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Physical properties and glycaemic response of tapioca noodles fortified with herb mixture

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Abstract

High noodle consumption is associated with an increased risk of generative diseases due to noodles' relatively high glycaemic response. Plants containing high phenolic compounds can reduce the glycaemic response of carbohydrate-rich foods. The present work thus aimed to evaluate the physical properties and glycaemic response of tapioca noodles fortified with a mixture of turmeric (T), cinnamon (C), and guava leaves (G) powder. The proportions of herbs (T: C: G) were 0.00: 0.00: 0.00 g (C1); 1.00: 0.50: 1.50 g (C2); 1.33: 0.67: 1.00 g (C3); 1.67: 0.83: 0.50 g (C4); and 2.00: 1.00: 0.00 g (C5). Herb mixtures increased the total phenolic and flavonoid contents of the noodles. Noodles with higher tensile strength (TS) were harder and less swollen because the water absorption capacity (WAC) was lower, but effect of the formulas on the oil absorption capacity (OAC) varied. Area under the curve (AUC) of blood sugar levels showed that C2 noodles had the smallest area (2,321 units) as compared to C1 (3,066 units) and C5 (3,241 units) noodles, but the difference was not statistically significant, thus indicating that the glycaemic responses of these noodles were similar to that of the original noodles when consumed by healthy volunteers.

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Introduction

Noodles are considered the second staple food after rice in some Asian countries, including Indonesia. The popularity of noodles continues to increase in most parts of the world due to their low price, good taste, and convenience. As a result, the noodles industry has consistently grown in recent decades. Research shows a significant increase in noodles sales in low- and middle-income countries caused by factors such as increased incomes, urbanisation, global trade, and government policies (Sievert *et al.*, 2019). Consequently, the demand for wheat flour keeps increasing, and predicted to reach 30,000 tons to fulfil the demand of the noodle industry in 2030 (AEGIC, 2019).

Some studies have shown that high noodle consumption is associated with an increased risk of cardiometabolic diseases in school students and adults in South Korea (Shin *et al.*, 2014; Huh *et al.*, 2017). Regular consumption of instant noodles by Indonesian male and female adults increases the risk factors of chronic diseases indicated by the increase of high-sensitivity c-reactive protein (hs-CRP) (Oddo *et al.*, 2019). Increased consumption of noodles also contributes to increased blood sugar levels of Singaporean adults because of increasing insulin resistance (Zuñiga *et al.*, 2014). Noodles are products

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rich in starch; the increased risk of diseases is thought to be related to the relatively high glycaemic index of noodles (Atkinson *et al.*, 2008; Lok *et al.*, 2010). One of the promising strategies to prevent an increase in disease prevalence is to reduce carbohydrate digestibility (May *et al.*, 2020).

Carbohydrate-rich foods with high digestible carbohydrates proportion will have a high glycaemic index. Some researchers have reduced carbohydrates digestibility or the glycaemic index of noodles by adding waste nuts and cereals, using high amylose flour, or supplementing with banana flour (Ang *et al.*, 2020; Beniwal and Jood, 2015; Tangthanantorn *et al.*, 2022). Another method suggested as a surrogate strategy to reduce the digestibility of carbohydrate in noodles is adding phenolic compounds as noodle ingredient (Yazdankhah *et al.*, 2019; Heredia-Sandoval *et al.*, 2020; Ajayi *et al.*, 2021).

Plants rich in phenolic compounds, such as turmeric and cinnamon, have long been used as spices in some traditional dishes. High phenolic compounds can inhibit the activity of enzymes involved in starch digestion (Nurdin *et al.*, 2017; 2019). The combination of these plants with the addition of guava leaves in the rice cooking process produced rice containing higher phenolic and antioxidant compounds than regular rice (Nurdin *et al.*, 2018b).

Tapioca is a starch extracted from cassava. It is used as raw material for various food products, including noodles (Pato *et al.*, 2016). Indonesia is one of the largest cassava producers globally, along with Nigeria and Thailand (Word Atlas, 2017). Therefore, the use of tapioca for noodles will be beneficial due to its abundance and similar nutritional composition to wheat flour (Abidin *et al.*, 2013). In the present work, combinations of turmeric, cinnamon, and guava leaves were used as ingredients in tapioca noodle production, and their effects on the noodles' physical properties and glycaemic response were elucidated.

