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# QUALITY EVALUATION OF WAFFLES PRODUCED FROM THE PARTIAL REPLACEMENT OF WHEAT FLOUR WITH GREEN BANANA FLOUR AND POTATO STARCH

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## ABSTRACT

**Background.** Low GI and alkaline food products have been the attention of research aimed at supporting the health of consumers.
**Materials and methods.** This study aims to develop a waffle formula for a low energy, alkaline food with a high nutritional value and low glycemic index (GI) from the partial replacement of wheat flour with green banana flour and potato starch ranging from 2.5 to 12.5% (of the total weight of flour used) in the formulas. To assess this, the quality of the product was analyzed.
**Results.** The research results show that low GI, alkaline waffles with a high nutritional value can successfully be prepared with green banana flour and potato starch substitutes, at 12.5 and 7.5% of the formula respectively (w/w) (formula F5). The nutritional value of the product for one waffle (110 g) is 305.6 kcal, 40.9 g carbohydrates, 9.2 g protein, 11.7g fat and 1.43 g fiber, with an estimated GI of 62.54 ±0.46 (lower than a waffle made entirely of wheat flour, which had a GI of 76.38 ±0.90). The macronutrient energy distribution (carbohydrate:protein:lipid of 53.6:12.1:34.3) meets the recommendations of the AMDR.
**Conclusion.** The F5 product has proper nutritional characteristics, low GI, and an estimated negative PRAL (–0.67), indicating that the waffles tend to cause more alkalinity in the body when consumed. Further studies should be considered to develop and improve the production of waffles with better nutrients and biological functional properties.

**Keywords:** waffle, quality, nutritional characteristics, banana flour, potato starch

## INTRODUCTION

Waffles have gradually become a common dish amongst Vietnamese people in recent years. However, carbohydrate-rich foods often have a high glycemic index (GI) and are not recommended for people with diabetes (Choi et al., 2009). White wheat flour is also a major ingredient in waffle making, so waffles are known to be a high GI product. For example, the GI database shows that waffles prepared with refined wheat flour have a mean GI of 76 (high GI as classification) (Chandra, 2020). Substituting it with other flours can reduce the glycemic index of waffles, making them useful for the prevention and management of type II diabetes and other associated diseases. Since the introduction of other flours into waffle production,

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the keto-waffle has begun to gain attention in a number of countries.

Keto-waffles are a delicious low-carb breakfast. They can be made with other flours with a high content of resistant starch (RS), which has been associated with a low glycemic response after consumption (Jyoshna and Hymavathi, 2017). Adding RS as an ingredient in foods will lower the overall glycemic index value because it replaces other readily absorbed forms of carbohydrate (Nugent, 2005). RS can be found naturally in food products like green bananas, legumes, and potatoes (Thuy et al., 2022), so the incorporation of high RS from green banana flour and potato starch increases the RS content of waffles. However, this substitution can affect the texture of the waffles. So, we need to balance the amount of supplemented flour to achieve high RS waffles with desirable physical properties.

In addition, people following a keto diet are instructed to focus on eating lots of alkaline foods and fewer acidic foods. A food with a positive potential renal acid load (PRAL) is considered acid-producing, while a negative PRAL is suggestive of food that is more basic (Scialla and Anderson, 2013). In general, fruits and vegetables promote systemic alkalinity (Caciano, 2015). Based on PRAL Food lists, the PRAL scores of banana and potato are –6.9 and –4.0, respectively (Klopfer-Nährmittel, 2004). Consuming more alkaline foods can improve the overall nutrient density of a diet and reduce the risk of common lifestyle diseases. Thus, green bananas and potatoes have a high content of RS and are alkaline food sources, so they are a good source of raw materials for forming part of the keto-waffle formula. Processing keto-waffles can be considered a necessary issue, not only to meet the needs of waffles in the daily life of consumers in a developed society but also to reduce the energy and GI of the product. The aim of this research was to develop healthy and nutritious waffles by partial replacement of wheat flour with green banana flour and potato starch in the recipe. The proper formula was selected through an assessment of the physico-chemical properties and nutritional characteristics of the product.

