of analog rice production using kimpul tuber *(Xanthosoma sagittifolium)* and anjasmoro soybeans for enhanced energy and protein content

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Abstract. Indonesia ranks third globally in rice consumption, with an annual per capita intake of 139.15 kg—almost double that of other Asian countries (65–70 kg). Such dependency on rice contributes to high prices, unstable supply, and vulnerability to poverty and malnutrition. One critical nutritional issue in Indonesia is Protein-Energy Malnutrition (PEM), particularly among toddlers, manifested in conditions such as kwashiorkor and marasmus. The contribution of this research is to demonstrate how statistical modeling can be used to predict nutritional responses (protein and energy) from changes in raw material formulations and to expand the application of RSM in the field of local foods based on tubers and soybeans. Kimpul flour contains up to 145 g of carbohydrates per 100 g, compared to only 79.3 g in conventional rice, while soybeans are rich in protein. This study aims to optimize the formulation of composite flour from kimpul and soybean using Response Surface Methodology (RSM). A Box–Behnken three-variable design was applied with kimpul flour (X_1), soybean flour (X_2), and tapioca (X_3) at three concentration levels, generating 15 treatment combinations to determine the optimum protein content and energy value. The optimum points for each variable of energy content and protein content are the variables of cassava flour concentration, soybean flour concentration, and tapioca concentration, respectively, which are 135,5 grams; 63,16 grams; 1,52 grams.

1 Introduction

Rice is the main staple food for most Indonesians and is the primary source of energy in their daily diet. This high dependence on rice poses a major challenge to national food security, especially when there is a decline in production, climate change, or price fluctuations [1]. Therefore, efforts to diversify food based on local resources are very important to reduce dependence on rice and improve national food security. If rice stocks decrease, the community, especially low-income groups, will lack daily calorie intake. This problem triggers macro nutritional problems, especially in children. Carbohydrates from rice are the main source of energy. When rice decreases, calorie intake also decreases. As a result, the body uses energy reserves from fat and muscle protein for daily needs. Over time, this leads to weakness, fatigue, weight loss, and growth disorders in children. This condition is called Protein-Energy Malnutrition (PEM), so the solution to this problem is to optimize protein and energy in analog rice that utilizes local raw materials.

Basically, tubers have the potential to be used as raw materials for imitation rice, one of which is kimpul tubers (Xanthosoma Sigittifolium). Kimpul is a source of carbohydrates, so it is used as a substitute for wheat and rice [2]. Every 100 grams of fresh kimpul tubers contain 23.7 grams of carbohydrates. However, in the production of imitation rice, kimpul tubers are used in the form of flour [3]. The carbohydrate content of kimpul tuber flour is 90,62%. Kimpul flour has a lower protein content and energy value, so it is necessary to add protein sources and energy intake. Soybean flour has a protein content of 41.78%-42.05% and an energy content of 503.9 kcal. Good imitation rice has a compact consistency, so in its manufacture, a binder compound is needed to bind the raw materials into a compact mass, namely by adding tapioca. Anjasmoro soybeans are one of the nationally superior varieties widely cultivated in Indonesia. This variety is known for its high protein content (around 40% of dry seed weight) and its quality for both food and industrial use.The protein content of Anjasmoro soybeans can be an alternative to animal protein, making it suitable for vegetarians and people who want to reduce their meat consumption.

The objective of this study is to determine the appropriate formulation to optimize protein and energy intake from kimpul flour and anjasmoro soybeans flour (composite flour) as well as tapioca using the response surface methodology. This research needs to be conducted to examine the effect of using a proportion of kimpul tuber flour and soybean flour (composite flour) and the addition of tapioca to the resulting imitation rice. The use of a proportion of composite flour and tapioca flour is expected to improve the organoleptic value of imitation rice and increase its

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nutritional value, namely carbohydrates and protein, so that it can be accepted by the community.

Several studies on food diversification in the form of imitation rice include:

1. "Production and Physicochemical Characterization of Analog Rice Obtained from Sago Flour, Mung Bean Flour, and Corn Flour Using Hot Extrusion Technology " [4]
2. "Development Of Analog Rice By Utilizing Red Seaweed (Eucheuma Spinosum) and Native Sago From The Riau Islands, Indonesia Eucheuma Cottonii Seaweed as a Source of Dietary Fiber" [5].