Materials and methods

Materials

Cinnamon and turmeric were purchased from a local market in Bandar Lampung, Indonesia. Immediately after purchase, the turmeric rhizomes were thoroughly washed with water, peeled, sliced (0.1 cm), and dried in an oven (Shang Hang 101) at 60°C. The cinnamon was purchased as dried barks. The guava leaves were picked from the 4 - 10th leaf position from the shoot in Sukarame District, Bandar Lampung, Indonesia, then washed with water, and dried in an oven at 60°C. All dried materials were processed using a grinder (Fomac FCT-z300) to produce 80 mesh powders.

Experimental design and data analysis

The present work employed randomised complete design with single treatment in triplicate. Five herb formulations containing turmeric, cinnamon, and guava leaves were added as tapioca noodle ingredients. The weight of the herb mixtures was 3.0 g for each formulation as listed in Table 1 (Nurdin *et al*., 2018a).

One way ANOVA was applied to identify the effects of the treatments, and least significant difference was used for further analysis. The results were considered statistically significant if $p < 0.05$.

Table 1. Weights of turmeric, cinnamon, and guava leaves in 3 g of herb mixtures (Nurdin *et al*., 2018a).

Formula	Weight of herb in herb mixture (g)		
	Turmeric (T)	**Cinnamon (C)**	**Guava leaves (G)**
C1	0	0	0
C2	1	0.5	1.5
C3	1.33	0.67	1
C4	1.67	0.83	0.5
C5	2	1	0

Tapioca noodle preparation

Firstly, 130 mL of water was heated until 80°C, then added with 0.5 g of cooking salt (NaCl) and 3 g of herb mixture. Then, 100 g of tapioca flour was added and mixed while the heating process continued until the starch gelatinised. Off heat, 100 g more tapioca flour (Sagu Tani) was added along with 2% (of tapioca flour) carrageenan (INDOgum), and kneaded until smooth dough was formed. The smooth dough was put through a sheeter (Nagako amp150) to form a sheet, and then the noodle sheet was cut to get the noodle strands.

Total phenolic content

The total phenolic content of the noodles was analysed using the method of Gulçin *et al.* (2019) with slight modification. The powdered noodle (1.0 g) in 5.0 mL of ethanol (Sigma) was vortexed for 1 min, then macerated for 24 h in the dark. After 24 h, 0.20 mL of supernatant was pipetted into a 15-mL centrifuge tube. Then, 0.20 mL of distilled water and

0.20 mL of Folin Ciocalteu reagent (Sigma) were added, and the mixture was vortexed. Sodium carbonate (2.0%) was added to the mixture and homogenised for 1 min. After 30 min incubation at room temperature in the dark, the absorbance of the sample was read at 760 nm (INASA 23 722G Visible Spectrophotometer). The total phenolic content was expressed as ppm of gallic acid equivalent (GAE) using the calibration curve (y = 0.0006x + 0.006) of gallic acid (Sigma) standards (0 - 100 ppm).

Total flavonoid content

The total flavonoid content of the noodles was estimated using the aluminium chloride ($AlCl_3$) colorimetric method with slight modification (Bag and Devi, 2015). Noodle extract was prepared by weighing 1.0 g of powdered noodles, diluting it with 5 mL of ethanol (Sigma), and mixing until homogenised. Next, 0.5 mL of extract was added with 0.10 mL of 10% $AlCl_3$ (Sigma), 0.10 mL of 1 M sodium acetate (Sigma), and 2.80 mL of distilled water, and the mixture was vortexed. After 30 min of incubation, the absorbance was taken at 415 nm (INASA 23 722G Visible Spectrophotometer) against a suitable blank. For total flavonoid determination, quercetin was used to make the standard calibration curve. Stock quercetin solution was prepared by dissolving 10.0 mg of quercetin in 10.0 mL of ethanol, then the standard solutions of quercetin were prepared by serial dilutions using ethanol (5 - 20 µg/mL). The concentration of total flavonoid content in the test samples was calculated from the calibration plot (y = 0.002x + 0.007), and expressed as ppm quercetin equivalent (QE) of dried noodle.

