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ORIGINAL PAPER

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QUALITY IMPROVEMENT OF NOODLES FORTIFIED WITH MORINGA LEAF POWDER, KONJAC GLUCOMANNAN, AND ACETYLATED STARCH

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ABSTRACT

Background. Egg noodles are a commonly consumed food in Asia and are increasingly eaten around the world. Consumers now have more new requirements concerning the quality and healthiness of products. Therefore, the objective of this study is to determine the effects of Moringa leaf powder (MLP), konjac glucomannan (KG), and acetylated starch (AS) on the quality of noodles.

Materials and methods. The Box–Behnken design via the response surface methodology was used, and cooking quality, weight increase, and cooking loss were the main responses. Quadratic polynomial equations were established to determine the influence of 3 independent variables (MLP, KG, and AS) on the cooking quality of the studied noodles.

Results. A significance test and analysis of variance results demonstrated that the MLP, KG, and AS contributed significantly to the increase in rehydration rate and reduction of cooking loss. The joint interaction effects of dependent variables were also significant for cooking quality. Increasing the percentage of MLP and AS resulted in an increase in weight increase and cooking loss, while increasing the percentage of KG resulted in an increase in the rehydration rate and a significant reduction in cooking loss. Based on the fitted model for two responses, simultaneous optimization was also carried out. The optimal values were MLP, KG, and MS at 5%, 4.89%, and 3%, respectively, which gave an estimated maximum value for weight increase (83.61%) and a minimum value for cooking loss (3.05%). A scanning electron micrograph of noodles containing these concentrations showed that the continuity of the gluten network was enhanced.

Conclusion. In this study, the parameters of the input variables were optimized to increase the weight of noodles after cooking and reduce the cooking loss, using the response surface methodology. The accuracy of the model has been verified by actual experimental data. The results obtained may provide new insight into the addition of high bioactive compounds available in plants to the formulation of common food products and the development of new food products for the manufacturing industry.

Keywords: Box–Behnken design, fortification, cooking quality, nutrients, noodles

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INTRODUCTION

Noodles are starchy foods, so they contain a lot of carbohydrates and could raise blood sugar. Noodles are also considered a poor source of protein and their protein has a low quantity of essential amino acids (Borneo and Aguirre, 2008). Therefore, when noodles are commonly used in households, the addition of fiber, minerals, protein, and many valuable healthy ingredients from high-quality plant sources is a matter of concern. Studies to improve the nutritional value of noodles by looking at the nutritional aspects of plant proteins have also been carried out. Petitot et al. (2009) produced nutritionally fortified spaghetti by adding 35% of legumes. Thuy et al. (2020a) reported that orange-fleshed sweet potato was also considered as a potential source for making noodles.

Green noodles are already in the market, mainly with spinach in their formulation. Moringa leaves contain important bioactive compounds and are commonly known for their healing powers, blood sugar lowering, and antidiabetic effects (Farid and Hegazy 2019; Ngo et al., 2022). Moringa leaves contain high levels of fiber, minerals, β-carotene, proteins, and vitamins E, C, and B. In addition, about 17 amino acids have been quantified, including both essential and non-essential. In particular, the amino acids found in higher levels are leucine and lysine (Hodas et al., 2021). However, the addition of fiber may also adversely affect texture properties. Therefore, adding supporting ingredients and improving the noodle structure is a matter of concern. Recently, several types of noodles using high-fiber flour have been shown to give noodles an acceptable texture and organoleptic properties (Heo et al., 2013). Konjac glucomannan (KG) is a water-soluble dietary fiber obtained from the tuber of *Amorphophallus konjac* (Fang and Wu, 2004) and is known as one of the most flexible fibers having good water holding capacity. KG is considered for use as a supplement in fiber-rich pasta recipes. The gluten network also grows continuously and closely when observing the microstructure. Acetylated starch (AS), obtained by esterification of starch with acetic anhydride, is widely used to improve the texture and physical properties of noodles. Starch acetate has low pasting temperature, strong adhesion property, transparency, and good aging stability (Shintani, 2020). In fact, noodles can be considered a functional food if added to a recipe with healthy ingredients. The aim of this study was to evaluate the addition of moringa leaf powder as a green ingredient; together with the effects of konjac glucomannan and acetylated starch to improve the product quality properties of noodles with high acceptance by consumers.

