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Modeling and optimization of functional muffin composition using multi-criteria analysis and fuzzy decision logic

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Abstract

In order to develop a functional product with antioxidant properties and also to use waste to produce value-added products, in the present study, Citron fruit peel powder was used in the present study as a rich source of bioactive compounds for the production of healthy muffins. In this study, flour in muffin formulations was replaced with different percentages of Citron fruit peel powder (0, 5, 10, 15 and 20 percent), and then the chemical, textural, antioxidant and organoleptic properties of the final products were investigated and analyzed. The results of the studies showed that enriching muffins with Citron fruit peel powder increased the amount of fiber and ash and reduced the amount of protein in the formulation, while adding Citron fruit peel powder had no significant effect on the fat content of the muffins. Examination of the product texture with a texture measuring device also showed that adding Citron fruit peel powder to the muffins made the texture of the samples firmer. Measurement of the antioxidant properties of muffins using the reducing power method and the free radical scavenging method (DPPH) showed that the addition of Citron peel powder significantly improved the antioxidant properties of the samples. The sensory characteristics also showed that at a lower level of Citron peel powder, the muffin samples were desirable for consumers, but at high percentages, especially 20 percent, a slightly bitter taste was observed in the samples. Overall, the results of this study suggest that by using a suitable 1 percent Citron peel powder in terms of its properties, muffins can be produced that are not only functional but also sensory acceptable to consumers.

Keywords: muffin, citron peel powder, physicochemical properties, antioxidant activity, sensory evaluation
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1 Introduction

In recent years, the food industry has encountered a range of significant challenges, among which the development of innovative, healthy, and functional food products stands out as a critical concern. Considering the extensively documented positive impact of nutritious dietary patterns on consumers' quality of life, the formulation and production of functional food products have attracted considerable attention from researchers across various disciplines [15]. Baked and flour-based products, particularly cakes, have been the focus of extensive research aimed at modifying their formulations to enhance health-promoting properties, such as antioxidant activity. These products, which encompass various categories, have gained popularity as convenient snack options across diverse segments of society [11]. Sponge

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cakes, oil cakes, and muffins are among the most commonly studied categories of flour-based products in efforts to enhance their nutritional and functional attributes. One promising ingredient utilized for this purpose is citrus peel powder—a by-product of the fruit juice industry traditionally regarded as waste. The incorporation of citrus peel powder not only contributes to the development of value-added products but also enhances the overall health benefits of baked goods. Citrus peels are rich in bioactive compounds, with phenolic compounds, flavonoids, and dietary fibers being the most notable constituents [1]. Citron is a well-known citrus fruit recognized for its numerous beneficial properties, most notably its richness in antioxidant compounds.

Citron (Citrus medica), a traditional citrus fruit with notable therapeutic potential, is particularly rich in antioxidant compounds and essential oils [10]. Its peel, often treated as waste, presents an underutilized opportunity for sustainable food innovation. Incorporating citron peel powder into bakery products not only adds nutritional value but also supports environmental goals by reducing organic waste. In line with global efforts to enhance public health through functional food development, this study investigates the effect of incorporating varying levels of citron peel powder (0%, 5%, 10%, 15%, and 20%) into muffin formulations. The resulting samples were analyzed for their chemical composition, textural quality, antioxidant activity, and sensory characteristics using standardized evaluation methods.

To guide the formulation toward an optimal balance of nutritional and sensory attributes, mathematical modeling techniques including linear regression, fuzzy logic, and multi-criteria decision-making (MCDM) approaches were employed. These tools allow for the integration of multiple conflicting parameters into a unified decision framework, enabling objective evaluation and optimization of product performance.

2 Theoretical framework

Numerous studies have highlighted the functional and preservative potential of fruit peel extracts in food systems:

Habashi et al. identified and compared the compounds present in the essential oil of the Citron fruit peel using two extraction methods: water distillation and cold pressing. The results of this study indicated that the most important compounds obtained from the distilled essential oil were limonene, terpinene and neral, and in the essential oil produced by the cold pressing method, the most important compounds were limonene, geranial and gamma terpinene. Therefore, these researchers concluded that due to the presence of bioactive compounds in the Citron fruit peel, this material can be used to produce functional food products [2].