However, the research they conducted only discussed the characteristics that are unique to imitation rice itself and the production process of making imitation rice. The discussion on optimizing protein and energy content in the production of imitation rice using the response surface method has not yet been discussed. The contribution of this research is to demonstrate how statistical modeling can be used to predict nutritional responses (protein and energy) from changes in raw material formulations and to expand the application of RSM in the field of local foods based on tubers and soybeans.

2 Literature review

2.1 Kimpul tuber and anjasmoro soybeans

In this study, the raw material used came from kimpul *(Xanthosoma sagittifolium),* which is an alternative staple food in various regions of Indonesia, either consumed directly by steaming, baking, or boiling. Kimpul is a commodity that is a source of carbohydrates, but until now it has not received much attention in terms of cultivation or processing. Kimpul tubers have a high carbohydrate content ranging from 70-80% [6]. The size and shape of kimpul depend on the type of planting material and ecological factors, especially soil characteristics. In highland areas, kimpul is usually round and slightly elongated. This plant consists of three main parts, namely the skin, cortex, and core. The skin is smooth, fibrous, and covered with scales. This plant can grow up to two meters or more. The leaves are arrow-shaped, thick, and have long stems. The kimpul plant is a source of carbohydrate food. Not only that, kimpul tubers also contain protein, fat, fiber, and minerals. One of the advantages of kimpul tubers is that they contain bioactive compounds that aid digestion [7].

Fig. 1. Kimpul Tuber *(Xanthosoma sagittifolium).*

All tubers are foodstuffs that have high water content and continue to metabolize even after harvesting. To prevent spoilage and extend shelf life, tubers are stored under controlled conditions or made into flour. Flour is a processed form of the material obtained by grinding or milling. In the grinding process, dried tubers in the form of chips or shavings are reduced in size by being pressed mechanically with a grinding tool. Processing into flour, in addition to extending shelf life due to low water content, also provides advantages such as ease of further processing and increased economic value [8].

Soybeans are a commodity that is needed as a nutritious food, animal feed, and industrial raw material. The demand for soybeans continues to increase from year to year in line with the increasing population growth rate and public awareness of food nutrition. Soybeans are high in protein, low in cholesterol, and affordable [9]. Government attention to soybean development has increased with the rise in consumption from year to year. Meanwhile, the rate of increase in soybean production has not been able to keep pace with the rate of increase in demand, resulting in an increase in imports from year to year.

Anjasmoro is a superior soybean variety that has the highest protein content of 72.3% and can adapt to agroecosystems in rice fields, dry land, swampy land, and tidal swampy land. Superior varieties are favored by farmers because of their high yield, large seeds, and pods that do not break easily. The Anjasmoro variety has a yield of 2.03–2.25 t/ha, is resistant to lodging, and is moderately resistant to leaf rust [10].

Fig. 2. Anjasmoro soybeans.

Tapioca flour is flour made from cassava, which is why people sometimes refer to it as cassava flour or starch. This flour contains a lot of carbohydrates and little protein, fiber, or other nutrients. The nutritional content of tapioca flour per 100 g sample is 362 calories, 0.59% protein, 3.39% fat, 12.9% water, and 6.99% carbohydrates. Tapioca flour is used as a binding agen [11].

2.2 Respon surface methodology

It is a combined method of mathematical and statistical techniques used to create models and analyze a response y that is influenced by several variables x, with the aim of optimizing that response. The functions of the Response Surface Method are: 1. To show how the response variable y is influenced by the independent variable x in a specific area of interest. 2. To determine

the most appropriate setting of the independent variable that will produce results that meet the specifications of the response, such as yield, impurity, color, texture, and so on. 3. To explore the space of the independent variable x to obtain maximum results. To implement the response surface methodology (RSM), there are planning stages that must be carried out, where planning is defined as the process, method, or activity of planning, organizing, and outlining the steps for implementing an activity [12].