Water absorption capacity

The WAC of the noodles was measured following Sirichokworrakita *et al*. (2015) with slight modification. WAC was measured after cooking (90 - 100°C) 5.0 g of dried noodles (W0) in 50 mL of distilled water for 10 min and draining. Then, the cooked noodles were weighed (WA). The water absorption capacity was calculated using Eq. 1:

$$\text{WAC (\%)} = \frac{(W0 - WA)}{W0} \times 100 \qquad \text{(Eq. 1)}$$

Oil absorption capacity

The OAC of the noodles was determined following Mwangwela *et al.* (2007) with slight modification. Briefly, 0.5 g of powdered noodles (M0) was dispersed in 10 mL of palm oil, vortexed for 3 min, and incubated at room temperature for 18 h. The samples were then centrifuged at 2,000 rpm, and the supernatant was decanted. The residue was weighed (M1), and the OAC was calculated using Eq. 2:

$$\text{OAC (\%)} = \frac{(\text{M1} - \text{M0})}{\text{M0}} \times 100 \qquad \text{(Eq. 2)}$$

Swelling capacity

The SC was determined following Billina (2015). Briefly, 15.0 g of dried noodles were weighed. The diameter of the dried noodles was measured in ten different positions (D0). Then, the noodles were cooked in 300 mL of water (80°C) for 15 min (optimum cooking condition), and drained. The diameter of the cooked noodles in ten different positions (D1) was then determined. The SC was calculated using Eq. 3:

$$\text{SC (\%)} = \frac{(\text{D1} - \text{D0})}{\text{D0}} \times 100 \qquad \text{(Eq. 3)}$$

Tensile strength

The TS test was carried out using a rheometer (Sun Rheometer 100) on cooked noodles. Briefly, 15.0 g of dried noodles was cooked in 300 mL of water (80°C) for 15 min, and then the cooked noodle strand (5.0 cm) was installed in the sample holder. The rheometer was set up as TRAC mode with 19.9 mm/s tensile speed. The TS test was performed in triplicates, and expressed as N.

Degree of hydrolysis with α-amylase

The degree of hydrolysis with α-amylase was performed based on the procedure available in the literature and as follows: 0.05 g of powdered noodles was added with 9.0 mL of distilled water, and heated to 90°C for 30 min in a water bath (H-WBE 8L), then cooled (Muchtadi, 1989). The sample was then added with 3.0 mL of pH 7 phosphate buffer solution (0.1 M) and 1 mL of the α-amylase enzyme (1.0%) in pH 7 phosphate buffer solution (0.05 M), incubated at 37°C for 0 and 60 min, and centrifuged at 3,000 rpm for 15 min. The glucose content of the supernatants was then determined using the DNS method. The degree of hydrolysis of the noodles was expressed as the percentage of increment of the glucose content of the sample after 60 min of incubation with α-amylase enzyme using Eq. 4:

$$\text{Degree of hidrolysis (\%)} = \frac{(G1 - G0)}{G0} \times 100 \quad \text{(Eq. 4)}$$

where, G0 = glucose content of sample after incubation at 0.0 min; G1 = glucose content of sample after incubation at 60.0 min.

Glycaemic response

The GR was the changes in blood glucose level after consuming a quantity of noodles, expressed as the area under the curve (AUC) of the blood glucose concentration of respondents (Nurdin *et al.*, 2018a). The GR was determined through several steps: selecting respondents, explaining the research to respondents, GR testing, and calculating the AUC. Eligible respondents were: 18 - 25 years old of any gender, normal body mass index (18.5 - 22.9 kg/m^2), healthy, no history of diabetes, and neither smoking nor drinking alcohol (ethical approval no: 2021/UN26/8/DL/2019).

Preceding the GR test, the seven respondents were asked to fast overnight (drinking water was allowed) between 10 pm the previous night until 8 am in the morning of the test. The GR test started by measuring respondents' blood glucose levels (min 0), then giving them a portion of noodles (containing 40 g of carbohydrate). More blood glucose tests were carried out at min 30, 60, 90, and 120. A drop of capillary blood samples was taken using a lancet, and the blood glucose concentrations were determined using a blood glucose tester (Accu-Chek Active). The GR tests were done for three types of noodles, namely C1 (tapioca noodles without herb fortification), C2 (tapioca noodles added with 1.0 g turmeric, 0.5 g cinnamon, and 1.5 g guava leaves), and C5 (tapioca noodles added with 2.0 g turmeric and 1.0 g cinnamon). Each noodle was given equivalent to 40 g of carbohydrates after taking into account its water content. During the blood sampling, the respondents were relaxed and not allowed to do any works. The interval between two measurements was 4 d. The blood glucose concentrations were then plotted onto an XY graph, where X was for the time of blood sampling, and Y was for blood glucose concentration. The AUC was then calculated using Eq. 5:

