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Effect of turmeric starch, lecithin, and canola oil supplements on waffles quality

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Abstract

This study aimed to produce waffles with increased quality by adding turmeric starch (1–2%), lecithin (0.6–1%), and canola oil (7.5–12.5%) to the recipe. The physicochemical characteristics and sensory values of the product were analyzed together with radical scavenging activity (DPPH% testing). Multiple regression was used to analyze the relationship between curcumin in waffles/firmness and three independent variables (turmeric starch, lecithin, and canola oil), with the goal of using the independent variables to predict the dependent variables. Response surface methodology was used to optimize the content of the dependent variables to obtain the highest curcumin content and the best firmness. Being formulated with the optimal values of turmeric starch (2%), lecithin (0.86%), and canola oil (11.2%), waffles contain the optimal curcumin content (5.84 mg/100 g) and a good texture (not too hard or too soft at 209.7 g force). An amount of 100 g of waffles contain 6.90 g of protein, 36.64 g of carbohydrates, 16.78 g of lipids, 3.8 g of resistant starch, 1.32 g of fiber, and 0.6 g of ash. Analysis results of total polyphenolic content and 2,2-diphenyl-1-picryl-hydrazyl (DPPH) inhibition were also found, with 37.81 mg GAE/100 g and 27.25% DPPH inhibition, respectively. The product was also highly appreciated for its sensory properties.

Keywords: waffles; quality; turmeric starch; lecithin; canola oil.

Practical Application: Canola oil, lecithin, and turmeric starch could improve the nutritional (high in antioxidant content and activity) as well as sensorial properties of the product in the desired direction. Adding the ingredients at appropriate content could be applied at different technological scales, helping the food industry to provide new foods with nutritional value to meet the diverse food consumption of consumers.

1. Introduction

Waffles are made from flour, sugar, fat, and eggs. Regular waffles have a high sugar content, and butter is used. Carbohydrate-rich foods mostly have a high glycemic index and are not recommended for patients with diabetes (Choi et al., 2009; Ngo et al., 2022). A keto-waffles recipe that partially replaces wheat flour with banana flour and potato starch has been studied (Giau et al., 2023) to increase the content of resistant starch in the waffles recipe and reduce the GI (62.54). Waffles can be popular and a favorite, so adding healthy ingredients to the products is our concern. The use of natural antioxidants is also a general trend in food processing (López-Pedrouso et al., 2022). With the light-yellow background available from the waffles, the addition of turmeric starch is a way to improve the color and increase both the medicinal and functional values of the waffles. Turmeric starch is the quintessential part of fresh turmeric; after removing fiber, oil, and impurities, only starch and curcumin remain. The antioxidant and antimicrobial effects of turmeric are related to the presence of phenolic derivatives known as curcuminoids, namely curcumin, dimethoxycurcumin, and bis-dimethoxycurcumin (Dall'Acqua et al., 2016). Curcumin is a hydrophobic polyphenolic compound, known as the golden nutrient, with antioxidant, antibacterial, anticancer, and hepatoprotective properties (Yang et al., 2020). It is a naturally occurring yellow-orange polyphenol with many beneficial properties. This compound is an effective antioxidant and has many beneficial health effects, such as neuroprotective, antitumor, anti-HIV, and cardioprotective properties, improves dysregulation, reduces depression, and ameliorates oxidative stress and inflammation (Panahi et al., 2015). An evaluation of the quality and antioxidant properties of yellow-layered cake containing Korean turmeric was studied by Lim et al. (2010). Especially, with the COVID-19 pandemic situation, some studies have shown that some potential effects of curcumin, such as inhibition of the virus entry into cells and inhibition of encapsulation and protease of virus, can suppress pulmonary edema and fibrosis-related pathways in COVID-19 infection, have antiviral, anti-infective, anti-inflammatory, antipyretic and anti-fatigue effects, and effectively treat symptoms of patients infected with COVID-19 (Babaei et al., 2020; Zahedipour et al., 2020).

In commercial baking, lecithin is a group of naturally occurring phospholipids widely used because of its surfactant properties. This is an emulsifier, which can help other ingredients

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mix more easily and maintain their mixing state. In addition, due to its surfactant and emulsifying properties, the reaction forms a lipoprotein complex, so lecithin can help strengthen the protein structure of dough; gluten becomes more elastic, finer, and improves air holding capacity. Furthermore, lecithin inhibits starch degradation, so the shelf life of cakes can be extended (Guo et al., 2023). Besides, dietary fat is a nutrient the body needs to absorb important vitamins A, D, E, and K, as well as antioxidants. The fats and oils used in the waffle recipe can make their texture softer. In traditional waffle recipes, butter is used; however, they are high in saturated fat, which can negatively affect heart health when eaten in large amounts, so it should be considered to limit their use in the diet. Among the vegetable oils, canola oil is characterized by low levels of saturated fatty acids (only 7%), high levels of monounsaturated fatty acids, and polyunsaturated fatty acids, including 61% oleic acid, 21% linoleic acid, and 11% alpha-linolenic acid (Johnson et al., 2007). Canola oil also contains plant sterols (0.53–0.97%) and tocopherols (700–1,200 ppm) (Gunstone, 2011). Gillingham et al. (2011) also reported the positive effects of monounsaturated fatty acids compared with saturated fatty acids on cardiovascular health. At present, there is no literature on the optimization of turmeric starch, lecithin, and canola oil in the waffle baking process and the nutritional profile analysis as stated. The aim of this study was to explore the effects of dough supplementation, consisting of turmeric, lecithin, and canola oil (replacing butter), to highlight antioxidant activity, nutritional properties, functional characteristics, and overall quality of waffles with consumer acceptance and appreciation.