MATERIALS AND METHODS

Materials

Baker's Choice Wheat Flour No. 13 (Vietnam), acetylated starch E1420 (Vietnam), and Konjac glucomannan (Microingredients, USA) were used for this study. Moringa leaves were treated in 1.5% $NaHCO_3$ solution for 30 minutes. They were then drained and dried at 65°C in an oven dryer (SIBATA SD-60, Japan) for about 3 hours to a moisture content of about 5–6% (Thuy et al., 2021). Finely ground dried leaves (100 mesh) contained high protein (29.9%) and bioactive compounds (total flavonoid content of 62.8 mgQE/g, β-carotene of 61.1 mg/100 g and calcium content of 1789.6 mg/100 g).

Noodles preparation

The noodle recipe included wheat flour (200 g), egg (65 g), water (63 g), semolina (40 g), potato starch (50 g), xanthan gum (5.8 g), and salt (0.5 g) (Thuy et al., 2020a). In this study, three factors (MLP, 3–5%; KG, 3–5%; AS, 2–4%) were selected to investigate the cooking qualities of noodles. All ingredients were put through a sieve and then into the noodle making machine (HR2375/05, Germany) and followed the procedure of Thuy et al. (2020a). Noodle quality was analyzed.

Experimental design

A Box-Behnken design according to the response surface method was performed to investigate the effect of parameters [MLP (X_1), KG (X_2), and AS (X_3)] on the cooking quality of the noodles [cooking loss (%) and weight increase (%)]. Each independent variable was coded at three levels (−1, 0, and +1), corresponding to low, medium, and high levels. The variables are arranged as follows: MLP: 3, 4, and 5%; KG: 3, 4, and 5%; AS: 2, 3, and 4%. A total of 18 runs of experiments were conducted, with six replicated at center points (Table 1).

Table 1. Variables and levels used in Box–Behnken design

Variables, %	Levels		
	Low (–1)	Central (0)	High (1)
Moringa leaf powder, X_1	3	4	5
Konjac glucomannan, X_2	3	4	5
Acetylated starch, X_3	2	3	4

The model representing the relationship between the response and the factors was developed using the coefficients from the analysis of variance by STATGRAPHIC Centurion XV software. The full quadratic polynomial model (Equation 1) was chosen as the most suitable model to demonstrate the effect of a factor and the interaction of factors on the responses (Thuy et al., 2022).

$$Y = a_o + a_1X_1 + a_2X_2 + a_3X_3 + a_{11}(X_1)^2 + a_{22}(X_2)^2 + a_{33}(X_3)^2 + a_{12}X_1X_2 + a_{13}X_1X_3 + a_{23}X_2X_3 \quad (1)$$

where

Y is the response;
a_o is the model intercept
a_1, a_2, and a_3 are the linear coefficients
a_{12}, a_{13}, and a_{23} are the interaction coefficients
a_{11}, a_{22}, and a_{33} are the quadratic coefficients.

To obtain the optimal parameters for eating quality of MLP supplemented noodles with KG and AS, an optimization method was applied using the multi-desirability function. The goal of optimized responses was to minimize cooking loss and maximize weight gain.

Proximate analysis of noodles and total calories calculation

Samples were analyzed for their contents of moisture, protein, lipid, carbohydrate, crude fiber, ash (AOAC, 2005), β-carotene (Fikselová et al., 2008), and total phenolic content (Van Tai et al., 2021). The antioxidant activity was determined using the method of Demarchi et al. (2013). Total calories of the product were calculated according to Thompson and Manore (2017).

Cooking quality of noodles

Cooking loss (%) and weight increase (%) were performed to determine the cooking quality. The determination of these parameters followed the description of Thuy et al. (2020a).

Scanning Electron Microscopy (SEM)

SEM dried macaroni was analyzed as described by Thuy et al. (2020a), using a JEOL model J550 scanning electron microscope (Japan)

Sensory evaluation

The members participating in sensory evaluation are students of Food Technology, Can Tho University, Vietnam. A total of 20 participants passed the Food sensory evaluation course. Sensory evaluation was performed using a five-point pleasure scale (1 = very dislike, 2 = dislike, 3 = neither like nor dislike, 4 = like, and 5 = very like) in terms of color, taste, aroma, and texture (Thuy et al., 2020b; Too et al., 2022).