$$AUC = \int_0^{120} f(x)dx \quad \text{(Eq. 5)}$$

Results and discussion

Total phenolic and flavonoid contents

The mixture of turmeric, cinnamon, and guava leaves increased the total phenolic and flavonoid contents of tapioca noodles, but the increase depended on the proportion of the herbs added (Figures 1a and 1b). C2 formula had the highest total phenolic and flavonoid contents, possibly due to the formula's high proportion of guava leaves, giving the greatest contribution to the total phenolic and flavonoid contents. When the proportion of guava leaves in the mixture was decreased, the total phenolic and flavonoid contents of tapioca noodles also decreased. The total phenolic content of guava leaves water extracts reached 285,210 ppm (GAE), while cinnamon and turmeric contained 153,500 and 4967.6 ppm (GAE), respectively (Iamjud *et al.*, 2014; Nisar *et al.*, 2015; Gulçin *et al.*, 2019).

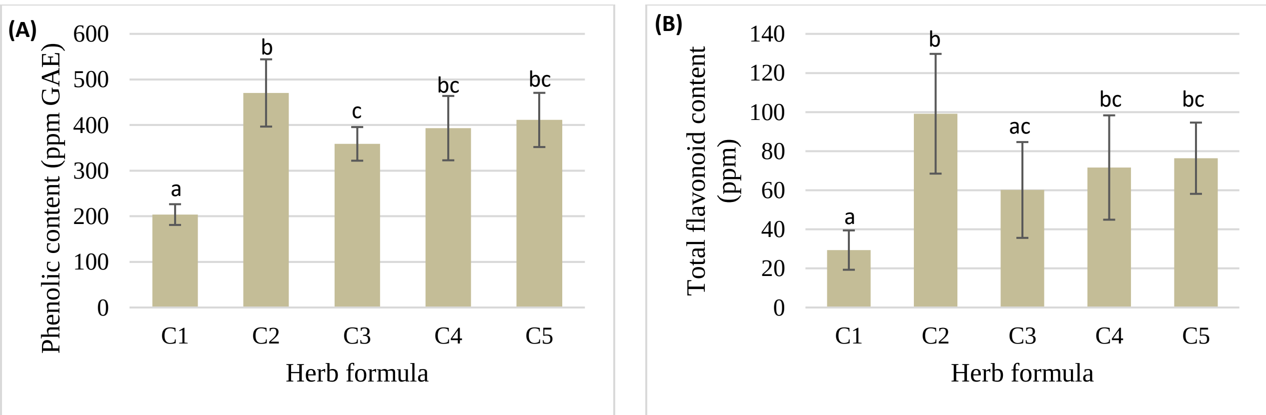


Figure 1. Effect of herb composition on total phenolic and flavonoid contents of tapioca noodles. C1: tapioca noodles without herb mixture; C2: tapioca noodles fortified with 1.00 g T: 0.50 C: 1.50 g G; C3: tapioca noodles fortified with 1.33 g T: 0.67 g C: 1.00 g G; C4: tapioca noodles fortified with 1.67 g T: 0.83 g C: 0.50 g G; C5: tapioca noodles fortified with 2.00 g T: 1.00 g C: 0.00 g G. Bars represent means, and lines represent standard deviation of four replicates (n = 4). Means followed by different lowercase letters are significantly different ($p < 0.05$).

The total phenolic content of guava leaves varies depending on the variety, leaf maturity, and pre-treatment before extraction, as well as the solvent used for the extraction (Nantitanon *et al.*, 2010; Iamjud *et al.*, 2014; Camarena-Tello *et al.*, 2018). For example, green guava leaves contain higher total phenolic content than the brown ones; young leaves have higher total phenolic content than old leaves; and the total extracted phenols are higher when ultrasonically pre-treated (Nantitanon *et al.*, 2010; Iamjud *et al.*, 2014; Amaral *et al.*, 2020). Camarena-Tello *et al*. (2018) found that the total phenolic content of guava leaf extracts depended on the variety and solvent used. Water extracts of the Calvillo Siglo XXI variety contained a higher total phenolic content than Hidrozac, but lower than those of acetone or chloroform solvents.

