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Original Research Article

Nutritional and Physical Changes of Crispy Waffles Due to the Replacement of Wheat Flour with Coconut Flour

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ABSTRACT

Coconut flour, a by-product produced in abundance from the coconut milk and oil industry, is rich in vitamins, minerals, dietary fiber, and protein and also has a unique taste and aroma. As such, it can be incorporated in various types of baked goods to improve their nutritional values. This study focused on the nutritional and physical changes that occur in crispy waffles when wheat flour was substituted with coconut flour at 50%, 60%, 70% and 80% by weight of wheat flour. The formulation with 100% wheat flour was used as a control. Comparing the waffles with 80% coconut flour versus the control, protein, fat, ash, and crude fiber content increased from 9.64% to 12.44%, 12.87% to 25.64%, 1.42% to 2.44%, and 1.08% to 5.45% (dry basis), respectively. In addition, moisture and carbohydrate content of crispy waffles decreased. Increasing coconut flour content significantly increased the thickness but reduced the width and spread ratio of crispy waffles ($p \leq 0.05$). This led to greater hardness when replacing wheat flour with coconut flour ($p \leq 0.05$). Lightness (L*), redness (a*), yellowness (b*), total color difference (ΔE), and browning index of crispy waffles significantly increased with the increase of coconut flour ($p \leq 0.05$). Substituting wheat flour with coconut flour higher than 50% could improve nutrition values of crispy waffles including protein, fat, and dietary fiber content but influences their hardness, color, diameters, thickness, and spread ratio. The further study on sensory evaluation is necessary in order to select the suitable formulation.

INTRODUCTION

Coconut (*Cocos nucifera* L.) is rich in a wide variety of nutrients and also high in economic value. Main three components of coconut are exocarp (husk), endosperm (coconut meat), and endocarp (shell). Coconut meat has been used for coconut oil and coconut milk production and as a food ingredient (Panghal et al., 2019). The high demand of coconut milk and coconut-related products in world markets was reported in 2017 (KasikornResearch Center, 2017). In 2018, Thailand exported all types of coconut products worth 1.4 billion baht which 90% of export value was coconut milk (posttoday, 2018). Coconut flour can be produced from fresh coconut and by-products of both coconut milk and coconut oil industry using a simple and inexpensive process (Dat and Phoung, 2017; FutureMarketInsight, 2022). To produce coconut flour, coconut residues generated during the wet process of coconut milk extraction or dry process for coconut oil extraction

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are dried in a tray or vacuum drier and ground to be powder (Makinde et al., 2019; Adeloye et al., 2020). Coconut flour, powder with a pure white color and a unique flavor and aroma, is also rich in dietary fiber (60.9%), protein (12.1%), fat (10.9%), and ash (3.1%) (Trinidad et al., 2001; Hossain et al., 2016). Dietary fiber isolated from coconut flour is fermentable and causes the production of short chain fatty acids including butyrate, acetate, and propionate which are beneficial for health (Trinidad et al., 2001).

Presently, the use of alternative flour is becoming more popular and there will be an upward trend in the functional food market (Teodoro, 2017). Coconut flour is an alternative flour that is widely used in healthy food products (Choudhury, 2022), especially as a high dietary fiber ingredient (Panghal et al., 2019). Various types of snacks such as cookies or biscuits were fortified with coconut flour in order to increase dietary fiber and protein in products (Panghal et al., 2019). However, the addition of coconut flour in bakery products affects not only their nutritional values but also physical characteristics. For instance, coconut cookies had higher fiber content but lower spread ratio and hardness, compared to cookies made of wheat flour (Dhankhar, 2013). Replacements of wheat flour with 10%, 20% and 30% coconut flour in cake formulations increased the protein, minerals, fat and crude fiber content, and improved the flavor, color, texture, volume, specific volume and weight of cake (Hossain et al., 2016). Substitution of wheat flour with coconut flour at 10, 20, 30, 40, and 50% significantly decreased the width, thickness, weight, hardness, and brittleness of biscuit; however, its dietary fiber content, roughness, coconut odor and flavor, crumbliness, crispiness, and being hard to swallow significantly increased (Jiamjariyatam et al., 2021).