RESULTS AND DISCUSSION

Influence of independent variables on cooking quality

Weight increase

The addition of the right amount of MLP has significantly contributed to improving the water absorption capacity of noodles. Good water absorption is a necessary factor to determine the quality of noodle products. The weight of noodles increased from 82.67% to 83.46% when the amount of MLP used was raised from 3 to 5% (Table 2).

The weight increase of the control sample was 80.58% – lower than that of the sample supplemented with moringa leaf powder. The weight of cooked noodles gradually increased with increasing concentration of MLP (Kumar, 2021). The combination of parsley leaf powder in pasta greatly increases water absorption (Bouasla et al., 2022). Fiber can promote water absorption and retention in the starch-polysaccharide network to swell the starch granules, and the high-fiber mushroom powder in noodles led to an increase in water absorption in cooked noodles (Parvin et al., 2020). KG added to the noodles also showed a similar effect. The weight increase of the cooked noodles was from 82.82 to 83.30% when the percentage of

Table 2. Weight increase and cooking loss of different moringa noodles

Variables	Level	Weight increase, %	Cooking loss, %
MLP, %	3	82.67[a]	2.84[a]
	4	83.27[b]	3.29[b]
	5	83.46[b]	3.45[b]
KG, %	3	82.82[a]	3.51[b]
	4	83.30[b]	3.17[a]
	5	83.24[b]	3.06[a]
AS, %	2	82.93[a]	3.23[a]
	3	83.20[ab]	3.10[a]
	4	83.38[b]	3.52[b]

The means with same superscripts within a column (with different input variables MLP, KG and AS) are not significantly different at $p < 0.05$.

KG used was from 3 to 5% (also indicated in Table 3). Zhou et al. (2013) reported that the addition of KG has contributed to increasing the cooking yield and reducing the cooking loss of noodles. KG is one of the most flexible fibers known because of its extremely high-water holding capacity (Chua et al., 2010). Both KG and gluten compete for water in the dough making and make the dough thicker. Consequently, it can activate the gluten network more and allow for enhanced water absorption.

AS was shown to be a noodle quality improver. The weight increase was calculated to be about 82.93 to 83.38% (also in Table 2) when AS used increased from 2 to 4%. This is probably because the added starch acetate filled the gluten network and enhanced its elongation. When added to this matrix, starch acetate formed certain hydrophilic groups, which improved the hydrophilicity of the dough (Zhang et al., 2022). The effect of three independent variables (MLP, KG, and AS) on the weight increase was determined at the single, interaction, and second order levels determined through a polynomial quadratic equation. The ANOVA table (Table 3) showed 5 effects with P-values < 0.05, showing that they were statistically different at 95.0% confidence. Since the P-value for lack-of-fit in the ANOVA table is 0.39 (>0.05), the model fits the observed data at a level of 95% confidence. The interactions X_1X_2,

Table 3. Analysis of variance for weight increase

Source	Sum of squares	Df	F-ratio	*p*-value
X_1: Moringa powder	3.6895	1	100.46	0.0000
X_2: Konjac Glucomannan	1.0752	1	29.28	0.0000
X_3: Acetylated starch	1.1748	1	31.99	0.0000
X_1X_1	0.4112	1	11.19	0.0018
X_1X_2	0.0169	1	0.46	0.5017
X_1X_3	0.0320	1	0.87	0.3558
X_2X_2	0.8383	1	22.82	0.0000
X_2X_3	0.0010	1	0.03	0.8692
X_3X_3	0.00006	1	0.00	0.9667
Lack-of-fit	0.1112	3	1.01	0.3986
Pure error	1.5058	41		
Total (corr.)	9.0013	53		
R^2 = 82%	R^2 (adjusted for Df = 80%		Standard error of est. = 0.19	

X_1X_3, X_2X_3, and X_3^2 are not significant (p-value > 0.05); therefore, they were removed from the model and the fitted model is presented (Equation 2).

$$\textit{Weight increase}\ (\%) = 73.40 + 1.81X_1 + 2.24X_2 + 0.22X_3 - 0.177X_1^2 - 0.253X_2^2 \quad (2)$$

The optimal values of the variables are obtained by direct search and numerical analysis, based on the desired functional criteria using the Analysis Options dialog box. The optimal concentrations of MLP, KG, and AS were 5%, 4.42%, and 3.99%, respectively, and have been determined to obtain the maximum weight increase at the optimal value of 83.85%.