## MATERIALS AND METHODS

### Materials

Wheat flour (Interflour Vietnam Company); potato starch (Aunt Michelle, Netherlands); Eggs, sugar, and milk (Vietnam); Tuong An margarine and TH true milk (Vietnam); Lecithin (AmiLife® Standard Soya Lecithin Non-GMO Liquid, India); Sorbitol (Braumarkt, Netherlands); Cream of Tartar (McCormick, USA); Glycerin (Vegetable Glycerin, Food Grade, USP Grade, USA); rapeseed oil (Simply, Vietnam).

Preparation of banana powder: Bunches of bananas (*Musa* spp.) were collected from Ca Mau province, Vietnam, when the fruits were still green but had reached maturity as indicated in the banana color chart (Thuy et al., 2021). The fruits were washed in running water, then they were peeled and soaked in a 500 ppm sodium metabisulfite ($Na_2S_2O_5$) solution for 30 minutes to prevent oxidation of the polyphenols in the bananas. The sliced bananas (≈2 mm thickness) were dried at 60°C for 7 h (moisture content of 12%). The dried samples were ground into a powder and sieved through US standard mesh No. 70 (212 μm). The sieved powder was placed in a sealed airtight container and stored at 28 ±2°C for further use (Tai et al., 2021).

### Formulation of the waffle

The six main waffle recipes are listed in Table 1. The total mass of each formula is 554.71 g.

The ingredients used and their amounts were standardized during pretrials (results not shown here). The

**Table 1.** Ingredients of six different waffle formulas, g

| Ingredients | F0 | F1 | F2 | F3 | F4 | F5 | F6 |
|---|---|---|---|---|---|---|---|
| Wheat flour | 155 | 139.50 | 139.50 | 131.75 | 131.75 | 124 | 124 |
| Green banana flour | 0 | 3.88 | 11.63 | 15.50 | 7.75 | 19.38 | 11.63 |
| Potato starch | 0 | 11.63 | 3.88 | 7.75 | 15.50 | 11.63 | 19.38 |

recipe F0 acted as the control sample (using all wheat flour), while the remaining 6 formulas replaced a part of the wheat flour with green banana flour and potato starch in different proportions. In the formulas, other ingredients were used in fixed amounts: fresh milk: 170 g, egg: 60 g, sugar: 50 g, margarine: 71.2 g, baking powder: 10 g, glycerin: 11.2 g, sorbitol: 22.25 g, lecithin: 3.56 g and cream of tartar: 1.5 g.

### Preparation of the waffle batter

Preparation of the batter was performed using a Klarstein Bella Food Processor-Kneading and Mixing Machine (Germany) with 6 speed levels following the usual mixing sequence steps for waffles: *Step 1*: Egg yolks and egg whites were separated; *Step 2*: Egg whites were put into the machine, cream of tartar was added and it was mixed at level 2 and 3 until it was almost stiff, at which point the mixing was stopped; *Step 3*: The calculated contents of egg yolk, sugar, glycerin, and sorbitol were added, then the mixture was stirred at level 1 for 2 minutes; *Step 4*: All the remaining ingredients were added, including wheat flour, green banana flour, potato starch, baking powder, unsweetened fresh milk, butter, and lecithin according to the recipes arranged by the designed experiment. The mixture continued to be stirred until well combined using level 4 for 3–4 minutes; *Step 5*: The dough was left to rest for about 10 minutes. During this time, the waffle maker was preheated (Belgium). When the machine was hot enough, the butter was put in the cake pan; *Step 6*: The flour mixture was put into the cake pan. The baking temperature was set at level 3 for 2 to 4 minutes.