2. Materials and methods

2.1. Ingredients

The following ingredients were used: wheat flour (Interflour Vietnam Company); green banana flour, which was prepared following the procedure suggested by Tai et al. (2021); potato starch (Aunt Michelle, The Netherlands); turmeric starch (Honimore, Vietnam); eggs, sugar, margarine, and sterilized milk (Vietnam); lecithin (AmiLife® Standard Soya Lecithin Non-GMO Liquid, India); sorbitol (Braumarkt, The Netherlands); cream of tartar (McCormick, USA); glycerin (Vegetable Glycerin, Food Grade, USP Grade, USA); and canola oil (Simply, Vietnam).

2.2. Formulation of the waffle

The waffle recipe was prepared according to the method suggested by Giau et al. (2023). In this study, the content of turmeric starch was added from 1 to 2%, lecithin was used between 0.6 and 1%, and canola oil was used between 7.5 and 12.5% (of the total fat used in the recipe is 14.5% which is equivalent to 71 g/batch and the rest is margarine). All the ingredients are calculated according to the total mass of a production batch (550.95 g). In the recipe, other ingredients are used in fixed amounts: wheat flour 124 g, green banana flour 19.375 g, potato starch 11.625 g, fresh milk 170 g, eggs 60 g, sugar 50 g, baking powder 10 g, glycerin 11.2 g, sorbitol 22.25 g, and cream of tartar 1.5 g.

2.3. Waffles making

The dough preparation was performed according to Giau et al. (2023), with some minor modifications. Klarstein Bella (Germany) food processor and mixer with six speed levels were used. The waffle maker (Cuisinart 4-Slice Waffle Maker, Belgium) was used.

2.4. Proximate compositions analysis

The proximate values of waffles for moisture, protein, lipid, fiber, and ash content were determined according to the AOAC method (AOAC, 2005). The carbohydrate content (%) of waffles was calculated by subtracting the crude protein, fat, ash, and moisture contents (%) from 100. Resistant starch (RS) was analyzed using the standard procedure of AOAC (2002).

2.5. Curcumin content determination

The concentration of curcumin was determined according to the method suggested by Hazra et al. (2015) using a spectrophotometer (YOKE UV1200 UV-VIS, China). Standard curves showing a linear response of peak area versus curcumin concentration (UV detection at 421 nm). The regression correlation (r^2) of the standard curves was at least 0.99. The concentration of curcumin was calculated based on its peak area in comparison to the external standard solutions (in the range of 0–0.1 mg/mL) of the same component. The curcumin content of the finished product was selected from the formulations analyzed by HPLC method from the Analytical and Test Centers.

2.6. Total phenolic content determination

Total phenolics were determined using the Folin–Ciocalteau method. Gallic acid was used as a standard, and results were expressed as milligram gallic acid equivalent/100 g (mg GAE/100 g) (Teixeira et al., 2013).

2.7. DPPH activity

The antioxidant activity of the product was measured based on the scavenging activity of the stable 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical according to the method described by Brand-Williams et al. (1995).

2.8. Texture analysis

The hardness of each waffle was measured using the TA.XT-plusC-Texture Analyzer (Stable Micro System, England). Waffle samples (4×4×1 cm) taken from the midsection were used for measurement. A 35-mm diameter aluminm cylinder probe was used to measure the required compression force. The optimal test conditions were 5 kg.f force capacity, 40–60% deformation, and a 0.01–40 mm/s speed range. The hardness of waffles was recorded. The samples were placed in an airtight plastic bag to avoid moisture loss and be used for further analysis.

2.9. Sensory evaluation

Check-all-that-apply (CATA) was applied for sensory evaluation and analysis. A total of 20 panelists were trained and participated in this assessment (Nguyen et al., 2020). The panelists are undergraduate and master's students with an average age of 20–25 years. The questions for the CATA are multiple choice questions, often used in marketing research to reduce the number of responses (Espitia-López et al., 2019). Data are recorded in binary format (0 – unmarked attribute, 1 – marked attribute) with specified organoleptic characteristics. Every product is rated for overall liking (9-point hedonic scale) by each individual consumer.