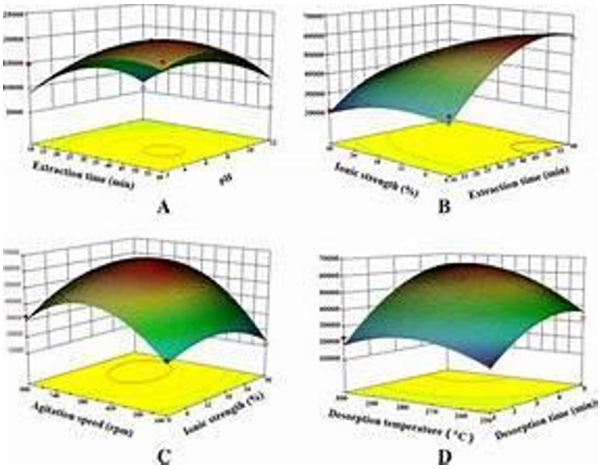

Fig. 3. Response surface methodology model with box behnken design.

Box–Behnken Design: an experimental design for RSM that is efficient for building quadratic models without requiring all extreme combinations (fewer extreme points than full factorial). BBD does not include corner points (all factors ±1 at once), so it is safe if the extreme points are dangerous/expensive.

3 Research methodology

3.1 Research design and Model

This study was compiled and designed using a three-variable Box Behnken Design (BBD) using Design Expert software. The Box–Behnken (BBD) method is an experimental design that is included in the response surface methodology (RSM) and is a derivative of DOE (Design of Experiments). The Box Behnken Design was designed by George EP Box and Donald Behnken in 1960. The percentage of kimpul flour (X_1), the proportion of soybean flour (X_2), and the proportion of tapioca flour (X_3). The amount of each proportion was based on previous research that produced analog rice characteristics similar to those of regular rice [13]. The optimized responses were protein and energy. Three levels of factors were used for the Box-Behnken three-variable design as follows:

X_1: Kimpul Flour Proportion = 130 grams; 140 grams; 150 grams

X_2: Soybean Flour Proportion = 50 grams; 60 grams; 70 grams

X_3: Tapioca Proportion = 1 gram; 2 grams; 3 grams

In the Box-Behnken design with 3 factors, there are three independent variables (factors), and the design explores the response to different combinations of these factors at different levels. The number of levels per factor is 3: low (-1), medium (0), and high (+1) [14].

Table 1. Treatment combination scenario with three-variable box behnken design.

No	Original variable			Code variable		
	Proportion of Kimpul Flour (gr)	Proportion of Soybeans Flour (gr)	Proportion of Tapioca Flour (gr)	X1	X2	X3
1	140	60	2	-1	-1	0
2	130	50	2	-1	1	0
3	140	50	1	1	-1	0
4	130	60	1	1	1	0
5	140	60	2	-1	0	-1
6	140	70	3	-1	0	-1
7	150	60	3	1	0	-1
8	150	60	1	1	0	1
9	140	70	1	0	-1	-1
10	150	50	2	0	-1	1
11	130	70	2	0	1	-1
12	150	70	2	0	1	1
13	140	60	2	0	0	0
14	130	60	3	0	0	0
15	140	50	3	0	0	0

Data analysis was performed using Design Expert DX version 13. Variable 0 indicates a concentration between variables -1 and +1, which is 140 grams. For the soybean flour concentration variable, -1 indicates a soybean flour concentration of 50 grams, while +1 indicates a soybean flour concentration of 70 grams. Variable 0 indicates a concentration between variables -1 and +1, which is 60 grams, while the tapioca concentration variable is 3 grams. Variable 0 indicates a concentration between variables -1 and +1, which is 2 grams.

3.2 Preparation of raw materials

The tools used for the process of making imitation rice include a winnowing tool, plastic basin, cabinet dryer, blender (Panasonic brand), brush, analytical scales, 100 ml and 200 ml measuring cups, steamer, and imitation rice molding tool. The tools used for analysis include a Soxhlet extractor, spectrophotometer, drying machine, moisture oven, acid cabinet, extruder machine, desiccator, and muffle furnace. The materials used during the analog rice production process consist of main ingredients and auxiliary ingredients. The main ingredients include Nealson Reagent, Arsenomolybdate Reagent, Na Metabisulfite, Potassium Iodide, 32% Concentrated HCL, 98% Concentrated H2SO4, NH4OH, CaCl2, KMnO4, Petroleum Ether (PE), Kjedahl Tablets, PP Indicator, Laboratory Filter Paper, Distilled Water, Litmus Paper [15].