Noshirvani et al. used green walnut peel powder to reduce the oxidation process in the formulation of sunflower oil. These researchers stated that green walnut peel powder can be used as a natural antioxidant to prevent oil oxidation, which, unlike synthetic antioxidant compounds, is safe for consumers and does not pose a health risk [9].

Mahmoudi et al. in studied the effect of essential oil of the skin of the lingonberry on the chemical and microbial properties of rainbow trout fillets. The results of this study showed that adding essential oil of the skin of the lingonberry to the fish slowed down the oxidation process in the fish and limited bacterial growth in this fish [4].

Naqvi and Seyedlangi studied the effect of adding red pomegranate peel powder and cardamom on the sensory and rheological properties of oil cake. The results of this study showed that adding red pomegranate peel powder and cardamom to the oil cake dough caused significant changes in the rheological and physicochemical properties. The best sample was also related to the treatment containing 4.5% pomegranate peel and 0.06% cardamom [7].

Najafi et al. investigated the effect of replacing orange fiber with oil and eggs on the physicochemical and organoleptic properties of muffins. These researchers stated that adding orange fiber to muffins delayed the staleness and increased the health benefits of the product [6].

Shojaei Mehr and Alamholo studied the antibacterial activity of aqueous and alcoholic extracts of different parts of the fruit on human pathogens. The results of this study showed that the colored and white peel extracts of this fruit have antipathogenic properties due to the presence of bioactive compounds and can be used as a herbal medicine [14].

Khormaeipour et al. used lemon peel powder to enrich sponge cake. In this study, 5 and 10% levels of lemon peel powder were used in the sponge cake formulation. After adding lemon peel powder, the physicochemical properties of the cakes were examined. The results of the texture evaluation of the cake samples showed that adding lemon peel powder to the formulation reduced the springiness and also increased the adhesion and firmness of the texture. In general, according to the results obtained in this study, it can be concluded that lemon peel powder can be used as a bioactive ingredient in the formulation of food products to improve their health properties [3].

Nasrabad et al. studied the effect of replacing wheat flour with grapefruit fiber on the physicochemical and sensory properties of sponge cake. These researchers stated that with increasing fiber content, dough viscosity, fiber percentage,

cake moisture and texture firmness increased. The results of sensory evaluation also showed that the sample containing 1% grapefruit fiber had the highest acceptance among taste judges [8].

Malekpour and Ansari used pomegranate peel powder in the formulation of sponge cakes and examined the organoleptic and physicochemical properties of the cakes. In this study, different percentages of pomegranate peel were used and the results showed that with increasing the amount of pomegranate peel powder in the formulation, the textural properties of the cakes changed and the firmness increased. Also, the samples containing pomegranate peel powder were comparable to the control sample in terms of sensory properties and were well accepted by the evaluators [5].

Sharifi and Filbanzadeh evaluated the antimicrobial activity of the ethanolic extract of the inner layer of the peel of the Citron fruit in a lemon-flavored carbonated drink. In this study, different concentrations of the extract were used in the formulation of lemon-flavored carbonated drink. The effects of this extract on the bacteria Lactobacillus delbrueckii, the bacteria Leuconostoc mesentroides and the yeasts Saccharomyces cereus and Candida cruzoi were investigated. The observations of this study indicated that a carbonated soft drink with a long shelf life can be produced using an appropriate concentration of Citron bark extract, and this antimicrobial compound can be a very suitable replacement for the preservative sodium benzoate in soft drinks [13].

While the functional efficacy of peel powders has been widely examined, fewer studies have integrated systematic modeling and optimization frameworks to evaluate their use across multiple conflicting criteria, such as health impact, sensory acceptability, and processing properties. In response to this gap, the present study adopts two complementary analytical approaches—Fuzzy Logic and Multi-Criteria Decision-Making (MCDM).

By combining chemical and physical analysis with fuzzy and MCDM-based modeling, the present study offers a comprehensive framework for evaluating and optimizing functional food formulations. This integrated approach is particularly valuable in scenarios where improvement in one parameter (e.g., nutritional value) may trade off against another (e.g., taste or texture), requiring a balanced, data-driven decision.

3 Research methodology

Devices, supplies and equipment used in the present study

The following table lists the devices and equipment used to conduct the tests.