Cooking loss

The effect of MLP on cooking loss of noodles was noted: cooking loss increased from 2.84% to 3.44% when the combined level of dried moringa leaves increased from 3 to 5% (Table 3); the cooking loss of the control sample was 3.22%. This result is similar to the published results of (Makhlouf et al., 2019). This suggests that the MLP added at lower level (3%) may not cause apparent interruption to the gluten network in the noodles matrix. However, at a higher percentage (4 to 5%), cooking loss of noodle formulation exceeded that of the control, suggesting that increased quantity of solids in the noodles matrix had disrupted the protein–starch network, causing starches to leach out during the cooking, and consequently resulting in a decrease in cooking quality (cooking loss increase). The quantity of solids lost in cooking water is an important indicator of noodle quality (Kamble et al., 2022). Adding non-gluten ingredients to noodle products dilutes gluten intensity and can damage the starch–gluten network responsible for maintaining the physical integrity of pasta during cooking (Rani et al., 2019). Therefore, the addition of fiber interferes with the gluten base, increasing the leaching of starch from the noodles into the water. Similar increases in cooking losses were observed for noodle products made with gluten-free ingredients from moringa leaf powder (Simonato et al., 2021). Kumar (2021) showed that the cooking loss of pasta during cooking increased as the MLP content increased from 5 to 15 g, which was higher than that of the control sample. Therefore, the use of appropriate binders/stabilizers is also essential.

When increasing the additional concentration of KG from 3 to 5%, the dry matter loss decreased from 3.51 to 3.06%. During cooking, the gluten protein network was discontinuous, or the starch-protein complex was weak, allowing large amounts of water-soluble ingredients to be dissolved into hot water. It has since been shown that the enhanced water-binding capacity of the protein-starch substrate, developed with the combination of KG, protects the starch granules undergoing rapid swelling and rupture, due to separation from the gluten network (Zhou et al., 2013). In other words, an intrinsic polymeric interaction in which the hydrated polysaccharide network encloses the starch granules causes the starch granules to stably adhere to the matrix, resulting in a significant reduction in the cooking loss as the addition of konjac powder increases. Noodles with 3% KG were relatively good in terms of texture properties and scored the highest in sensory evaluation (Zhou et al., 2013).

With the addition of AS, the cooking loss rate of noodles was increased and higher than that of the control during boiling (from 3.23 to 3.52%) (as indicated in Table 3). The addition of excess starch acetates weakened the bonds between the gluten networks in the noodles, which could have led to the dissolution of water-soluble substances. Zhang et al. (2022) reported that the loss rate increased when the added amount reached 30%. The cooking quality of noodles is related to the cooking loss rate: the lower the loss ratio, the better the quality (Lin et al., 2019). They suggested 20% starch acetate as the optimal amount of additive to make frozen cooked noodles. As discussed, all variables affect cooking loss, so analysis of variance for cooking loss was performed (Table 4).

In this case, 7 effects have p-values less than 0.05, indicating that they are significantly different at the 95% confidence level. The p-value for lack-of-fit in the ANOVA table is 0.22 (>0.05), this model appears to be adequate for the observed data at the 95% confidence level. From this analysis, the interactions of X_1X_3 and X_2X_3 are not significant (p-value > 0.05), so these interactions are omitted from the equation. Equation 3 of the fitted model is:

$$\textit{Cooking loss}\ (\%) = 2.2 + 2.1X_1 - 0.7X_2 - 1.5X_3 - 0.2X_1^2 - 0.1X_1X_2 + 0.1X_2^2 + 0.3X_3^2 \quad (3)$$

Table 4. Analysis of variance for cooking loss

Source	Sum of squares	Df	F-ratio	*p*-value
X_1: Moringa powder	2.19615	1	105.20	0.0000
X_2: Konjac Glucomannan	1.2195	1	58.42	0.0000
X_3: Acetylated starch	0.525104	1	25.15	0.0000
X_1X_1	0.434683	1	20.82	0.0000
X_1X_2	0.110208	1	5.28	0.0268
X_1X_3	0.0602083	1	2.88	0.0970
X_2X_2	0.149722	1	7.17	0.0106
X_2X_3	0.0341333	1	1.64	0.2082
X_3X_3	1.02836	1	49.26	0.0000
Lack-of-fit	0.095075	3	1.52	0.2241
Pure error	0.855894	41		
Total (corr.)	6.63068	53		
R^2 = 86%	R^2 (adjusted for Df = 83%)		Standard error of est. = 0.144483	

The R^2 statistic indicates that the model as fitted explains 84.24% of cooking loss variable. The optimal concentrations of MLP, KG, and AS were 3.0%, 4.6%, and 2.7%, respectively, and have been determined to obtain the minimized cooking loss at 2.589%.