Of the herbs used in Indian cooking, cinnamon and guava belong to the group containing the highest total phenolic content (Nair *et al.*, 1998). Therefore, in C4 formula, the lower total phenolic content due to the decreased in the proportion of guava leaves was countered by increasing the cinnamon proportion (from 0.67 on C3 to 0.83 on C4); and during processing, the phenolic compound was resistance against processing condition. Cinnamon methanolic extract contained a total phenol of 189.4 ppm (GAE), which was higher than those of garlic and black cumin methanolic extracts of 54.6 and 84.5 ppm (GAE), respectively (Wijewardhana *et al.*, 2019).

Cerio *et al.* (2015) reported that guava leaf extracts contained phenolic components such as catechins, gallic acid, guajaverin, gallocatechin, and quercitrin, with catechins being more abundant than other phenolic components, which was 846.19 mg/100 g (Simao *et al.*, 2017).

Studies on the addition of phenolic compounds from plants to increase total phenolic levels have been carried out in spaghetti, egg noodles, and snacks (Marinelli *et al.*, 2015; Jirukkakul, 2021; Oniszczuk *et al.*, 2021). Spaghetti enriched with grape waste extract contained higher total phenolic and flavonoid contents than the original spaghetti, and the addition did not affect its organoleptic properties (Marinelli *et al.*, 2015). The quality of egg noodles supplemented with 40 - 60% banana pulp was similar to the original one, but the total phenolic content increased by more than 45% (Jirukkakul, 2021). The addition of dragonhead seeds by 12% increased the total phenolic content of the snacks from 239 to 874 ppm, accompanied by an increase in their antioxidant activity (Oniszczuk *et al.*, 2021). In the present work, adding the herb mixture increased the total phenolic and flavonoid contents of tapioca noodles by 76 - 131% and 105 - 237%, respectively.

Physical properties

The physical properties of the tapioca noodles were affected by the proportion of the herbs in the mixture (Table 2). Phenolic compounds significantly modulated the functional properties of starch as indicated by their ability to reduce the hardness of starch gels or increase starch stickiness (Zhu *et al.*, 2008). The interaction of phenolic compounds and starch formed inclusive complexes facilitated by hydrophobic bonds or other complexes with weaker bonds, where the bonds were mainly hydrogen bonds (Zhu, 2015). Their interaction affected the dynamics of viscoelasticity, pasting and thermal properties, retrogradation, and starch digestibility (Chou *et al.*, 2019; Xu *et al.*, 2021). The modulation of the functional properties of starch due to its interactions with phenolic compounds has been observed in potato starch, maize, wheat, and rice starch (Li *et al.*, 2018; Chou *et al.*, 2019; Xu *et al.*, 2021).

Table 2. Effect of herb composition on water holding capacity, oil holding capacity, swelling capacity, and tensile strength of tapioca noodles.

	C1	C2	C3	C4	C5
Water holding capacity (%)	99.41 ± 0.15^{a}	98.87 ± 0.20^{b}	98.56 ± 0.17^{b}	98.95 ± 0.42^{b}	98.89 ± 0.38^{b}
Oil holding capacity (%)	119.90 ± 4.4^{a}	105.90 ± 4.00^{b}	108.10 ± 2.94^{bc}	117.80 ± 5.90^{ac}	115.80 ± 14.02^{ab}
Swelling capacity (%)	14.66 ± 0.74^{a}	13.13 ± 0.76^{b}	14.17 ± 0.59^{a}	13.78 ± 0.48^{ab}	13.20 ± 0.36^{b}
Tensile strength (N)	0.37 ± 0.03^{a}	0.37 ± 0.05^{a}	0.41 ± 0.05^{ac}	0.47 ± 0.07^{bc}	0.45 ± 0.05^{ac}

C1: tapioca noodles without herb mixture; C2: tapioca noodles fortified with 1.00 g T: 0.50 g C: 1.50 g G; C3: tapioca noodles fortified with 1.33 g T: 0.67 g C: 1.00 g G; C4: tapioca noodles fortified with 1.67 g T: 0.83 g C: 0.50 g G; C5: tapioca noodles fortified with 2.00 g T: 1.00 g C: 0.00 g G. Means followed by different lowercase superscripts in a row are significantly different ($p < 0.05$).