Waffle, a popular dessert and baked product, is a battercake or dough which is cooked between two plates that causes it a deep grid pattern. Crispy waffles have similar physical characteristics to waffle cones without forming into a cone (Cordy, 2017; Amprocontent, 2021). Interestingly, waffle cone and crispy waffle products have increased in the food market from 2014-2020 (Mintel, 2021). Wheat flour is a main ingredient of crispy waffles, after combining with other ingredients, this product is normally high in calories and low in fiber. Regarding the potential of coconut flour as a functional flour with high nutritional values, coconut flour was used to substitute wheat flour in crispy waffles in this work. The aim of this study was to investigate the effect of wheat flour substitution with coconut flour at 50%, 60%, 70% and 80% by weight on nutritional composition and physical properties of crispy waffles.

MATERIALS AND METHODS

Materials

Coconut flour was supplied by Ampol Food Processing Co., Ltd., which is a by-product from the process of coconut milk extraction. Wheat flour, egg, sugar, salt, milk, vanilla flavor and butter were purchased from a local market. All chemicals and solvents were AR grade and purchased from Elago Enterprises Pty Ltd., RCI Labscan Co., Ltd. and Sigma-Aldrich (Thailand) Co., Ltd.

Preparation of crispy waffle

The formulation of crispy waffle is shown in Table 1. The crispy waffle was prepared according to method of Dailydelicious (2019) as follows. Wet ingredients were prepared by mixing melted butter, milk and egg in a bowl, then sugar was added and mixed for 1 minute by hand mixer. Dry ingredients including wheat flour and salt were mixed with wet ingredients and then vanilla flavor was added and mixed by hand mixer. The batter was kept at 4°C for 22 hours and 8.5 g of batter was put into a cone waffle maker and heated for 4 minutes. Crispy waffles were kept in a sealed plastic bag and stored at room temperature for further analysis.

The formulation with 100% wheat flour (0% coconut flour) was used as a control crispy waffle. Substitution with coconut flour at 50%, 60%, 70% and 80% of wheat flour was conducted for 3 replications of each level to investigate the effect of coconut flour on the quality of crispy waffles. Chemical composition, texture, color, and physical parameter analysis were further performed.

Table 1. Formulation of crispy waffle

Ingredients	% Substitution with coconut flour				
	0	50	60	70	80
Milk (%)	39	39	39	39	39
Salted butter (%)	9.4	9.4	9.4	9.4	9.4
Salt (%)	0.3	0.3	0.3	0.3	0.3
Vanilla flavor (%)	0.2	0.2	0.2	0.2	0.2
Sugar (%)	18	18	18	18	18
Wheat flour (%)	23.5	11.75	9.4	7.05	4.7
Coconut flour (%)	0	11.75	14.1	16.45	18.8
Egg (%)	9.4	9.4	9.4	9.4	9.4

Chemical composition of crispy waffle

The chemical compositions of crispy waffles, including moisture, protein, fat, ash, and crude fiber were determined using standard procedures (AOAC, 2012). Carbohydrate content was determined by difference.

Spread ratio, diameter and thickness

Spread ratio, diameter and thickness was determined according to method described by Naseer et al. (2021). Diameter and thickness of crispy waffle were determined using a vernier caliper. Crispy waffles (3 pieces) obtained from a replication of each formulation and 2 different positions of each piece were selected for diameter and thickness measurement. All data from triplicate experiments (9 pieces of crispy waffle) were analyzed. Spread ratio was calculated using the following equation (1) given below.

$$\text{Spread ratio} = \frac{\text{Diameter (mm)}}{\text{Thickness (mm)}} \quad (1)$$

Color measurement

Surface color of crispy waffle was determined according to the method modified from Wang et al. (2012) and Su et al. (2017). Color was measured using color spectrophotometer (HunterLab, Ultrascan Pro, Hunter Associates Laboratory, Inc., Virginia, USA) with RSEX-MAV mode and 0.35-inch probe. The colorimeter was calibrated using white tile and light trap. The color value was recorded as L*, a* and b*. Five pieces of crispy waffle obtained from a replication of each formulation and 6 different positions of each piece were selected for color measurement. All data from triplicate experiments (15 pieces of crispy waffle) were analyzed. The total color difference (ΔE) and browning index were calculated from L*, a* and b* using the following equation (2) and (3) given below.