The main ingredients are kimpul flour and a mixture of soybeans anjasmoro according to the treatment scenario by the design expert. Additional ingredients such as tapioca are used to improve the texture of the analog rice, then the dough is pressed through a small

mold or torn to resemble the shape of rice. The goal is to produce a physical shape that resembles real rice. Soak the imitation rice grains in warm water at 60°C for 10 minutes. Stir gently to prevent sticking. The purpose is to hydrate the grains (increase water content evenly). Start the process of partial starch gelatinization. Make the texture more chewy when cooked. After soaking, drain the grains from the water. Place them in a fine sieve or cheesecloth to remove excess water. Let them sit for a few minutes. Purpose: to reduce free water before the steaming process so that they do not become mushy or crumble. Steam the drained grains for 15–25 minutes (depending on grain size). Use a steam temperature of around 100°C (as for steaming regular rice) [16]. Purpose: Complete starch gelatinization. Strengthen the structure and chewiness of the imitation rice. Produce "cooked imitation rice" that is ready for consumption. Dry in an oven at 50–60°C until the moisture content is <14%.

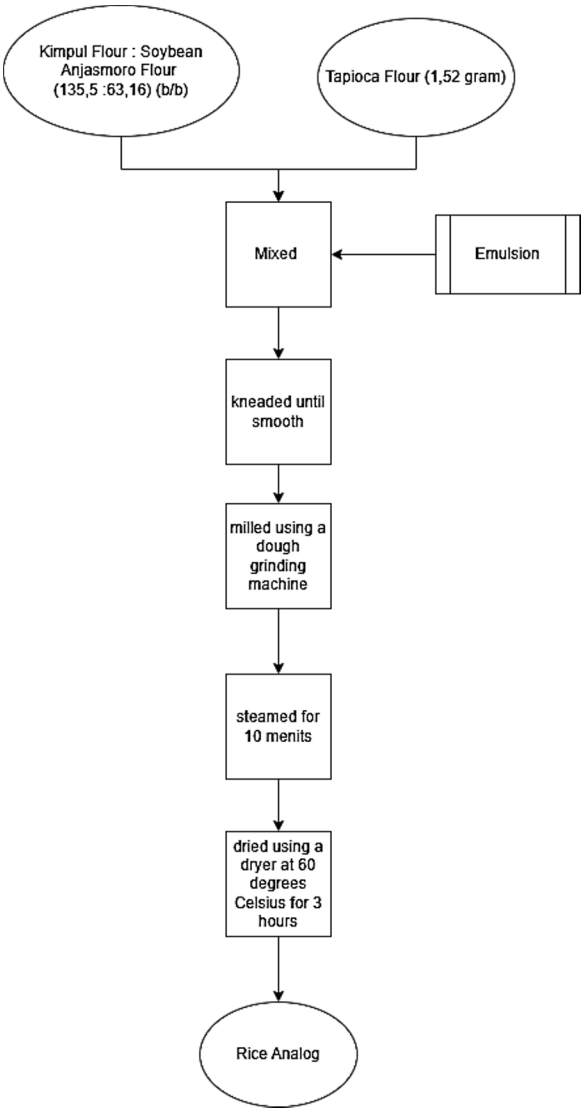

Fig. 4. Flowchart of the best treatment for producing analog rice.

4 Data processing with RSM

Data analysis was performed using Design Expert using the Box Behnken Design Response Surface Methodology (RSM) version 13. Verification was then carried out by comparing the response analysis values in the study with the response values calculated using the Design Expert software.

Source	Sequential p-value	Lack of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	0.0247	0.0568	0.4388	0.1731	
2FI	0.2387	0.0624	0.5315	0.0681	
Quadratic	**0.0061**	**0.3024**	**0.9253**	**0.6516**	**Suggested**
Cubic	0.3024		0.9602		**Aliased**

Fig. 5. Analysist velues using design expert.