2.10. Multiple regression analysis

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.

$$Y=b_o+b_1X_1+b_2X_2+b_3X_3+b_{11}(X_1)^2+b_{22}(X_2)^2+b_{33}(X_3)^2+b_{12}X_1X_2+b_{13}X_1X_3+b_{23}X_2X_3 \quad (1)$$

Where:

Y: the response;

b_o: the model intercept;

b_1, b_2, and b_3: the linear coefficients;

b_{12}, b_{13}, and b_{23}: the interaction coefficients;

b_{11}, b_{22}, and b_{33}: the quadratic coefficients.

2.11. Data analysis

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

3. Results and discussions

3.1. Effect of addition of turmeric starch, lecithin, and canola oil on waffles quality

3.1.1. Curcumin content

The response surface plot showing the effect of each pair of independent variables is presented in Figure 1. At a fixed ratio of canola oil (10%) (Figure 1A), the curcumin content in waffles varied from 2.62 to 5.49 mg/100 g when the percentage of turmeric starch used was 1–2%.

Waffles usually do not contain curcumin, so the curcumin content is completely dependent on the amount of turmeric added to the dough. Turmeric is one of the sources of recommended dietary supplements such as curcumin (El-Saadony et al., 2023). The use of turmeric not only gives the waffle a beautiful yellow color but is also beneficial in improving its functional properties. Curcuminoids in turmeric are stable during baking, and their high content remains in waffles. With a fixed lecithin ratio of 0.8% (Figure 1B), using canola oil with an increase from 7.5 to 12.5%, the curcumin content in waffles varied from 5.41 to 5.79 mg/100 g. This is probably because increasing oil phase concentration increases curcumin content, particle size, and emulsion viscosity (Ma et al., 2017). Curcumin content is also related to osmotic and thermodynamically stable effects and thus also affects the solubility of curcumin in the oil phase, which drives the curcumin content in waffles to have a slightly higher value when a higher ratio of oil is added. To make waffles, a stabilized fat with a low unsaturated fatty acid content and an iodine value of less than 85 should be used to minimize thermal fat breakdown and prolong shelf life (Huber & Schoenlechner, 2017). Fatty acids with more double bonds are less stable due

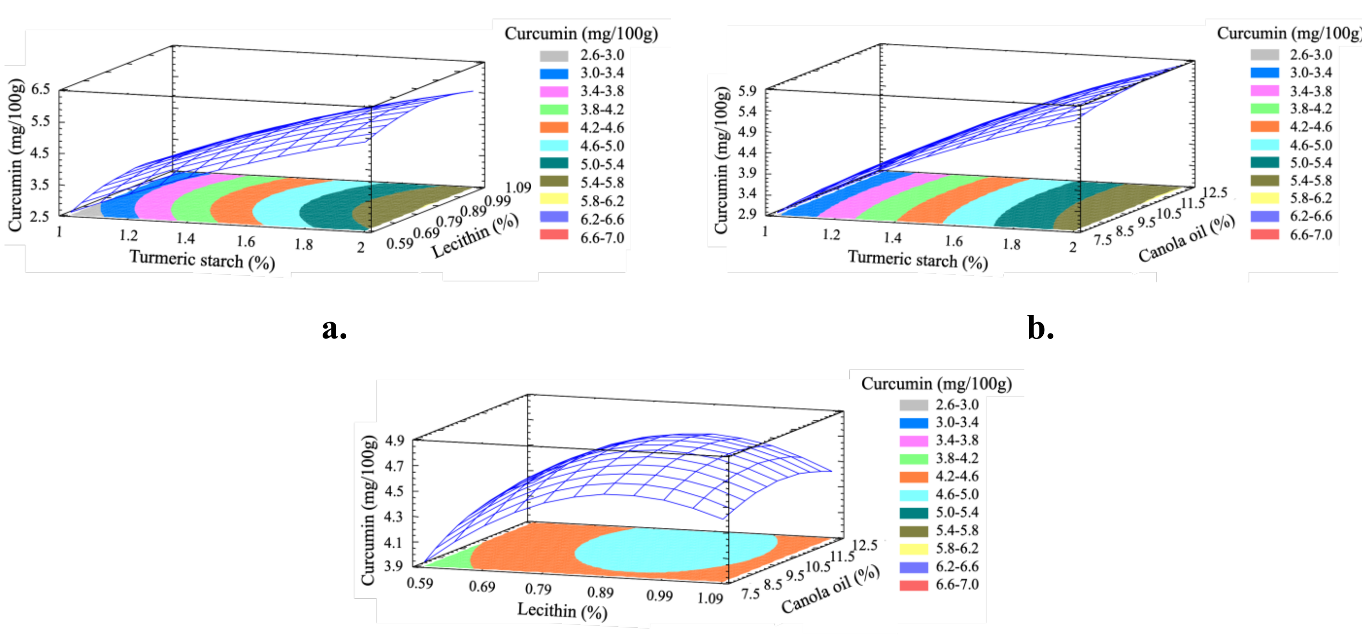


Figure 1. The response surface of curcumin as a function of turmeric starch, lecithin, and canola oil (amount of butter substitution) with (A) canola oil 10%; (B) lecithin 0.8%; (C) turmeric starch 1.5%