$$\Delta E = \sqrt{(L^*-L_0^*)^2 - (a^*-a_0^*)^2 - (b^*-b_0^*)^2} \qquad (2)$$

where L_0^*, a_0^* *and* b_0^* are L*, a* and b* values of control crispy waffle, respectively.

$$\text{Browning index} = \frac{100(x-0.31)}{0.17} \qquad (3)$$

where $$x = \frac{a^*+1.75L^*}{5.645L^*+a^*-0.3012b^*}$$

Textural measurement

The texture characteristic of crispy waffles was measured using a texture analyzer (TA.XT Plus, Stable Macro Systems, Surrey, UK). Hardness was determined according to the method modified from Janve et al. (2015) and Zou et al. (2013). Hardness measurement was performed using a ball probe (P/0.25s) and a support with a crisp fracture rig (HDP/CFS) in compression mode with 5-kg load cell. The probe was passed through a sample at pre-test, test speed, post-test of 1, 1 and 5 mm/s, respectively and trigger force was 5 g. The peak positive force (N) value was recorded as hardness. At least 6 pieces of crispy waffle obtained from a replication of each formulation were selected for texture measurement. All data from triplicate experiments (18 pieces of crispy waffle) were analyzed.

Statistical analysis

The data were analyzed and calculated using IBM SPSS Statistics version 28.0 (Thaisoftup Co., Ltd., Thailand). All analyses were recorded in triplicate. Data were reported as mean ± standard deviation. One-way Analysis of Variance (ANOVA) was used, then multiple comparison was analyzed by Duncan's new multiple range test.

RESULTS AND DISCUSSION

Chemical composition of crispy waffles

The chemical composition of crispy waffle produced from wheat flour and mixture of wheat flour and coconut flour is shown in Table 2. Crispy waffle with 100% of wheat flour contained the highest moisture and carbohydrate content. Moisture content of crispy waffle was in the range of 4.18% to 5.00% which decreased with increasing the amount of coconut flour. The change of carbohydrate content also has a similar trend which reduced from 69.95% to 49.85% (dry basis). These were in agreement with the study of Adebowale and Komolafe (2018) who reported that moisture and carbohydrate content of kokoro snack decreased from 8.77% to 7.87% and 65.52% to 48.68%, respectively when maize flour was replaced with 50% coconut flour.

On the other hand, fat, protein and ash content of crispy waffles increased, ranging from 12.87% to 25.64%, 9.64% to 12.44% and 1.44% to 2.44% (dry basis), respectively (Table 2). Similar trends were obtained by Adebowale and Komolafe (2018). Fat, protein and ash content of kokoro snack also increased from 12.63% to 20.27%, 8.23% to 15.23% and 2.13% to 4.43%, respectively by substituting maize flour with 50% coconut flour. Despite an increase in fat content, major fatty acid in coconut flour may provide some health benefits. Lauric acid (C12:0), a medium-chain fatty acids (MCFA), is the main saturated fatty acid found in coconut meat and oil (Ngampeerapong and Chavasit, 2019; Wallace, 2019). After digestion, MCFAs are generally absorbed into the portal vein, metabolized by the liver to generate energy for immediate use by the brain, organs, and/or muscles and not being deposited as fat in the body (Wallace, 2019). Also, lauric acid can increase blood HDL-cholesterol and reduce the ratio of TC/HDL-cholesterol (Mensink, 2016). These health benefits of MCFAs and lauric acid can be an advantage of fat in crispy waffles substituted with coconut flour.

Furthermore, crude fiber content in crispy waffles increased from 1.08% to 5.45% since crude fiber content of coconut flour (16.61%) was higher than that of wheat flour (1.08%) (data was not shown). Gunathilake and Abeyrathne (2008) also reported that coconut flour contains higher crude fiber content (10.45%) than wheat flour (0.50%). Additionally, an increase in total dietary fiber content of biscuit from 5% to 27% was found when wheat flour was substituted with 50% coconut flour (Jiamjariyatam et al., 2021).