Fit Summary is the initial table that appears after we perform model fitting on RSM experimental data. The purpose is to determine the best model (linear, 2FI, quadratic, or cubic) that best fits the response data.statistically significant In the Fit Summary results, the quadratic model usually has a Sequential p-value < 0.05 (0,0061), meaning that this model is significantly better than the linear model or two-factor interaction (2FI). No significant lack of fit A Lack of Fit p-value > 0.05 indicates that the model fits the experimental data—there are no major deviations between the model results and the actual data [17]. High and balanced R^2, Adj R^2, and Pred R^2 values This indicates that the quadratic model explains the response variation well and is able to predict accurately (the difference between Adj R^2 and Pred R^2 is small). Can be used for optimization The quadratic model allows us to find the optimum point (maximum/minimum) of the response to several factors. The linear model cannot show the peak response, only the direction of increase or decrease.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	979.60	9	108.84	20.28	0.0020	significant
A-Kimpul	137.61	1	137.61	25.64	0.0039	
B-Kedelai	289.19	1	289.19	53.88	0.0007	
C-Tapioka	135.84	1	135.84	25.31	0.0040	
AB	26.59	1	26.59	4.96	0.0765	
AC	3.83	1	3.83	0.7140	0.4367	
BC	143.94	1	143.94	26.82	0.0035	
A^2	7.26	1	7.26	1.35	0.2974	
B^2	231.49	1	231.49	43.13	0.0012	
C^2	17.85	1	17.85	3.33	0.1278	
Residual	26.83	5	5.37			
Lack of Fit	21.11	3	7.04	2.46	0.3024	not significant
Pure Error	5.73	2	2.86			
Cor Total	1006.44	14				

Fig. 6. Results of analysis of variance (ANOVA) of energy content response.

The results of the analysis of variance show that the linear graph model of cassava flour concentration (A), soybean flour concentration (B), and tapioca concentration (C) has a significant effect on the energy content response, as indicated by a p-value of less than 0.05 ($p < 0.05$). This indicates that these three variables influence the response. The combination of starchy flour (kimpul) with protein flour (soybean) creates a balanced nutritional composition, there by increasing

the total energy per 100 g of product and stabilizing its energy distribution. The soybean mixture increases the calories per unit weight (energy density), so that the measured energy response (e.g., in proximate tests or RSM analysis) becomes more significant. Thermal process (soaking–steaming) increases energy availability. Heat treatment causes starch to gelatinize and proteins to partially denature, making them easier to digest, thereby increasing the energy released during metabolism [18]. Effects on statistical models (RSM) Statistically, the proportion of cassava flour and soybean flour significantly affects energy values because variations in their composition result in large changes in total calorie values (Y). A p-value < 0.05 indicates a significant effect.

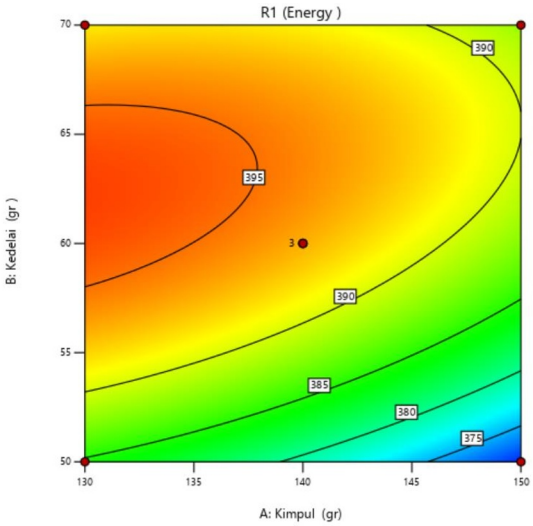

Fig. 7. Contour plot.

In Response Surface Methodology (RSM), contour plots are used to show the relationship between two independent variables and the response (dependent variable) on the response surface. The colors on the contour plot represent the response values (Y). Red indicates the highest (maximum) response value [19].