to auto-oxidation; a combination of margarine and canola oil in our study can provide good nutritional properties and meet this criterion. Similarly, when the percentage of turmeric starch was fixed at 1.5% (Figure 1C), the analytical results showed that the curcumin content ranged from 3.95 to 4.48 mg/100 g when the lecithin content increased from 0.6 to 0.85%. However, when the lecithin content increased to 1%, the curcumin content in the waffle tended to decrease (4.50 mg/100 g). The molecular structure of lecithin contains polar and non-polar fractions, which can be used as natural amphoteric ionic surfactants to emulsify bioactive compounds. Based on its molecular structure, curcumin can be trapped in the hydrophobic cavity formed by the hydrophobic tail of lecithin, according to the same compatibility principle. The high-viscosity polymers are mainly adsorbed on the surface of the suspended particles (Rueda et al., 2017), leading to intergranular steric hindrance and thus increasing the stability. This may be because curcumin is kept in a hydrophobic cavity formed by the hydrophobic tail of lecithin, while the hydrophilic head of lecithin is directed outward and is further enclosed by hydrophilic polymers to form a stable nanocomplex that determines and protects curcumin from adverse effects. Lecithin used in waffle processing could improve the stability of the fat and water phases from the ingredients used and the color distribution on the waffle surface (Huber & Schoenlechner, 2017). Complexes of curcumin and lecithin have been developed to improve the bioavailability of curcumin (Yang et al., 2023). In addition, the combination of lecithin and protein (from the raw materials used) can have a synergistic effect on emulsion stabilization. On the other hand, the effect can be antagonistic because the lecithin or protein is displaced from the interface. The interaction between protein and lecithin can lead to decreased surface activity, open the tertiary structure of the protein, enhance the flexibility of the molecule, change elastic viscosity, and increase the incorporation of proteins into surfactant and vesicle mixtures.

Analysis of variance (ANOVA) partitioned curcumin's variation into separate sections for each effect and tested the statistical significance of each effect by comparing the mean square with an estimate of experimental error. It was observed that six effects, including turmeric (X_1), lecithin (X_2), canola oil (X_3), and double interactions (X_1X_1, X_2X_2, and X_3X_3), had p-values <0.05, indicating that they are statistically different from zero with 95.0% confidence. However, X_1X_2, X_2X_3, and X_1X_3 interaction effects did not have a significant contribution (p>0.05), so they were excluded from the correlation model. In addition, since the p-value of the lack of fit in ANOVA is greater than 0.05 (0.1296), the model seems to fit the observed data with 95.0% confidence. R-squared statistics indicated that the fit model explained 98.03% of the variation in curcumin content (mg/100 g). The adjusted R-squared statistic, which is more suitable for comparing models with different independent variables, is 97.78%. The standard error of the estimate shows that the standard deviation of the residual is 0.16. From the above analysis, a new model (Equation 2) was performed. The high values of R^2 (97.80%) and R^2 adj (97.63%) for the dependent variable, together with a lack of fit 0.06 (p>0.05), showed that the selected model is accurate enough to predict curcumin content from the independent variables.

$$Y_1\,(\text{mg/100 g}) = -8.53 + 5.23X_1 + 11.43X_2 + 0.41X_3 - 0.89X_1^2 - 5.47X_2^2 - 0.018X_3^2 \quad (2)$$

To optimize response with the goal of maximum curcumin content at the optimal value of 5.85 mg/100 g, a combination of curcumin-optimizing factor levels in the indicated region was performed. The optimal concentrations of turmeric, lecithin, and canola oil were 2, 0.87, and 11.36%, respectively. In addition, the Pareto plot shows the absolute values of the effects normalized from the largest to the smallest effect. The reference line plotted on the graph already shows which effects are statistically significant, so the Pareto plot shows the magnitude and importance of the effects. On the Pareto chart (Figure 2), bars that cross the reference line can be found to be statistically significant, including bars representing the factors X_1, X_2, X_3, X_1X_1, X_2X_2, and X_3X_3 cross the reference line at 1.97. These factors are all statistically significant at the 0.05 level with the current model conditions.

3.1.2. The hardness

In general, waffles are made with a high content of fresh eggs, sugar, milk, fat, etc., so they have the same texture as cakes. However, the structure of the waffle also has a very important influence on consumer preferences. The response surface of curcumin as a function of turmeric starch, lecithin, and canola oil (substitute a portion of butter) is shown in Figure 3. The obtained results showed that the percentage of turmeric starch used (1–2%) did not seem to significantly affect the firmness, but the ratio of lecithin and canola oil significantly affected the firmness of the waffles.