Spread ratio, diameter and thickness

Spread ratio, diameter and thickness of crispy waffles produced from wheat flour and mixture of wheat flour and coconut flour were illustrated in Table 3. Partial substitution with coconut flour in crispy waffles at 50%, 60%, 70% and 80% affected their spread ratio, diameter and thickness. Thickness of crispy waffles increased significantly ($p \leq 0.05$) from 2.11 to 3.56 mm by substituting more coconut flour. However, comparing between control crispy waffle and formulation with 80% coconut flour, diameter and spread ratio of crispy waffles reduced significantly ($p \leq 0.05$) from 90.20 to 63.82 mm and from 42.89 to 17.94, respectively. The changes of diameter, thickness, and spread ratio of crispy waffles were caused by the higher batter viscosity which is related to the higher swelling capacity, water-holding capacity, and oil-holding capacity of coconut flour compared to wheat flour. Lower spread ratio of coconut cookies was also found in the study of Dhankhar (2013).

Color measurement

The effect of substituting coconut flour on the color of crispy waffles is indicated in Table 4. L*, a* and b* values increased dramatically with increasing coconut flour in crispy waffles. Lightness (L*), redness (a*) and yellowness (b*) increased from 66.55 to 74.42, 1.99 to 8.36 and 23.55 to 32.80, respectively. The increases in the lightness (L*), redness (a*) and yellowness (b*) of several food products such as pasta (Sykut - Domańska et al., 2020) and white rolls (Wirkijowska et al., 2022) were also reported when wheat flour was replaced with coconut flour. The total color difference (ΔE), calculated from L*, a*, and b*, illustrated overall impact on the color change in crispy waffles. The total color difference of crispy waffles significantly increased with the increase in amount of coconut flour ($p \leq 0.05$). The browning reaction was performed during the baking process caused by caramelization and Maillard reaction (Purlis, 2010). Abdul and Iqbal (2011) reported that coconut meat contains glucose and fructose (reducing sugar), sucrose (non-reducing sugar) and protein. Protein and reducing sugar in coconuts can cause the Maillard reaction (Martins et al., 2000). Therefore, browning index of control crispy waffle was significantly different from other formulations ($p \leq 0.05$) due to the Maillard reaction caused by the reaction between reducing sugar and protein in coconut flour. Meanwhile, the browning index of crispy waffles was not significantly different when substituting wheat flour with coconut flour at 50%, 60%, 70% and 80%.

Table 2. Chemical composition of crispy waffle substituted wheat flour with coconut flour

Chemical composition (%)	% Substitution with coconut flour				
	0	50	60	70	80
Moisture	5.00 ± 0.05^{a}	4.57 ± 0.07^{b}	4.40 ± 0.03^{c}	4.22 ± 0.02^{d}	4.18 ± 0.02^{d}
Fat	12.87 ± 0.83^{d}	23.57 ± 0.44^{c}	24.70 ± 0.24^{b}	25.03 ± 0.05^{ab}	25.64 ± 0.11^{a}
Protein	9.64 ± 0.03^{e}	11.89 ± 0.03^{d}	12.00 ± 0.04^{c}	12.29 ± 0.03^{b}	12.44 ± 0.06^{a}
Ash	1.42 ± 0.02^{e}	2.04 ± 0.05^{d}	2.18 ± 0.01^{c}	2.29 ± 0.03^{b}	2.44 ± 0.03^{a}
Crude fiber	1.08 ± 0.11^{e}	3.54 ± 0.02^{d}	3.74 ± 0.03^{c}	4.77 ± 0.08^{b}	5.45 ± 0.06^{a}
Carbohydrate	69.95 ± 0.90^{a}	54.39 ± 0.45^{b}	52.98 ± 0.21^{c}	51.40 ± 0.06^{d}	49.85 ± 0.15^{e}

$^{a\text{-}e}$ Mean values in the same row with different letters are significantly different ($p \leq 0.05$).