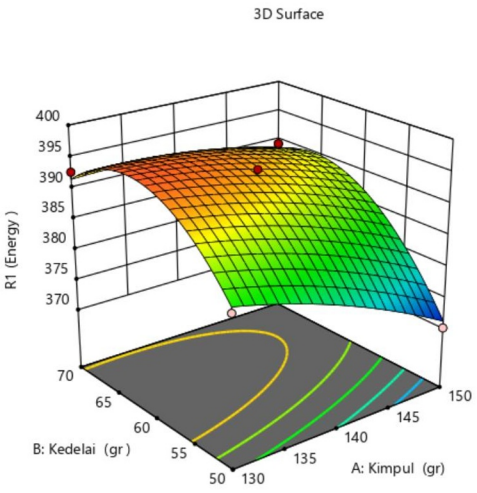

Fig 8. Graph of the effect of kimpul flour, soybean flour, and tapioca flour concentration variables on energy and protein content response.

The "desirability" contour in Figure (8) is a contour that shows the accuracy of the optimization results. This contour is marked with a flag in the center of the contour, which indicates the optimal point located at the node shown on the flag. Based on the solution obtained from the Design Expert software calculation system, the optimum points for the variables of cassava flour, soybean flour, and tapioca concentration are 135,5 grams, 63,16 grams, and 1,52 grams, respectively. From the solution of the free variable optimum point, the optimum response values obtained were 398.07 kcal for energy content and 20,53 grams for protein. The optimum point solution obtained from the Design Expert computation results is shown in Table 2.

Table 2. Design expert computation results.

	Concentration Kimpul Flour	Concentration Soybean Flour	Concentration tapioca	Energy Level	Protein Level	Desirability	Remarks
Prediction	135,5	63,16	1,52	398,08	20,5	1,000	Selected

The results of this design expert computation show a energy content of 20,5% in the optimum formulation (Anjasmoro + kimpul) after RSM optimization. This value is higher than a number of previous studies that applied the addition of soybean flour/isolate or nuts to increase the protein content of rice analog. Previous researchers, namely Wahyuningsih et al [17]. The fiber content of analogrice with Moringa leaf flour substitution ranged from 11.16 to 13.65% for insoluble dietary fiber, 0.60 to 0.99% for soluble dietary fiber, and 11.80 to 14.62% for total dietary fiber.

The main finding of this study is that the optimum condition obtained through the desirability function produces a composition [e.g., 135.5 g of cassava flour, 63.16 g of soybean flour, and 1.52 g of tapioca] with a desirability value of 1.000. Under these conditions, the analog rice has a protein content of 20.5% and an energy value of 398.08 kcal/100 g, which shows a significant improvement compared to the initial formulation before optimization. This value is relatively high for a flour-based product, thanks to the contribution of protein-rich soybean flour. The desirability value in RSM indicates how optimal the combined response is to all desired objectives. Desirability scale: 0 (poor) → 1 (very optimal) A value of 1.000 means that this combination is the global optimum point, namely: All target responses (energy & protein) are achieved or close to the ideal target. There are no negative compromises between responses. The "Selected" label indicates that this combination was chosen as the final optimum condition from the RSM calculation results and the desirability optimization process (usually using Design Expert or Minitab) [20]. This means that the quadratic model used is valid and significant. There is no response conflict between

variables. This parameter can be used as the best formulation for experimental verification testing. [21].

These findings have important implications for the development of functional foods and staple food diversification in Indonesia. Scientifically, the results of this study reinforce the evidence that statistical optimization approaches such as RSM are effective in determining the best formulation of two or more local raw materials to achieve the desired nutritional characteristics and product quality. The equation model generated from RSM can be used as a basis for predicting and controlling the production process of analog rice in the future, both on a laboratory scale and in small to medium industries.

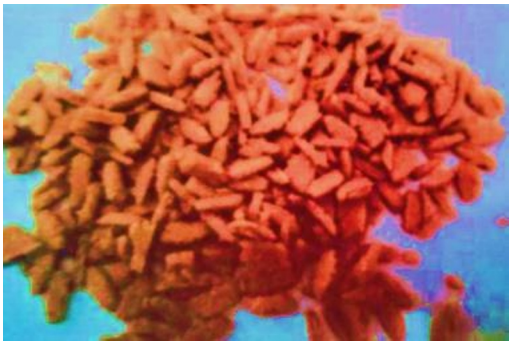

Fig. 9. Analog rice produce.