### Analysis of physico-chemical characteristics

The moisture, protein, and ash content were analyzed by AOAC (2005). The lipid content was analyzed by AOAC (1997). The carbohydrate content of the sample was computed by AOAC (1980). The crude fiber content of the sample was analyzed using the standard procedure of AOAC (1990). Resistant starch (RS) was analyzed using the standard procedure of AOAC (2002). The hardness of each waffle was measured using Rheotex. Each waffle was cut into 4 × 4 × 1 (cm) pieces and placed on the texture analyzer platform. The waffle pieces were compressed with a cylindrical probe using 50% strain. Then the g force was read from the instrument. The color of the samples was measured on the Hunter scale for *L*, *a*, and *b* using a Minolta chroma meter (CR-400 Minolta, Japan) with at least five measurements being carried out on each sample. The baking loss (%) gave information on the moisture loss during baking and was calculated for all the waffles according to the following formula (Eq. 1):

$$\text{Baking loss (\%)} = [1 - (\text{weight of waffle in g}) / \text{weight of batter in g})] \times 100 \quad (1)$$

### Estimation of PRAL

The PRAL of the foods was calculated to evaluate their acidifying or alkalizing potential and is represented by the following equation (Eq. 2):

$$\text{PRAL} = \text{P} \times 0.0366 + \text{Pro} \times 0.4888 - (\text{K} \times 0.0205 + \text{Ca} \times 0.0125 + \text{Mg} \times 0.0263) \quad (2)$$

where the units for PRAL are mEq/day, and P is phosphorous in mg/day, Pro is protein in g/day, K is potassium in mg/day, Ca is calcium in mg/day, and Mg is magnesium in mg/day (Remer and Manz, 1995).

### Estimated glycemic index

The glycemic index was estimated as described by Englyst et al. (1992) and calculated using the equation of Goni et al. (1997).

### Data analysis

Data analyses were carried out using STATGRAPHICS Centurion XV (USA). Values were expressed as mean ± SD.

## RESULTS AND DISCUSSION

### The RS content of the waffles produced with different formulas

### RS content in green banana flour and potato starch when used as a partial replacement for wheat flour in waffle formulas

The analysis results showed that the content of RS in potato starch was higher (65.38 g/100 g) than in green banana flour (62.20 g/100 g). The obtained values are quite similar to the results of previous studies. Tribess et al. (2009) and Vatanasuchart et al. (2012) stated that the RS content in banana powder was in the range of

40.9–58.5 g/100 g and 52.2–68.1 g/100 g, respectively. However, the RS content of potato starch analyzed in this study was lower than the RS content in Chen's study (2010), with the value of 79.3 g/100 g. Thuy et al. (2022) stated that the RS content in green banana and potato starch were 48.29 ±0.66 g/100 g and 56.43 ±0.78 g, respectively. The difference in RS content between the study results may be due to the harvest time, soil conditions of the region, and the locality where these materials were grown.

## RS content of batter before baking and waffle after baking, respectively from different formulas

Today, foods containing resistant starch are widely consumed. However, heat processing can affect the natural content of resistant starch in foods. The results presented in Table 2 showed that the batters in recipes F5 and F6 have the highest content of RS (4.21 and 4.26 g/100 g). In contrast, batters made from recipes F1 and F2 had the lowest content (2.55 and 2.51 g/100 g). It was observed that partial replacement of wheat flour with banana flour and potato starch increased the content of RS in the product and showed a significant difference compared with the control formula F0 (undetectable).

The RS loss of waffles from the recipes was shown to be quite low (about 20%) after baking. Arp et al. (2021) estimated the RS loss of the different starches before and after baking, finding that the RS3 (retrograded RS) was the most heat stable (49.5% loss), followed by the RS treated with acid and moist heat (58.8% loss), and incubation (90.5% loss). Waffles made using the F5 and F6 recipes maintained the highest RS content after baking; 3.37 and 3.41 g/100 g, respectively. There was no significant difference in RS content between these two recipes.

## The physical characteristics and baking loss of waffles produced with different formulas

The hardness, color, and baking loss of waffles with different formulas are shown in Table 3.

## The hardness of the waffles

The measurement results showed that the hardness of the waffles increased when the percentage of the partial replacement of wheat flour with banana flour and potato starch was increased, and was significantly different from the control formula F0 (100% wheat flour). The highest value was 152.33 g force in the sample processed from formula F5, and the lowest value was 77.33 g force in the control sample (F0). The hardness started to increase gradually from the F1 sample (96 g force) when replacing a total of 10% flour. The results obtained are similar to the study of Arp et al. (2021), who reported that RS2 and RS3 lead to stiffer dough. In the case of this study, banana flour and potato starch with a high RS content were used. In addition, the hardness of the waffles may be due to the added fibers diluting the gluten and distorting the gluten-starch network that is formed (Hung et al., 2007).