Table 3. Diameter, thickness and spread ratio of crispy waffle substituted wheat flour with coconut flour

% Substitution with coconut flour	Diameter (mm)	Thickness (mm)	Spread ratio
0	90.20 ± 1.33^{a}	2.11 ± 0.07^{e}	42.89 ± 1.79^{a}
50	77.70 ± 0.41^{b}	2.48 ± 0.03^{d}	31.40 ± 0.38^{b}
60	76.07 ± 0.40^{c}	2.96 ± 0.04^{c}	25.74 ± 0.38^{c}
70	68.74 ± 0.48^{d}	3.21 ± 0.04^{b}	21.43 ± 0.39^{d}
80	63.82 ± 0.34^{e}	3.56 ± 0.04^{a}	17.94 ± 0.25^{e}

$^{a\text{-}e}$ Mean values in the same column with different letters are significantly different ($p \leq 0.05$).

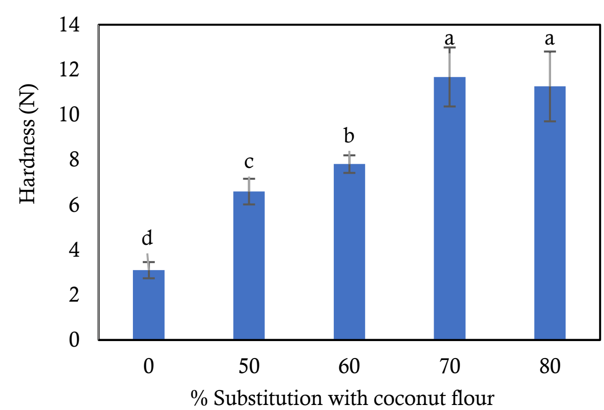

Figure 1. Hardness of crispy waffle substituted wheat flour with coconut flour. Each bar and its error bar represent mean value and standard deviation, respectively. Bars with different letter are significantly different ($p \leq 0.05$).

Textural measurement

Texture is one of the important parameters to evaluate the quality of crispy waffles. Hardness of crispy waffles produced from wheat flour and mixture of wheat flour and coconut flour was presented in Figure 1. Hardness increased significantly ($p \leq 0.05$) when more coconut flour was added in the formulation. The hardness of crispy waffles with 70% coconut flour was not significantly different from the ones with 80% coconut flour. The characteristic of batter was changed from viscous liquid to dough when the % substitution of coconut flour was higher than 60%. This might be due to the higher swelling capacity, water-holding capacity, and oil-holding capacity of coconut flour (5.17 ml/g, 0.22 g/g, and 0.09 g/g, respectively) compared to wheat flour (1.33 ml/g, 0.06 g/g, and 0.07 g/g, respectively) (data was not shown). Higher viscosity of batter resulted in higher thickness of crispy waffles (Table 3), causing an increase in hardness of crispy waffle when wheat flour was substituted with coconut flour.

Conclusions

This study has shown that substituting wheat flour with coconut flour in crispy waffles improves nutritional values in terms of higher crude fiber, protein, fat, and ash content but lower carbohydrate content. Nevertheless, physical properties of crispy waffles such as hardness, lightness (L*), redness (a*), yellowness (b*), browning index and thickness increased significantly ($p \leq 0.05$) while spread ratio and diameters decreased significantly ($p \leq 0.05$) due to the higher proportion of coconut flour in crispy waffles. Further study on sensory evaluation is necessary to select the appropriate formulation.

Table 4. Color of crispy waffle substituted wheat flour with coconut flour

% Substitution with coconut flour	L*	a*	b*	ΔE	Browning index
0	66.55 ± 3.62[e]	1.99 ± 0.78[d]	23.55 ± 1.87[e]	0[e]	5.69 ± 1.13[c]
50	68.35 ± 3.46[d]	7.36 ± 1.25[c]	30.60 ± 1.41[cd]	9.04 ±0.77[d]	12.21 ± 1.79[ab]
60	70.31 ± 3.50[c]	7.85 ± 1.47[b]	31.08 ± 2.30[bc]	10.41± 0.60[c]	12.43 ± 1.96[a]
70	71.60 ± 3.49[b]	8.35 ± 1.58[a]	31.39 ± 1.81[b]	11.29± 0.28[b]	12.74 ± 2.05[a]
80	74.42 ± 3.17[a]	8.36 ± 0.96[a]	32.80 ± 1.58[a]	13.41± 0.82[a]	12.45 ± 1.38[a]

[a-e] Mean values in the same column with different letters are significantly different ($p \leq 0.05$).

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