Table 1: Devices and equipment used in the present study

Device Name	Manufacturer Company	Manufacturer Country
Oven	Fan Azma	Iran
Electric Furnace	Fan Azma	Iran
Spectrophotometer	Especrom	Canada
Fabric Testing Machine	Brookfield	USA
Centrifuge	Hettich	Germany
Electric Balance	–	Iran
Heater Stirrer	Heidolph	Germany

3.1 Chemical compounds and consumables in the present study

The chemical compounds and consumables in the present study are as follows, Table 2.

Table 2: Materials and compounds used in the present study

Substance Name	Manufacturer Company	Manufacturer Country
Buffer Phosphate	Merck	Germany
Potassium Ferricyanide	Merck	Germany
Trichloroacetic Acid	Merck	Germany
Ferric Chloride	Merck	Germany
Ethanol	Jebem	Iran
DPPH Radical	Sigma	USA

Preparation of citron fruit peel powder to prepare citron peel powder, first the purchased citron was washed well, peeled, cut into small pieces, and dried in an oven for 24 hours. The dried peels were ground and sieved to obtain a uniform powder. Then the final powder was stored in plastic bags at the appropriate temperature to be used in

the production of muffin samples. Production of muffin samples containing citron peel powder Muffin samples were produced according to the method of Saedi et al. [11]. For this purpose, first, sugar and eggs were mixed in a high-speed mixer for 5 minutes. Then water and oil were added to this mixture and stirred again for 3 minutes to combine the ingredients well. In the next step, all powdered ingredients were added to this mixture after sieving and then stirred for 1 minute to produce a smooth and uniform dough. The produced dough was poured into special muffin molds (visible in Figure 1 and 2) and finally baked in an oven at 180 degrees Celsius for 50 minutes. Then the produced muffins were removed from the oven and kept at room temperature for half an hour to become stiff. After the production stages were completed, the muffins were packed in polyethylene bags with a suitable seal, on which the production date and other specifications related to the desired treatment were written. The formulation of the different muffin samples produced was as follows:

- Control sample: Wheat flour (150 g), eggs (100 g), sugar (90 g), liquid oil (77 g), baking powder (7 g), powdered milk (18 g) and water (56 g).
- Sample with 5% substitution of citron skin powder: Wheat flour (142.5 g), citron skin powder (7.5 g), eggs (100 g), sugar (90 g), liquid oil (77 g), baking powder (7 g), powdered milk (18 g) and water (56 g).
- Sample with 10% substitution of citron skin powder: Wheat flour (135 g), citron skin powder (15 g), eggs (100 g), sugar (90 g), liquid oil (77 g), baking powder (7 g), powdered milk (18 g) and water (56 g).
- Sample with 15% substitution of citron bark powder: wheat flour (127.5 g), citron bark powder (22.5 g), eggs (100 g), sugar (90 g), liquid oil (77 g), baking powder (7 g), powdered milk (18 g) and water (56 g).
- Sample with 20% substitution of citron bark powder: wheat flour (120 g), citron bark powder (30 g), eggs (100 g), sugar (90 g), liquid oil (77 g), baking powder (7 g), powdered milk (18 g) and water (56 g).

Mass balance of substitution:

$$F' = F - (F \times Sub\%) + (F \times Sub\% \times R) \tag{3.1}$$

where, F' is new flour mass, F is original flour mass, $Sub\%$ is substitution percentage, and R is density ratio of citron peel to flour.

Figure 1: The initial mixture of muffins before molding and baking

Figure 2: Molded muffins before baking

3.2 Calculating the percentage change in chemical composition

To calculate the change in chemical composition in the final product (such as fiber, protein, and fat), the percentage change formula is used:

$$\Delta C\% = \left(\frac{C_{Sample} - C_{Control}}{C_{Control}} \right) \times 100 \tag{3.2}$$

where:

C_{Sample} : Amount of compound in the test sample (with citron bark powder)

$C_{Control}$: Amount of compound in the control sample (without citron bark powder)

$\Delta C\%$: Percentage change in compound in the samples

3.3 Antioxidant activity formula (DPPH)

To evaluate antioxidant activity in the DPPH method, absorbance changes are used as a criterion for calculating antioxidant activity:

$$DPPH\ Inhibition\% = \left(\frac{A_0 - A_s}{A_0} \right) \times 100 \tag{3.3}$$

where:

A_0: Absorbance of control

A_s: Absorbance of sample

$DPPH\ Inhibition\%$: Percentage of DPPH radical inhibition, expressed as a measure of antioxidant activity

3.4 Modeling of antioxidant activity based on the percentage of citron bark powder

Modeling the effect of adding citron bark powder on antioxidant activity is done using linear regression. Suppose that Y represents antioxidant activity and X represents the percentage of citron bark powder. The linear regression equation will be as follows:

$$Y = \beta_0 + \beta_1 X + \varepsilon \tag{3.4}$$

where:

Y: Antioxidant activity.