With a fixed canola oil ratio of 10%, the analysis results showed that the hardness of waffles decreased significantly (from 305.26 to 86.69 g force) when the percentage of lecithin used increased from 0.6 to 1.0% (Figure 3A). Lecithin has emulsifying properties and helps to form an emulsion between the fat and water phases in the dough, increasing the uniformity of the dough and making it easier to knead and shape. Moreover, this activity also creates a soft texture for the crust. The measurement results from the study also proved this: the structure of the waffle was improved when using lecithin in the specified concentration range. At 0.8% lecithin fixation (Figure 3B), as the percentage of canola oil used increased from 7.5 to 12.5%, the hardness of waffles decreased significantly from 343.98 to 206.74 g force. In waffle processing, both the butter (margarine) and canola oil used in the recipe result in a softer waffle texture and avoid

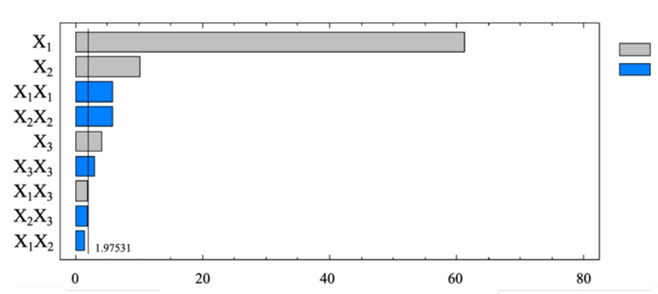


Figure 2. Standardized Pareto chart of curcumin.

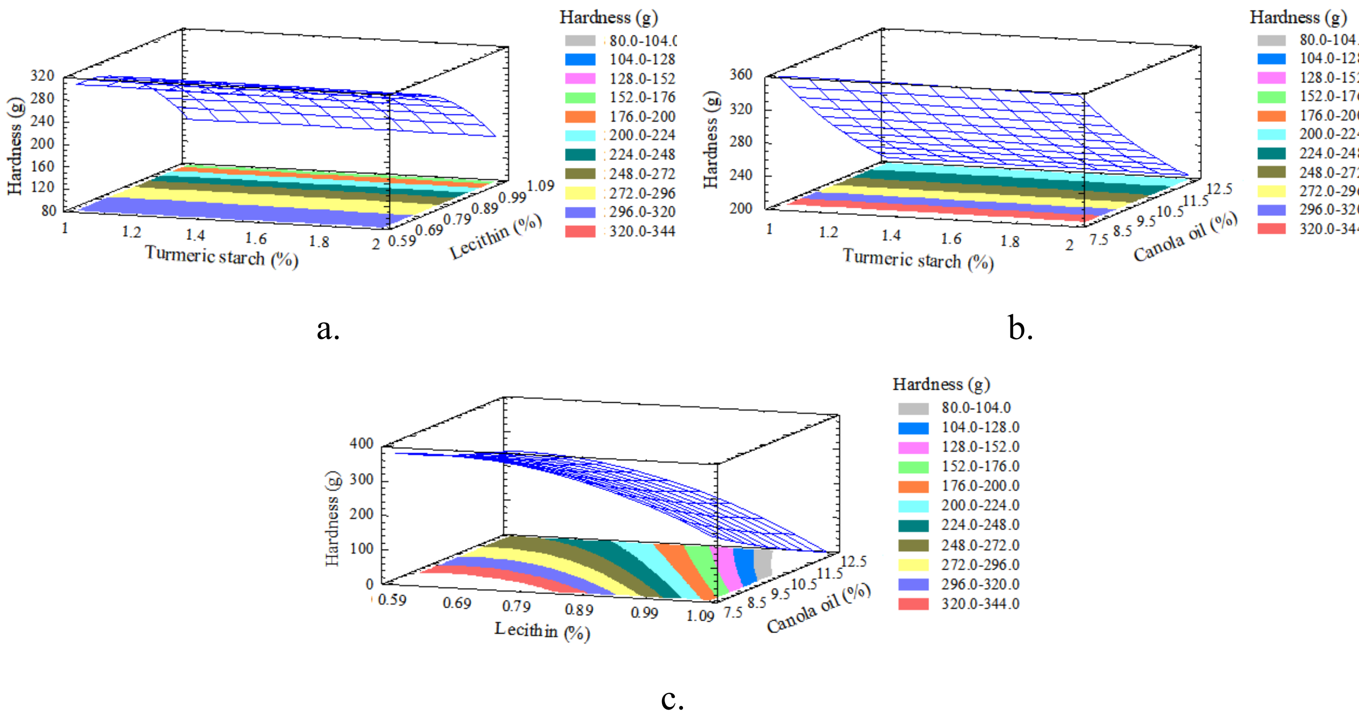


Figure 3. Response surfaces plot on hardness: (A) canola oil 10%; (B) lecithin 0.8%; (C) turmeric starch 1.5%.

a dry mouth feeling (Tiefenbacher, 2018). Sharma et al. (2022) reported that oil can perform another very important function by preventing starch degradation. The addition of oil helps the dough not stretch too much during mixing. In addition, fat contains molecules with hydrophilic heads such as phospholipids and diglycerides, which could interact with water, limit moisture loss during baking, slow down the hardening process of egg and flour proteins, and increase the softness and smoothness of the product (Sharma et al., 2022).