The phenolic compounds of the herbs were thought to be linked to tapioca starch forming food matrix, which inhibited water absorption and starch granule expansion (Zhu, 2015). Consequently, the WAC and SC tended to decrease. WAC is the ability of noodles to absorb water during the cooking process, an important factor in noodles' development. A lower WAC value also tends to lower the SC. However, in the present work, the decrease in WAC was not always concomitant with the decrease in SC, presumably because the different types and concentrations of phenolic compounds in the herb mixture modulated the different interactions with starch in the noodles (Zhu *et al.*, 2008). Starch granules that absorb less water lead to harder and less swollen noodles with higher tensile strength (TS). The increase in TS can also be caused by phenolic compounds reacting with starch to form a matrix that strengthens the noodle structure (Xu *et al.*, 2021).

OAC is a noodle's ability to retain oil. This characteristic is related to flavour and mouthfeel sensations (Alarcón-García *et al.*, 2020). OAC depends on the non-polar groups' existence in the noodles. Due to the phenolic compounds of the noodles that depended on the proportion of the herbs added, the effect of different formulas on the OAC varied (Table 2). Besides the fat content in the noodles, the phenolic compounds of the herbs, presumably also contribute to the hydrophobic properties of the noodles significantly (Zhu, 2015).

Degree of hydrolysis with α-amylase enzyme

The degree of starch hydrolysis by the α-amylase enzyme indicates the degree of ease for starch to be hydrolysed into simpler carbohydrates. The more hydrolysable, the easier the starch is to be digested, thus potentially causing a high glycaemic index (Giri *et al.*, 2017). The proportion of herbs in the mixture affected the degree of starch hydrolysis of tapioca noodles by the α-amylase enzyme. This was indicated by the difference in glucose concentration produced after 60 min of incubation with the enzyme (Figure 2).

C2 formula produced noodles that were harder to be hydrolysed than noodles added with the C3, C4, or C5 formula. Moreover, the hydrolysis rate of C2 formula was lower than that of original tapioca noodles (C1) ($p = 0.053$) (Figure 2). This was thought to be due to an increase in the total phenolic content of tapioca noodles, especially the addition of guava leaves. Ahmed *et al*. (2021) showed that guava leaf extract had a strong inhibitory effect on the α-amylase enzyme, mainly due to its anthraquinone and ellagic acid content. *In vivo* research supported the result that guava leaf extract could reduce blood sugar levels in diabetic rats through the inhibition of α-amylase and glucose transport enzymes (Shabbir *et al.*, 2020).

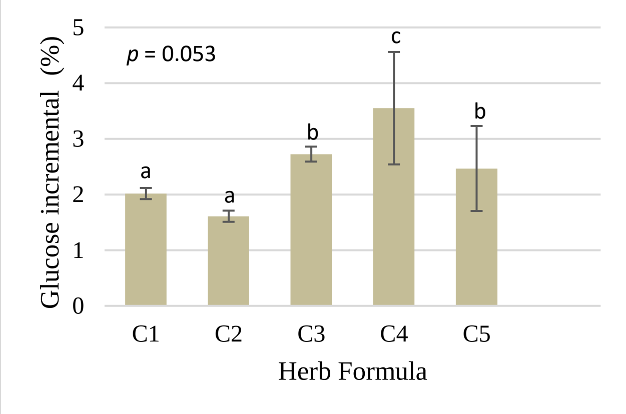


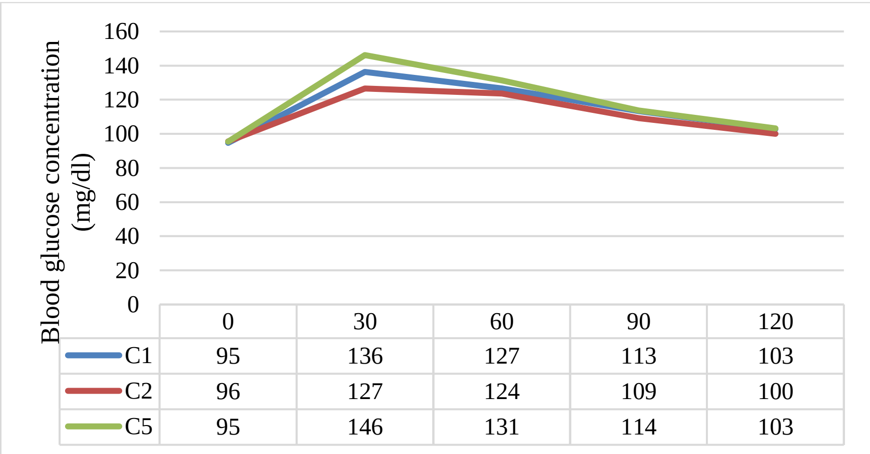
Figure 2. Effect of herb proportion in mixture on hydrolysis rate of tapioca noodles. C1: tapioca noodles without herb mixture; C2: tapioca noodles fortified with 1.00 g T: 0.50 C: 1.50 g G; C3: tapioca noodles fortified with 1.33 g T: 0.67 g C: 1.00 g G; C4: tapioca noodles fortified with 1.67 g T: 0.83 g C: 0.50 g G; C5: tapioca noodles fortified with 2.00 g T: 1.00 g C: 0.00 g G. Bars represent means, and lines represent standard deviation of four replicates ($n = 4$). Means followed by different lowercase letters are significantly different ($p < 0.05$).