**Table 2.** The RS content of batter before baking and waffles after baking

| Formulas | Green banana flour:potato starch:wheat flour, % | RS content of batter, g/100 g | RS content of waffle, g/100 g |
|---|---|---|---|
| F0 | 0:0:100 | 0*[a] | 0*[a] |
| F1 | 2.5:7.5:90 | 2.55[b] | 2.05[b] |
| F2 | 7.5:2.5:90 | 2.51[b] | 2.01[b] |
| F3 | 10:5:85 | 3.36[c] | 2.69[c] |
| F4 | 5:10:85 | 3.41[d] | 2.73[c] |
| F5 | 12.5:7.5:80 | 4.21[e] | 3.37[d] |
| F6 | 7.5:12.5:80 | 4.26[e] | 3.41[d] |

Mean values with different superscripts in the same column differ significantly at $p \leq 0.05$.
*Not detected because the content is too low (concentration is considered as zero).

**Table 3.** The hardness, color, and baking loss of waffles with different formulas

| Formulas | Banana flour:potato starch:wheat flour, % | Hardness g force | Color of waffle | | | Baking loss % |
|---|---|---|---|---|---|---|
| | | | $L^*$ | $a^*$ | $b^*$ | |
| F0 | 0:0:100 | $77.33^a$ | $55.58^a$ | $10.71^f$ | $28.21^a$ | $16.38^e$ |
| F1 | 2.5:7.5:90 | $96.0^b$ | $65.96^b$ | $7.38^e$ | $30.51^b$ | $15.84^d$ |
| F2 | 7.5:2.5:90 | $102.67^c$ | $66.96^b$ | $4.96^c$ | $33.04^d$ | $16.01^{de}$ |
| F3 | 10:5: 85 | $130.0^e$ | $70.58^c$ | $2.71^b$ | $34.96^e$ | $15.15^c$ |
| F4 | 5:10:85 | $121.33^d$ | $69.95^c$ | $6.14^d$ | $31.83^c$ | $15.75^d$ |
| F5 | 12.5:7.5:80 | $152.33^g$ | $75.67^d$ | $-3.92^a$ | $36.71^f$ | $11.98^a$ |
| F6 | 7.5:12.5:80 | $148.68^f$ | $74.83^d$ | $4.93^c$ | $33.29^d$ | $12.88^b$ |

Mean values with different superscripts in the same column differ significantly at $p \leq 0.05$.

On the other hand, swelling power had an inverse relationship with RS content. Foods that are high in RS have low swelling power as well as low water absorption capacity. This is why waffles made from the F5 and F6 formulas exhibited higher hardness. The RS of starchy food also had a strong correlation with amylose content (Thuy et al., 2022).

## The color of the waffles

The analysis results presented in Table 3 also show that the waffles prepared using formulas F5 and F6 had a higher $L^*$ value than that of formula F0, with 75.67, 74.83, and 55.58, respectively. The brightness of the waffles also clearly increased with these two alternative recipes. Arp et al. (2021) reported in their results that, in all cases, increased use of RS whitened cookies, possibly due to a reduction in the Maillard reaction. Kaewmak et al. (2020) had the same results: an increase in RS IV increased the $L^*$ value. The addition of potato starch resulted in highly stable waffles and more uniform color distribution compared to waffles produced with wheat flour alone (Huber et al., 2017). The $a^*$ value of recipe F5 (–3.92) is smaller than that of the control formula F0 (10.71), so the waffles in recipe F5 were greener than in the control sample. The $b^*$ value of the waffles increased slightly in the alternative recipes. Differences in color properties can be caused by protein content and type of protein (Shevkani et al., 2015), which has been shown in muffins.