The usual amount of fat used for the waffle recipe is in the range of 18–29% (Tiefenbacher, 2018), which is higher than the total butter and canola oil content used in our recipe (14.5%, in which canola oil replaces butter from 51.72 to 86.21%). Using less fat will be both economical and healthy while ensuring the quality of waffles. In this case, the canola oil used increases the amount of 18 carbon unsaturated fatty acids. Canola oil is relatively low in saturated fatty acids, the lowest of all major cooking oil sources, making it a healthy choice (Bowen et al., 2019). Thus, in the case of our study, the combined use of margarine (less) and canola oil (more) somewhat improved the good nutritional properties while maintaining the desired quality of the waffle product. In addition, when the percentage of turmeric starch was fixed at 1.5% (Figure 3C), the results again demonstrated a significant effect of supplemented lecithin and canola oil on the structure of waffles. When the lecithin used was increased from 0.6 to 0.64%, the hardness of the waffles did not change significantly (about 374.67 g); however, when the concentration was increased from 0.64 to 1%, a clear change in waffle hardness was found, with a measured value of 188.58 g force. Besides, the more the usage of canola oil, the softer the waffles will be, and the measured value decreases from 188.48 to 85.43 g force when the ratio of the usage of canola oil increases from 7.5 to 12.5%. As such, in this study, canola oil was used along with curcumin (from turmeric) in a waffle recipe with potential health benefits. Important possible benefits are cholesterol reduction and increased cardiovascular protection, antioxidant effects, and anti-inflammatory properties (Figorilli et al., 2022).

Similar to curcumin, optimization of the waffle hardness value according to the influencing factors (turmeric starch, lecithin, and canola oil) was also performed. The statistical significance of the model after acquisition was tested through analysis of variance (data not shown). A multivariable regression model is the suitable statistical model in this case ($p<0.05$) to predict the stiffness of waffles. It was observed that the linear effects of lecithin (X_2) and canola oil (X_3), double interactions (X_2X_2, X_3X_3) (quadratic effects), and interaction variables (X_2X_3) significantly affect the hardness ($p<0.05$). The linear variable (X_1), double interaction (X_1X_1), and interactive variables (X_1X_2, X_1X_3) did not have a significant effect ($p>0.05$). Therefore, non-significant interactions were removed from the equation, and the model was re-established with a correlation between the experimental data and the predicted data (Equation 3). R-squared statistics show that the fit model explains 96.59% of the variation in hardness. The adjusted R^2 statistic, which is more suitable for comparing models with different numbers of independent variables, is 96.37%. The standard error of the estimate shows that the standard deviation of the residual is 17.08.

$$Y_2(g\,force) = 210.45 + 1447X_2 - 44.44X_3 - 993.8X_2^2 - 21.32X_2X_3 + 1.56X_3^2 \quad (3)$$

The Pareto histogram (Figure 4) clearly defines bars that cross the reference line at level 1.99 with statistical significance,

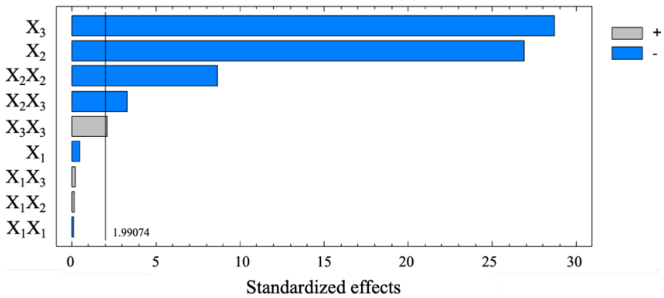


Figure 4. Standardized Pareto chart of hardness.

including bars representing the factors X_3, X_2, X_2X_2, X_2X_3 and X_3X_3. These factors are statistically significant at the 0.05 level with the current model.

3.1.3. Simultaneous optimization of response surfaces

In this study, response surface method was used to select elements for maximum or desired response. To maximize the curcumin content and achieve the desired waffle firmness, a method of simultaneous optimization of these responses was performed. Therefore, after determining the influence of different factors on the quality of waffles (mainly curcumin and hardness), the input optimization parameters were selected (turmeric starch content, lecithin, and canola oil). According to the analysis results by STATGRAPHICS (optimize desirability with an optimum value of 0.96), the optimal combinations proposed by the software were selected. The optimal values of turmeric starch, lecithin, and canola oil are 2, 0.86, and 11.2%, respectively, for curcumin content and optimum waffle firmness are 5.84 mg/100 g and 209.7 g force, respectively. All the optimal values of the determined input variables are in the research data series. To confirm the reliability of the feedback surface model, waffles were baked according to a recipe supplemented with optimal values of turmeric, lecithin, and canola oil. Output values, including curcumin and hardness, were evaluated and compared with the predicted value of the regression equation. The test results showed that there is a good agreement between actual values and predicted values; the values differ only very slightly, from 1.35 to 1.52%. The results confirmed the validity of the model and its application.