β_0: Width from the origin (fixed value)

β_1: Correlation coefficient showing the effect of the percentage of citron bark powder.

X: Percentage of citron bark powder.

ε: Model error.

3.5 Sensory evaluation

Triangular fuzzy numbers (TFNs) for sensory scores

$$\widetilde{A} = (l, m, u) \tag{3.5}$$

where:

l: lowest acceptable score

m: most likely score

u: highest possible score

Aggregate fuzzy scores:

$$\widetilde{S} = \sum_{i=1}^{n} w_i \cdot \widetilde{A}_i \tag{3.6}$$

Defuzzify:

$$S = \frac{(l, m, u)}{3} \tag{3.7}$$

3.6 Weighted sum model (WSM) for overall muffin quality

The Weighted Sum Model is one of the simplest and most widely used multi-criteria decision-making (MCDM) methods. It is used to evaluate several alternatives (in your case, different muffin formulations) based on multiple criteria (like protein content, fiber, texture, antioxidant activity, sensory scores, etc.).

In WSM, each criterion is given a weight based on its importance, and each alternative (muffin sample) is scored for each criterion. Then, a weighted score is calculated for each sample by summing the product of each score and its corresponding weight.

$$Q_j = \sum_{i=1}^{n} w_i \cdot s_{ij} \tag{3.8}$$

where:

Q_j: Overall quality score for muffin sample j

w_i: Weight of criterion i

s_{ij}: Normalized score of sample j for criterion i

4 Analysis

4.1 Production of muffin samples

In the present study, muffin skin powder was used to enrich muffins. In this study, muffins were produced with different percentages of citron skin powder including 0, 5, 10, 15 and 20. To produce these muffins, flour in the formulation was replaced with the mentioned percentages of citron skin powder, and the images of these produced muffins can be seen in Figure 3.

Figure 3: Images of muffins produced in the present study with different percentages of citron peel powder.

4.2 Chemical composition of produced muffin samples

In the present study, the chemical composition of different muffin samples was measured, and these chemical properties were protein, fat, ash, and fiber content. The protein content of different muffin samples is shown in Table 3 and Figure 4. The results of examining the protein content of different muffin samples showed that there was a significant difference in the protein content of different muffin samples, and with increasing the percentage of citron peel powder in the formulation, the protein content of the samples was slightly reduced. The fat content is also shown in Table 4 and Figure 5. As shown in the results, adding citron peel powder did not have a significant effect on the fat content of muffin samples (0.05).

In addition to fat and protein content, ash and dietary fiber content were also measured in the muffins produced in the present study. The results of ash content are shown in Table 5 and Figure 6. The results indicated that there

Table 3: Protein content of different muffin samples (Different superscript letters on the means indicate statistically significant differences ($P < 0.05$).)

Sample	Protein Percentage
Control muffin (without orange peel powder)	9.9 ± 0.13^{a}
Muffin with 5% orange peel powder	8.67 ± 0.10^{b}
Muffin with 10% orange peel powder	8.33 ± 0.05^{c}
Muffin with 15% orange peel powder	8.17 ± 0.03^{cd}
Muffin with 20% orange peel powder	7.96 ± 0.04^{d}

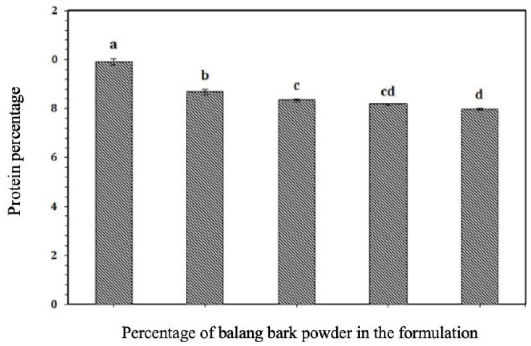

Figure 4: Protein content of muffin samples containing different percentages of citron fruit peel powder. Different superscript letters on the columns indicate significant differences between samples ($P < 0.05$).