Multiple response optimization

Weight increase and cooking loss of noodles are often used by both consumers and industry as predictors of overall cooking performance. High cooking yield (weight increase) and low cooking loss are related to the high cooking quality of the noodles. Therefore, multiple-response optimization is more useful when it is necessary to evaluate the impact of multiple variables on responses. Models are properly fit before multi-response optimization. Numerical optimization results show that the desired maximum (0.68) could be obtained using optimal concentrations of ingredients in noodle recipes, such as 5% MLP, 4.89% KG, and 3% AS. At these optimal levels, the predicted values of responses such as weight increase and cooking loss are 83.6% and 3.05%, respectively. Lyubetskaya and Dubtsov (2010) added modified starch at a dose of 5–10% per flour weight among other ingredients to study chemicophysical and organoleptic properties of fast-food pasta. Noodles with 3% KGM were relatively desirable in textural properties and scored best in sensory evaluation, as reported by Zhou et al. (2013). Model validity has also been confirmed through the implementation of the experiments at the optimal level of the independent variables. The validation results gave the experimental values almost good agreement with the response values that were predicted from the selected models (Table 5). In addition, the experimental data of the responses obtained at optimal levels

Table 5. Experimental validation of predicted values of responses obtained at optimal level and comparison with control noodles

Response variables	Optimized noodles (MLP 5%, KG 4.89% and AS 3%)		Control noodles
	Predicted values	Experimental values	
Weight increase, %	83.61	84.10 ±0.5	80.58 ±0.12
Cooking loss, %	3.05	2.90 ±0.1	3.22 ±0.1

Comparison of microstructure and quality of noodles fortified MLP, KG, and AS.

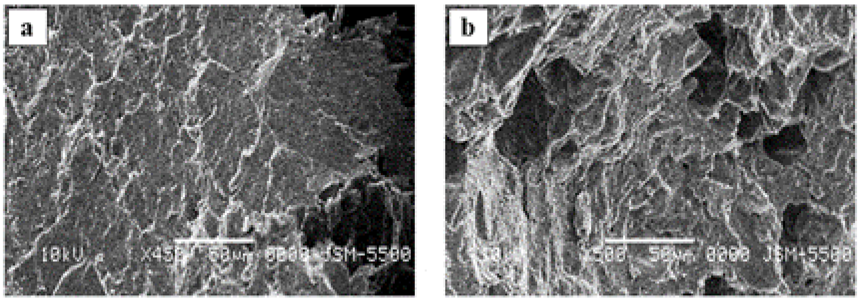

Fig. 1. The SEM images of cooked noodles with a. MLP 5%, KG 4.89%, AS 3% and b. control sample

have shown that the noodles improved cooking quality with additional ingredients.

Microstructure

SEM of cooked noodles reveals micron-scale fibrils that are cross-linked and layer upon layer, forming a continuous sheet-like structure. With MLP, KG, and AS addition at optimal values (Fig. 1a), it showed that the noodle matrix is slightly different from the control sample matrix (Fig. 1b), and that many holes in the network are formed (Fig. 1b), which can act as water reservoirs.

In the case of MLP, KG, and AS addition, it seems to be incorporated in the fibrils, causing them to flatten and elongate. The difference in pore size is distinguishable in this figure, where the average pore size is decreasing with increasing ingredients addition. Figure 1a shows starch granules encased in a highly developed gluten network, compressed by additional components. This suggests that, at the level of MLP, KG, and AS addition, a binding relationship between proteins and these components was established. KG and AS may have particularly influenced the overall structural complexity. With a certain amount of KG and AS filling the porous network of gluten and binding to the discrete starch granules, a stronger stable bond containing starch and protein is achieved. This increased water absorption and reduced cooking loss and the slightly altered texture characteristics. In addition, Figure 1a also showed starch deformation – high concentrations of hydrocolloid may be able to compete for water with other components before starch is gelatinized.