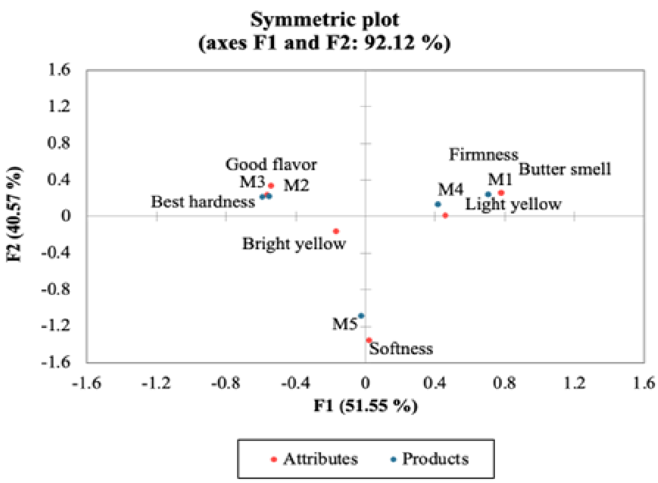
3.2. Sensory evaluation

In addition to the discussed optimization parameters, sensory evaluation of the waffles was also performed. Waffles should have the desired quality and high organoleptic value, exhibiting a favorite color (bright yellow), the best hardness (not too soft or too dry), and a good taste (light buttery, pleasant aroma, and mixing between the odors of the raw materials used). A sensory evaluation of the product was carried out and analyzed according to the CATA method. Reference standards for sensory attributes were discussed among panelists and adopted by consensus to assist the panel in understanding each attribute in the same way. There are a total of seven attributes (light yellow, bright yellow, good flavor, butter smell, firmness, softness, and best hardness) that are classified in terms of smell, taste, texture, and feel when assessing the appearance. The five selected samples were evaluated, including samples prepared under optimal conditions, samples selected from experimental setups (data not included here), and samples with slight differences in turmeric starch, lecithin, and canola oil content (Figure 5). The participants in the evaluation preferred the bright yellow appearance; the texture of the waffles was not too soft or too hard, making them easy to swallow. The dispersion of the waffle's samples on the graph (Figure 5A) shows that changing the ratio of turmeric starch, lecithin, and canola oil had a great influence on the sensory properties of waffles. The first principal component accounts for 51.55%, and the second principal component accounts for 40.57% of the variance. The quality of the analysis is good (92.12% of the explained total inertia on the first two dimensions). The first principal component is positively correlated with the properties of softness, light yellow, butter smell, and firmness and negatively correlated with the attributes of bright yellow, best hardness, and good flavor. As expected, the contrast properties manifest in opposite directions (firmness and softness, bright yellow, and light yellow). Based on the primary coordinate analysis, M2 and M3 are considered the best hardness, good flavor, and bright yellow samples. M5 is relatively soft, while M1 and M4 have firmness, butter smell, and light yellow attributes.

Scores of positive attributes were recorded as bright yellow, good flavor, softness, and best hardness. The mean impact chart (Figure 5B) shows the attributes with a significant mean impact. Mean increases are displayed in blue, and mean decreases are displayed in red. Sensory attributes such as best hardness and good flavor are attributes that positively affect product quality, and products are preferred when evaluated for their presence. However, firmness and butter smell are attributes that negatively affect product quality. Too firm the product is with the butter smell, the more the product is not accepted by consumers. The internal preference map (Figure 5C) confirmed a higher acceptability for waffle sample (M2 and M3) than other samples. Samples M2 and M3 were rated as having the best hardness, good flavor, and bright yellow of turmeric, which was the most favorite (80–100%). Meanwhile, samples M1, M4, and M5 were not accepted by the observer. Sample M1 is assessed to have a light yellow color, butter smell, and firmness due to the low percentage of turmeric (1.5%) and canola oil (10%). However, as sample M4 has a high percentage of turmeric starch (2%) and canola oil (10%), it has a beautiful bright yellow color but has a lot of butter smell and the product is hard. Along with that, sample M5 was evaluated similar to sample M4 with a bright yellow color but a poor smell and the product is soft due to high lecithin and canola oil at the rates of 1 and 12.5%, respectively.

3.3. Nutritional quality

In addition to the main nutritional components, the quality of waffles was improved with curcumin and total polyphenol contents (Figure 6 and Table 1). The DPPH scavenging activity of this product (27.25%) may be due to the presence of total polyphenols and curcumin, as indicated in the present study. The product also contains a good amount of fiber, resistant



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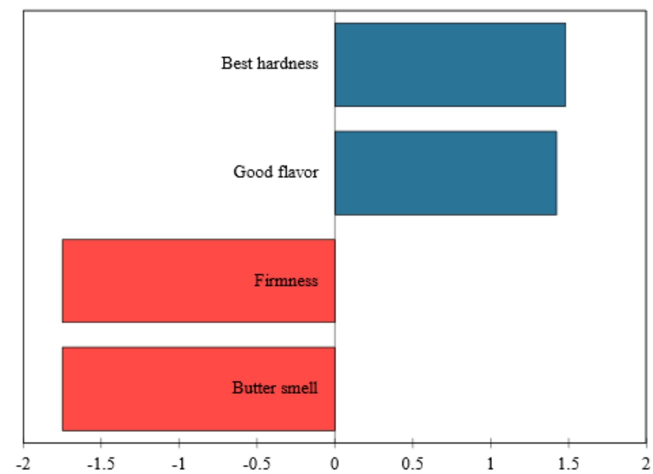