## Baking loss

The baking loss of the waffles was significantly different between the control formula F0 and the alternative formulas with different ratios. The highest losses occurred in formulas F0 to F2 (15.81–16.38%) and the lowest were recorded in formulas F5 and F6 (11.98–12.88%). During baking, several complex reactions occur, and the loss during baking is mainly due to moisture loss (Choi and Chung, 2010). In addition, as reported previously by Rosell et al. (2001), the high water holding capacity of fiber-rich flours is mainly due to the higher number of hydroxyl groups found in the fibrous structure, which tends to allow more interactions with water via hydrogen bonding. In this case, banana flour contained an important amount of fiber, with up to 15% of the content in some varieties (da Mota et al., 2000). This is also a common phenomenon when replacing gluten with fiber. This process is understood as being the result of prolonged gluten hydration and starch gelatinization (Yeom et al., 2017).

## Estimation of the PRAL of the waffles from blend recipes

Based on the nutritional composition of the ingredients used in the recipes, the PRAL of the waffles was calculated. The results showed that the PRAL values of banana flour and potato starch are –29.07 and –12.73 (Table 4), respectively, which are quite alkaline materials (PRAL < 0). Therefore, using partial replacement

**Table 4.** Nutritional composition and estimated PRAL of ingredients used in waffle making

| Ingredients | Nutritional compositions (per 100 g of edible portion) | | | | | | PRAL** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pro g | P mg | K mg | Ca mg | Mg mg | PRAL* | F0 | F1 | F2 | F3 | F4 | F5 | F6 |
| Wheat flour | 8 | 323 | 394 | 33 | 117 | 4.17 | 6.46 | 5.81 | 5.81 | 5.49 | 5.49 | 5.17 | 5.17 |
| Green banana | 3.9 | 74 | 1491 | 22 | 108 | –29.07 | 0.00 | –1.13 | –3.38 | –4.51 | –2.25 | –5.63 | –3.38 |
| Potato starch | 7 | 168 | 1 000 | 7 | 65 | –12.73 | 0.00 | –1.48 | –0.49 | –0.99 | –1.97 | –1.48 | –2.47 |
| Fresh milk | 3 | 84 | 132 | 104 | 10 | 0.27 | 0.46 | 0.46 | 0.46 | 0.46 | 0.46 | 0.46 | 0.46 |
| Sucrose | 0 | 72 | 346 | 178 | 29 | –7.45 | –4.47 | –4.47 | –4.47 | –4.47 | –4.47 | –4.47 | –4.47 |
| Egg | 12.6 | 198 | 138 | 56 | 12 | 9.56 | 4.78 | 4.78 | 4.78 | 4.78 | 4.78 | 4.78 | 4.78 |
| Butter | 0.31 | 10 | 22 | 10 | 1 | –0.08 | –0.06 | –0.06 | –0.06 | –0.06 | –0.06 | –0.06 | –0.06 |
| Baking powder | 0 | 2 191 | 20 | 5 875 | 27 | 5.63 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 |
| Total: | | | | | | | 7.73 | 4.48 | 3.22 | 1.27 | 2.54 | –0.67 | 0.60 |

All nutritional data of used ingredients retrieved from https://nutritiondata.self.com.
*Data was calculated based on the ingredients' nutritional profile.
**Data was calculated using the following equation: [$PRAL_{ingredient}$ (per 100 g) × amount of raw material (g)]/100; Pro: protein.

of flour with banana flour and potato starch in different formulas gave an estimated PRAL value of –0.67 (PRAL < 0), *e.g.*, in formula F5 (banana flour: potato starch: wheat flour of 12.5 : 7.5 : 70).

It can be concluded that the waffle made using the F5 formula is alkaline, compared with the control formula F0, which has an estimated PRAL score of 7.73 (PRAL > 0), which is acidic. With their alkaline properties, banana flour and potato starch (Scialla and Anderson, 2013) have been shown to improve the properties of waffles when replacing these two ingredients in the recipe, potentially supporting a well-supported human diet with health benefits such as the reduced risk of pancreatic cancer (Shi et al., 2021). Thus, from this study, replacing acid-forming foods (F0) with alkaline foods (F5) can support and improve human health.