Table 4: Fat content of different muffin samples.

Sample	Protein Percentage
Control muffin (without banana peel powder)	27.90 ± 0.24^{a}
Muffin with 5% banana peel powder	27.80 ± 0.35^{a}
Muffin with 10% banana peel powder	27.67 ± 0.28^{a}
Muffin with 15% banana peel powder	27.04 ± 0.31^{a}
Muffin with 20% banana peel powder	26.96 ± 0.42^{a}

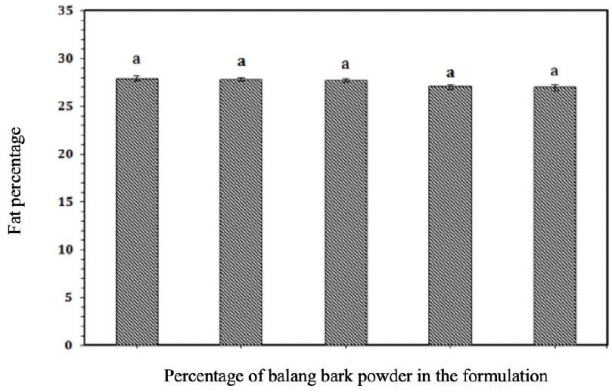

Figure 5: Fat content of muffin samples containing different percentages of citron fruit peel powder.

was a significant difference between the samples in terms of ash content ($p < 0.05$). The results showed that with increasing the amount of citron peel powder in the muffin samples, the ash content of the samples also increased, which could be due to the presence of minerals in the citron peel. The results of measuring the amount of dietary fiber in the muffin samples are also shown in Table 6 and Figure 7. Observations showed that adding citron peel powder had a significant effect on the fiber content of the muffin samples ($p < 0.05$). The results showed that with increasing the amount of citron peel powder in the muffin formulation, the fiber content in the product increased significantly, and the highest fiber content was related to the muffin sample containing 20% of citron peel powder. Therefore, these results indicate that muffins enriched with muffin peel powder are a rich and good source of dietary fiber that is very beneficial for improving the health of consumers. In line with the results of the present study, other researchers also reported that the amount of dietary fiber in the muffin samples increased significantly. Fiber and ash in cake samples

increased significantly with the addition of grapefruit peel powder [15]. Naqvi and Saydalangi also reported that the addition of pomegranate peel powder to oil cakes increased the amount of ash and fiber in the final product samples [7].

Table 5: Ash content of different muffin samples (Different superscript letters indicate significant differences between the means ($P < 0.05$)).

Sample	**Ash Percentage**
Control muffin (without banana peel powder)	1.94 ± 0.08^{d}
Muffin with 5% banana peel powder	2.14 ± 0.06^{c}
Muffin with 10% banana peel powder	2.26 ± 0.06^{bc}
Muffin with 15% banana peel powder	2.37 ± 0.05^{b}
Muffin with 20% banana peel powder	2.58 ± 0.04^{a}

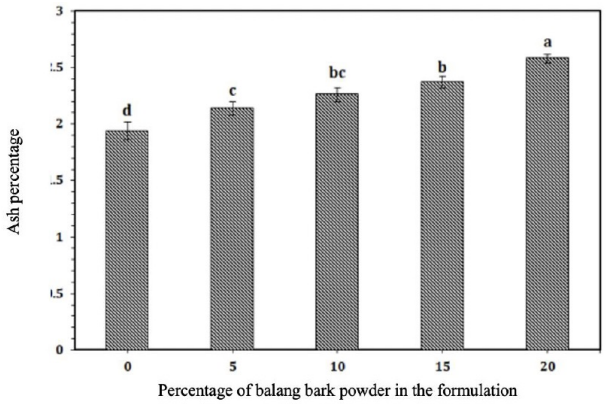

Figure 6: Ash content of muffin samples containing different percentages of citron fruit peel powder (Different superscript letters on the columns indicate significant differences between samples ($P < 0.05$)).

Table 6: Fiber content of different muffin samples.