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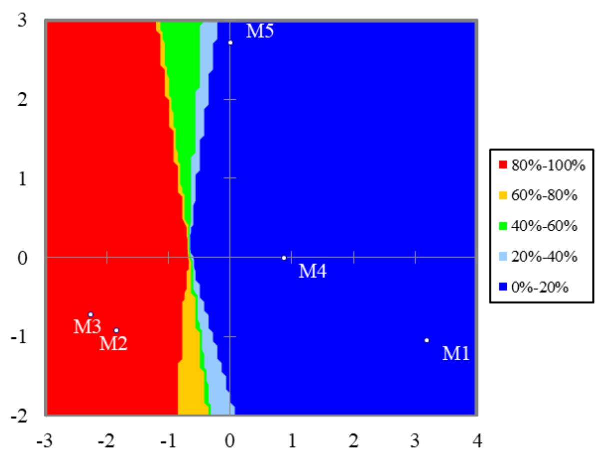
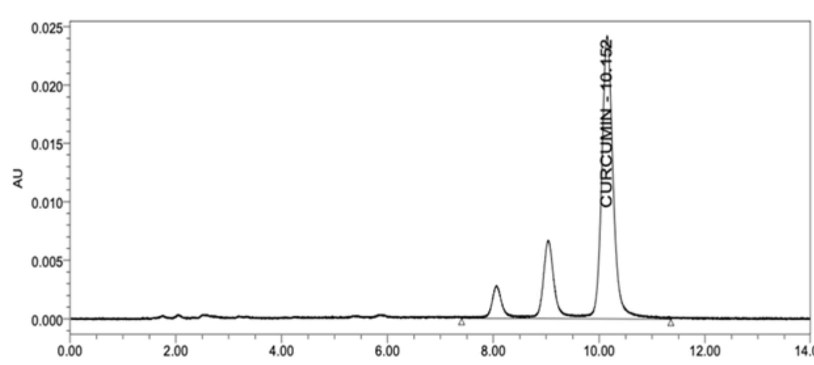


c

M1: Turmeric starch (%):lecithin (%):canola oil (%) ratio is 1.5:0.8:10; M2: Turmeric starch (%):lecithin (%):canola oil (%) ratio is 2:0.86:11.2; M3: Turmeric starch (%):lecithin (%):canola oil (%) ratio is 2:0.8:12.5; M4: Turmeric starch (%):lecithin (%):canola oil (%) ratio is 2:0.8:10; M5: Turmeric starch (%):lecithin (%):canola oil (%) ratio is 2:1:12.5.

Figure 5. Sensory properties of waffle by (A) PCA analysis, (B) mean impact, (C) reference map.

a



b

Figure 6. (A) Waffle "turmeric" and (B) curcumin content in products by HPLC analysis (analyzed at Center of Analytical Services and Experimentation HCMC).

Table 1. Physicochemical characteristics of waffle*.

Proximate analysis	Content	Proximate analysis	Content
Moisture content, %	35.10±0.06	Fiber, %	1.32±0.02
Protein, %	6.90±0.1	Ash, %	0.6±0.05
Carbohydrate, %	36.64±0.2	Curcumin, mg/100 g	5.87±0.06
Lipid, %	16.78±0.12	Total polyphenol, mg GAE/100 g	37.81±1.86
Resistant starch, %	3.8±0.07	DPPH, %	27.25±0.2

*Mean±SD.

starch, and ash. Dietary fiber helps maintain bowel health. Despite the healthy influence dietary fiber can have on reducing the risk of chronic disease, the intake remains low in many populations worldwide. Therefore, adding fiber to fast food is also a matter of concern. Besides, consumers are becoming more aware of the relationship between food, lifestyle, and health. This is one of the reasons for the popularity of fiber-rich foods, and resistant starch has also become important as a new source of fiber in processed foods (Bojarczuk et al., 2022). Resistant starch consumption has also been associated with decreased postprandial glycemic and insulin responsiveness, which may have beneficial implications in the management of diabetes (Bojarczuk et al., 2022).

4. Conclusion

The response surface method has proven to be an effective technique for optimizing experimental results by determining the optimal input parameters (turmeric starch, lecithin, and canola oil) to create waffles with different ingredients' characteristics such as good quality (bioactive compound curcumin and suitable structure) and high sensory value. Especially in this study, using canola oil instead to reduce the amount of butter used will increase the use of fat in food processing. Using a combination of margarine (less) and canola oil (more) improved the ingredients' nutritional properties while maintaining the desired quality of the waffle product. This analysis will greatly assist food manufacturers, especially research and development scientists, in creating new food formulations with desired quality characteristics.

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