## Nutritional composition, estimated glycemic index and energy balance of the waffles

The results presented in Table 5 showed that the moisture content of formula F5 (37.2 ±0.05%) is a little higher than that of the control formula F0 (36.9 ±0.1%). It was observed that both F5 and F0 formulas did not produce a noticeable change in the ash content (about 0.4% and 0.5%), protein (8.4% and 8.6%), or lipid content (10.6% and 10.4%). However, the carbohydrate content of the waffles made using the F5 formula was 37.16%, which was lower than that of the control recipe F0 (39.1%). This is probably because banana flour and potato starch contained lower carbohydrate content than wheat flour (Cui et al., 2013; Parinya et al., 2018). The RS content in the waffles also improved in the F5 formula. Due to the lower carbohydrate and higher RS, the lower estimated glycemic index was found in sample F5. Recent studies have successfully reduced the glycemic index in food by supplementing sources rich in RS (Thuy et al., 2022; Vuong et al., 2022; Thuy and Tai, 2022; Too et al., 2022). The increase in fiber in the product developed as expected in the F5 formula (1.3 ±0.03%), while F0 only had 0.75 ±0.02%, presumably due to bananas being a source of fiber (Rodríguez-Ambriz et al., 2008).

**Table 5.** Nutritional composition of the waffle formula F0 (control sample) and F5 (banana flour:potato starch:wheat flour is 12.5:7.5:70)

| Nutritional composition | Waffle (formula F0) | Waffle (formula F5) | Nutritional composition, % | Waffle (formula F0) | Waffle (formula F5) |
|---|---|---|---|---|---|
| Moisture content, % | 36.9 ±0.1 | 37.2 ±0.05 | protein | 8.6 ±0.08 | 8.4 ±0.13 |
| Carbohydrate, % | 39.1 ±0.15 | 37.2 ±0.1 | lipid | 10.4 ±0.16 | 10.6 ±0.11 |
| RS, % | 0* | 3.5 ±0.08 | fiber | 0.75 ±0.02 | 1.3 ±0.03 |
| eGI | 76.38 ±0.90 | 62.54 ±0.46 | ash | 0.4 ±0.05 | 0.5 ±0.04 |

Mean ±STD; eGI – estimated Glycemic index.

The results presented in Table 6 show that the percentage of energy provided from nutrients in the F5 waffle formula (protein content 8.4%, carbohydrate 37.2%, and lipid 10.6%, with the total energy being 277.8 kcal/100 g) is lower than the control sample (284.4 kcal), which is suitable for creating a healthy product with a low calorie content. The macronutrient content in the F5 formula was within a suitable range for AMDR (protein:lipid:carbohydrate of 12.1:34.3:53.6%). The waffles in the F5 formula have a weight of 110 g for each. When consumed, the energy produced is estimated to be 305.6 kcal. If the average energy requirement for an adult is 2,200 kcal/day, then one waffle (Fig. 1) can provide about 14% of the energy, so it is advisable to add extra food to meet the energy requirements of the meal per day.

**Table 6.** Energy distribution from macronutrients per 100 g of waffles (F5 formula)

| Macronutrients | Content g | Energy kcal | Energy distribution % |
|---|---|---|---|
| Protein | 8.4 | 33.6 | 12.1 |
| Carbohydrate | 37.2 | 148.8 | 53.6 |
| Lipid | 10.6 | 95.4 | 34.3 |
| Total | | 277.8 | 100 |

Total calories of the control recipe (100% flour) is 284.4 kcal. Energy calculated according to Thompson and Manore (2017).

**Fig. 1.** Waffles are partially replaced with banana flour and potato starch

## CONCLUSION

According to the obtained results, it is possible to replace wheat flour with banana flour and potato starch in the production of waffles in the ratio of 12.5% and 7.5%, respectively, without affecting the quality and sensory properties of the waffles. With the selected formula, the waffles clearly have improved GI values, as well as better nutritional and functional properties. A negative PRAL score indicated that waffles are classified as an alkaline food when digested in the body, which is beneficial in reducing the risk of pancreatic cancer, metabolic disorders, and other health conditions.

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