Based on RSM predictions, analog rice made from a mixture of kimpul flour, soybeans, and tapioca produces optimal energy and protein values. This composition can increase energy and protein because Kimpul tubers are high in starch, which serves as a source of carbohydrates that can increase the energy content (calories) per gram of product [22]. Soybean flour, which is high in protein and fat, can increase the total protein percentage and add biological value to the protein (complete amino acids are better than cassava flour alone). Tapioca (as a binder/texture agent), even in small amounts, helps improve dough elasticity and starch gelatinization, resulting in grains resembling rice grains (good texture affects palatability and water absorption during cooking) [23]. The interaction between the two ingredients (starch + protein) can enhance desirability by achieving the desired balance of energy, texture, and nutritional content.

Advantages this study uses Response Surface Methodology (RSM), which is capable of efficiently analyzing and optimizing the relationship between variables [24]. Using this method, the best formulation of ingredients and process conditions were obtained, which were statistically proven to be significant in increasing protein and energy content and the results of this research provide an alternative staple food to rice with better nutritional value, especially in terms of protein and energy. This is in line with the national program to reduce dependence on rice.

The limitations of this study are that it focuses more on optimizing protein and energy content, while organoleptic tests (taste, aroma, texture, and consumer acceptance) have not been discussed comprehensively [25]. In fact, sensory aspects are very important in market acceptance.

5 Conclusion

Analog rice can be made from kimpul flour, soybean flour, and tapioca. The optimum concentration of cassava flour, soybean flour, and tapioca in the production of analog rice produces an energy content of 398.08 kcal and a protein content of 20,5 grams. The energy content response obtained is linear and quadratic with Response Surface Methodology (RSM) yielding the equation:

$$Y = 154,35 + 1,76\,X_1 + 5,29\,X_2 - 36,77\,X_3 + 0,0257\,X_1X_2 + 0.097\,X_1X_3 + 0,599\,X_2X_3 - 0,014\,X_{12} - 0,079\,X_{22} - 2,198\,X_{32} \quad (1)$$

Meanwhile, the protein level response obtained was 2FI (interaction between factors) with Response Surface Methodology (RSM), resulting in the following equation:

$$Y = 233,70 - 1,55\,X_1 - 2,27\,X_2 - 64,06\,X_3 + 0,016\,X_1X_2 + 0,45\,X_1X_3 - 0,004\,X_2X_3 \quad (2)$$

With Y_1 = energy content response, Y_2 = protein content response, X_1 = cassava flour concentration (grams), X_2 = soybean flour concentration (grams), and X_3 = tapioca concentration (grams). The optimum points for each variable of energy content and protein content are the variables of cassava flour concentration, soybean flour concentration, and tapioca concentration, respectively, which are 135,5 grams; 63,16 grams; 1,52 grams.

This study contributes to the development of nutritionally balanced alternative food products that are not rice-based, with potential applications in supporting food diversification and increasing the added value of local ingredients. The combination of kimpul and Anjasmoro soybeans has been proven to produce an analog rice product that not only has physical characteristics similar to natural rice but also has higher nutritional value, particularly in terms of protein and energy. In addition, it enriches the foundation of food technology and process engineering by presenting a new RSM-based predictive model that can describe the relationship between ingredient proportions and process parameters on nutritional response (protein and energy). This model serves as a theoretical basis for understanding how the interaction between carbohydrate sources (*Kimpul* tubers) and plant-based protein sources *(Anjasmoro* soybeans) can be optimized to produce high-nutritional-value analog foods. Furthermore, this research expands the application of multivariate optimization theory in the field of local food formulation, making it a useful reference for the development of various similar functional food products.

Future research needs to evaluate the biological availability of protein and energy as well as the glycemic index of optimized analog rice, in order to ensure its actual nutritional benefits for the human body. These results are important for establishing the product as a scientifically supported functional food. Organoleptic aspects (color, taste, aroma, texture) still

need to be improved so that analog rice is more acceptable to consumers. Further research could focus on process modifications, the use of natural additives, or physical treatments to improve sensory quality without reducing nutritional value.

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