Proximate composition of noodles

Proximate composition of noodles made from the addition of MLP, KG, and AS indicates that it contains good levels of ash (0.65%), protein (7.9%), crude fiber (5.64%), and β-carotene (10.15 mg/100 g) (Table 6). These results are also quite similar to the results of previous studies (Seifu, 2015; Zula et al.,

Table 6. Quality of noodles prepared from optimized conditions and control samples

Parameters, %	Control sample	Optimized sample	Parameters	Control sample	Optimized sample
Moisture	36.5 ±0.15^{b}	35.4 ±0.1^{a}	β-carotene, mg%	not detected	10.15 ±0.05
Protein	7.00 ±0.1^{a}	7.88 ±0.05^{b}	ash, %	0.5 ±0.01^{a}	0.65 ±0.01^{b}
Carbohydrate	50.09 ±0.5^{b}	48.36 ±0.4^{b}	total polyphenol, mgGAE	43.33 ±2.1^{a}	65.45 ±3.4^{b}
Lipid	1.05 ±0.01^{a}	1.15 ±0.01^{b}	DPPH, %	16.20 ±0.25^{a}	22.62 ±0.1^{b}
Fiber	3.41 ±0.03^{a}	5.64 ±0.02^{b}	total calories, kcal	237.8^{a}	235.3^{a}

The means with same superscripts within a row are not significantly different at $p < 0.05$.

2021). The higher β-carotene content in the optimized noodles is probably due to the β-carotene content in the moringa leaf powder. With high protein and β-carotene content, optimized noodles can be used to overcome protein and vitamin A deficiency in children. Optimized noodles are rich in fiber (more than 5%), so there can be various health benefits for people when consuming high fiber products in their diet. In addition, the total phenolic content of the optimized noodles was significantly higher (65.45 ±3.4 mg/100 g GAE) than the control noodles (43.33 ±2.1 mg/100 g GAE); this may be related to the higher phenolic content of MLP used. The significantly higher DPPH inhibitory activity ($P<0.05$) (22.62 ±0.1%), compared to the control noodles (16.20 ±0.1%), could be related to the presence of natural antioxidants within the added ingredients. The moisture and carbohydrate content of the optimal sample was lower than that of the control sample, while the lipid content was slightly higher. The gross energy varies from 235.3 kcal (optimized noodles) to 237.8 kcal (control sample), showing that energy consumption is not high when using this product but has many additional health benefits.

Sensory evaluation

Results from the sensory evaluation studies are summarized in Table 7. The noodles made from MLP, KG, and AS addition obtained the highest score for all the attributes assessed. The score recorded in the current study is almost ≥4.6, indicating that the product is well accepted, especially color and structure. However, no significant differences were noted in the taste and aroma of the two samples. With bright green colors (Fig. 2) and improved structure, this new noodle product has been very well received by consumers.

Table 7. Organoleptic testing of noodles

Sample	Color	Taste	Aroma	Texture
Optimized sample	4.8 ±0.4^b	4.7 ±0.45^a	4.6 ±0.5^a	4.9 ±0.3^b
Control sample	3.5 ±0.5^a	4.6 ±0.49^a	4.3 ±0.46^a	3.75 ±0.54^a

The means with same superscripts within a column are not significantly different at $p < 0.05$.

Fig. 2. Noodle samples: left – control sample; right – optimized sample

CONCLUSION

Optimized processes offer many opportunities for scientific research in food product development. The Box-Behnken design appears to be a valuable tool for optimizing the effects of moringa leaf powder, konjac powder, and acetylated starch on the cooking quality of noodles. All statistically significant terms such as R^2 value, F value, and Lack-of-fit indicated the completeness of the model. All 3 variables had a significant impact on the weight gain of noodles after 3 minutes of boiling. While konjac glucomannan reduced cooking loss, moringa leaf powder and acetylated increased cooking loss. This study proposed a recipe to create delicious noodles when adding 5% MLP with a combination of 4.89% KG and 3% AS. With rich nutritional value, good structure, and high sensory value, these noodles can be added to family meals to overcome children's malnutrition. The obtained results of this study have shown the potential to expand the use of ingredients with exceptionally high nutritional value for the development of high-quality noodles on an industrial scale, while optimizing the development of native delicacies of each country.

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