Sample	**Fiber Percentage**
Control muffin (without banana peel powder)	2.40 ± 0.14^{c}
Muffin with 5% banana peel powder	2.95 ± 0.21^{d}
Muffin with 10% banana peel powder	5.05 ± 0.14^{c}
Muffin with 15% banana peel powder	6.51 ± 0.10^{b}
Muffin with 20% banana peel powder	9.77 ± 0.31^{a}

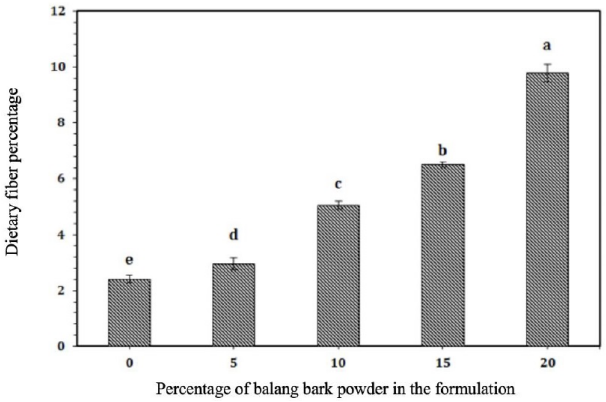

Figure 7: Fiber content of muffin samples containing different percentages of citron fruit peel powder. Different superscripts on the columns indicate significant differences between samples ($P < 0.05$).

Textural properties of produced muffin samples One of the most important characteristics of food products that also affects their sensory properties is textural properties. In the present study, a penetration test was used to examine the firmness of different muffin samples, and the results are shown in Table 6 and Figure 7. The results showed that adding citron peel powder to muffin samples changed the firmness of these samples. In general, with increasing the

amount of citron peel powder in the muffin formulation, the firmness of the samples also increased, but this difference was not significant in the 5% sample, while at higher percentages of citron peel powder, this difference in firmness compared to the control sample was significant. The increase in firmness of the texture due to the addition of citron peel powder to the formulation could be due to the interaction between the compounds in citron peel and the compounds in flour. In line with the results of the present study, other researchers also reported that adding citron peel powder and tangerine to muffins also changed the textural properties of muffin samples and increased their firmness. In addition to creating new interactions, it was also reported that the use of fruit peel powder in the formulation of flour products can increase the firmness of the texture by increasing water and oil retention, which is due to the presence of higher amounts of dietary fiber in fruit peel powder. These observations were also reported in connection with the addition of pomegranate peel powder to muffin cakes [12]. Malekpour and Ansari also stated that the addition of pomegranate peel powder to sponge cake increased the firmness of the texture of these products. These researchers reported that by increasing the replacement of cake flour in the formulation with pomegranate peel powder, the amount of hydrocolloid compounds and its fiber increases, and these compounds can weaken the gluten network, reduce the volume of the cake and produce a product with a more compact and firm texture, which is in line with the results of the present study [5].

5 Conclusion

Given the increasing interest of consumers in functional foods, today, much research has been conducted in the field of developing these products that improve the health of the community. In the present study, citron fruit peel powder was used as a rich source of functional compounds to produce enriched muffins. In this study, different percentages of citron fruit peel powder (0, 5, 10, 15 and 20 percent) were used in the muffin formulation and the chemical, antioxidant, textural and sensory properties of the samples were evaluated. The results showed that adding citron fruit peel powder to muffins changed the chemical composition and also increased the fiber content in them. Adding citron peel powder to muffins made the texture firmer and also improved their antioxidant properties, which were measured by the reducing power method and the free radical scavenging method (DPPH). Also, the results of sensory evaluation showed that at lower levels of citron peel powder, the muffin samples were desirable from the consumers' perspective, but at higher percentages, especially 20%, a slight bitter taste was observed in the samples. Overall, the results of this study showed that by using an appropriate percentage of citron peel powder, enriched muffins can be produced that, in addition to good health properties such as antioxidant activity, are also accepted by consumers in terms of organoleptic characteristics.

Suggestions

The following suggestions are presented for further studies:

- Investigating the antioxidant properties of muffin samples produced in laboratory mice
- Investigating the anticancer properties of muffin samples produced
- Investigating the possibility of producing low-fat and low-sugar muffins with the use of citron peel powder to produce more functional products
- Investigating the shelf-life effect on the characteristics of muffins enriched with citron peel powder
- Using artificial sweeteners in muffin samples enriched with citron peel powder to reduce the bitterness caused by citron peel powder in the formulation
- Investigating the possibility of industrial production of muffins enriched with citron peel powder

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