The effect of phenolic compounds on the activity of α-amylase enzymes possibly depends on the concentration, types, and composition of the phenolic compounds, as well as the processing methods (Tadera *et al.*, 2006; Sun and Miao, 2019; Wang *et al.*, 2021; Xu *et al.*, 2021; Aleixandre *et al.*, 2022). Phenolic compounds can interact directly with the α-amylase enzyme, and inhibit its activity or interact with starch affecting amylose structure and amorphous regions of starch granules, thus producing resistant starch (Li *et al.*, 2018; Sun and Miao, 2019; Wang *et al.*, 2021). The addition of phenolic compounds causes hydrophobic interaction driving formation of starch-phenolic acid complexes; therefore, the crystalline structure of starch was reduced due to a decrease in water content and reorganising skeletal α-1,4 glucosidic linkages of amylopectin granules (Li *et al.*, 2018). Even though previous studies have shown the inhibitory activity of some phenolic compounds against the α-amylase enzyme, the inhibition level also depends on the herbs' processing method (Wang *et al.*, 2021).

Glycaemic response

The GR was measured as an increase in blood sugar levels of respondents who consumed a certain quantity of tapioca noodles at min 0, 30, 60, 90, and 120. Changes in blood sugar levels were then plotted against the time of measurement, and AUC was measured based on the plotted graph. The GR test was carried out on C1 as a control, C2 as the one containing the highest total phenolic and flavonoid contents with three types of herbs, and C5 as the one containing two types of herbs widely used in the traditional yellow rice (*nasi kuning*).

The pattern of changes in respondents' blood sugar levels after consuming tapioca noodles depends on the type of noodles consumed (Figure 3). The respondents' peak blood sugar levels were reached after 30 min for all types of tapioca noodles at 136 mg/dL (C1), 127 mg/dL (C2), and 146 mg/dL (C3). The calculation of the average AUC showed that the C2 tapioca noodles had the smallest area (2,321 units) as compared to C1 (3,066 units) and C5 (3,241 units) (Figure 4), but the difference was not statistically significant. The standard deviation of each AUC of tapioca noodles was high, thus indicating high AUC variations between respondents (Figure 5). Therefore, although the mean of AUC of C2 formula was hugely different from C1 and C5 formula (745 and 920 units, respectively), the difference was not statistically significant.



	0	30	60	90	120
C1	95	136	127	113	103
C2	96	127	124	109	100
C5	95	146	131	114	103

Figure 3. Effect of herb composition on blood glucose levels of respondents after consuming tapioca noodles fortified with herb mixture. C1: tapioca noodles without herb mixture; C2: tapioca noodles fortified with 1.00 g T: 0.50 g C: 1.50 g G; C5: tapioca noodles fortified with 2.00 g T: 1.00 g C: 0.00 g G.

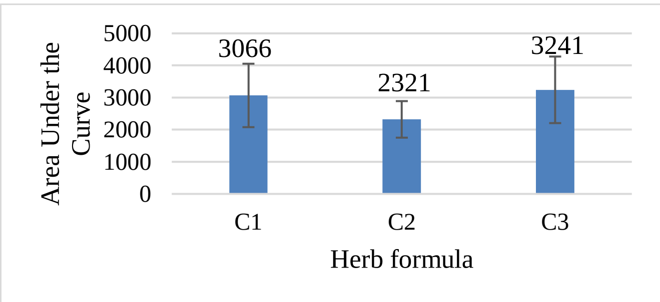


Figure 4. Effect of herb combination on area under curve for tapioca noodles fortified with herb mixture. C1: tapioca noodles without herb mixture; C2: tapioca noodles fortified with 1.00 g T: 0.50 C: 1.50 g G; C3: tapioca noodles fortified with 1.33 g T: 0.67 g C: 1.00 g G. Bars represent means, and lines represent standard deviation of four replicates ($n = 4$). Means followed by different lowercase letters are significantly different ($p < 0.05$).

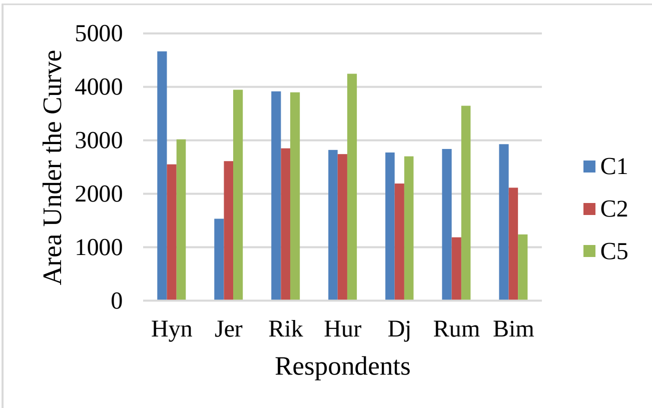


Figure 5. Area under curve of each respondent's glycaemic response after consuming tapioca noodles fortified with herb mixture. C1: tapioca noodles without herb mixture; C2: tapioca noodles fortified with 1.00 g T: 0.50 g C: 1.50 g G; C5: tapioca noodles fortified with 2.00 g T: 1.00 g C: 0.00 g G.

The increase in blood sugar level in response to consuming a type of food is individual (Vrolix and Mensink, 2010). The same type of food in the same amount, if consumed by different subjects, will result in different blood sugar level increments. Hirsch *et al.* (2013) reported that the consumption of white bread by ten healthy subjects resulted in individual AUCs with an average variation of 51.8%. Some factors were considered to be affecting the diversity of GR of the subjects, while other factors such as insulin index and glycated haemoglobin levels were not made into the criteria to select the subjects (Matthan *et al.*, 2016).

C2 formula contained a high proportion of guava leaves, thus resulting in high total phenolic and flavonoid contents (Figure 1). Some phenolic compounds from plants have been shown to be able to reduce GR through the inhibition of α-amylase and glucosidase enzymes. Inhibiting glucose absorption affects SGLT-1, stimulates insulin sensitivity and secretion, reduces sugar production from the liver, and controls appetite (Kim *et al.*, 2016; Li *et al.*, 2018; Sun and Miao, 2019; Xu *et al.*, 2021). Previous research revealed that phenolic compounds extracted from guava leaves significantly reduced blood sugar levels in diabetic rats through the inhibition of α-amylase enzyme and glucose transport (Musa *et al.*, 2012; Sun and Miao, 2019; Shabbir *et al.*, 2020; Sęczyk *et al.*, 2021). Guava leaves are rich in catechins that can inhibit the α-glucosidase enzyme (IC_{50} > 290 g/mL) better than acarbose (IC_{50} > 645 g/mL) (Musa *et al.*, 2012). The effect of phenolic compounds on GR is not only through the inhibition of starch digestive enzymes and glucose metabolism, but also through their interaction with starch, which converts the starch to resistant starch (Sun and Miao, 2019; Sęczyk *et al.*, 2021).

Conclusion

Herb mixture increased the total phenolic and flavonoid contents of tapioca noodles, but the increase depended on the proportion of herbs added. Starch granules that absorbed less water led to harder and less swollen noodles with higher tensile strength (TS). Due to the phenolic compounds of the noodles that depended on the proportion of the herbs added, the effect of different formulas on the OAC varied. C2 formula produced noodles that were harder to be hydrolysed than those added with the C3, C4, or C5 formula. Moreover, the hydrolysis rate by the α-amylase enzyme of C2 formula tended to be lower than that of the original one. The respondents' peak blood sugar levels were reached after 30 min of consumption for all types of tapioca noodles at 136 mg/dL (C1), 127 mg/dL (C2), and 146 mg/dL (C3). The AUC results showed that C2 formula had the smallest area (2,321 units) compared to C1 (3,066 units) and C5 (3,241 units) formula. However, the difference was not statistically significant, thus indicating that the glycaemic response of tapioca noodles fortified with herb mixture was similar to original tapioca noodles when consumed by healthy volunteers. Even though the glycaemic response of the herb-fortified noodles was similar with the original noodles, consuming the fortified noodles could be more beneficial due to their higher total phenolic and flavonoid contents.

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