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ORIGINAL RESEARCH PAPER

FLAXSEED - ARROWROOT GEL AS AN EGG REPLACER IN MUFFINS: NUTRITIONAL, PHYSICOCHEMICAL AND SENSORY PROPERTIES

Zhivka T. Goranova[1*], Hristo R. Kalaydzhiev[2], Jesús Blesa[3], Todorka V. Petrova[1], Anka Trajkovska Petkoska[4,5]

[1]*Institute of Food Preservation and Quality - Plovdiv, Agricultural Academy-Sofia, 154 Vasil Aprilov Blvd, 4000 Plovdiv, Bulgaria*
[2]*University of Food Technologies – Plovdiv, Technological Faculty, Department of Analytical Chemistry and Physical Chemistry, 26 Maritsa Blvd, 4002 Plovdiv, Bulgaria*
[3]*University of Valencia, Faculty of Pharmacy, Avenida Vicent Andrés Estellés, s/n, 46100 Burjassot, Spain*
[4]*St. Kliment Ohridski University-Bitola, Faculty of Technology and Technical Sciences, Dimitar Vlahov, 1400, Veles, North Macedonia*
[5]*Korea University, Department of Materials Science and Engineering, 145 Anam-no, Seongbuk-gu, Seoul, South Korea*

*Corresponding author: jivka_goranova@abv.bg

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Abstract: Flaxseeds and arrowroot starch are considered healthy ingredients for the development of functional foods due to their high nutritional and biological value. The egg substitute in the form of flaxseed and arrowroot gel is prepared in a ratio of 1:1:10 (flaxseed:arrowroot:water). This egg substitute was used in muffins at the levels of 0 %, 50 %, and 100 %. All samples were analyzed for physical-chemical, nutritional, and sensory properties. The results showed that flaxseed and arrowroot gel significantly improved the fiber and fat content, but the protein and carbohydrate content was reduced compared to egg muffins. Antioxidant activity increased in eggless muffins than in control. The caloric value was found to be reduced, resulting in a low-calorie product. The results of sensory characteristics show that up to 100 % replacement of eggs with plant-based gel in muffins is satisfactory in the qualitative aspect. Therefore, flaxseed and arrowroot gel can be used as an alternative to eggs and applied as a new functional ingredient in various bakery products.

Keywords: *antioxidant, arrowroot, color, egg replacement, flaxseed, gel, muffin*

INTRODUCTION

The muffin is highly appreciated by consumers as it has a soft texture and characteristic taste. Flour, eggs, sugar, and fat, the main ingredients of muffins, play an important role in the structure, appearance, and nutritional qualities of the final product [1]. The egg, one of the main ingredients, provides functional properties such as coagulation, cushioning, emulsification, foaming, impinging, glazing, and binding ingredients and also possesses high nutritional value [2]. However, the health risks associated with egg consumption and consumers' preference for a vegan diet led researchers to study egg substitutes [3, 4].

In addition, there are a lot of studies related to functional additions to muffins or other bakery products to achieve particular targets like an extension of shelf life [5], changes in texture or sensory properties [6 – 8]; fat replacers [9 – 11], or wheat flour substitute [12], then improving the nutritional profile and certain health benefits [13 – 17], providing better antioxidant capacity [18 – 20] or as natural color [21]. On the other hand, utilization of byproducts from food processing industries could supply plenty of bioactive compounds that could be used in novel formulations of bakery products as well as could contribute towards better planetary health with less pollution [22, 23].

Flaxseed is a functional food with high nutritional value [24, 25]. Flaxseed is rich in fat, protein, and dietary fiber. Other authors have analyzed the composition of brown Canadian flax and found that it contains an average of 41 % fat, 20 % protein, 28 % total dietary fiber, 7.7 % moisture, and 3.4 % ash [5]. It is a major source of omega-3 fatty acids, α-linolenic acid, and phenolic compounds known as lignans, it also contains hydrocolloid gum, also called glue (about 8 % by weight of the seed), and a good quality protein [6]. The functional properties are mostly related to the protein and carbohydrate fractions of the seeds, which will be concentrated in flaxseed flour [7]. Flaxseed gum is a new potential source of mucus that can be used in bakery products as a fat substitute or egg substitute. It has similar properties to other gums, which include good water-holding capacity, water-binding capability, and also rheological properties [8]. Since flaxseed clay has weak gel properties, it can be used to substitute most non-gelling gums for food and non-food applications [26].

Eggs are considered a top allergen [27]. Therefore, the use of plant proteins to partially or completely replace eggs in sweets seems to be an interesting target and especially for people with specific dietary needs or restrictions such as vegans, vegetarians, people with high cholesterol [28 – 30].

The husk of flaxseed, along with the endosperm, forms six layers. Slime or resin comes from the second wall material in the outermost layer. Mucus makes up approximately 8% of seed weight [31]. It is easily extracted from the seed shell by soaking it in water. When hydrated, the mucus cells swell and their contents are released on the surface of the seeds. In a study of Oomah [6] flaxseed mucus contains between 50 - 80 % carbohydrates and 4 - 20 % protein and ash. The main ingredient of flax glue consists of two polysaccharide components, neutral and acidic. The neutral fraction contained L-arabinose, D-xylose, and D-galactose in a molar ratio of 3.5:6.2:1, and the acid fraction contained L-rhamnose, L-fucose, L-galactose, and D-galacturonic acid in a molar ratio of 2.6:1:1.4:1.7 [32].

When baking, the protein in the egg white coagulates to provide structure. The addition of egg white to the muffin dough provides structure to the final product and produces a muffin that is easily broken without excessive crumbling. However, replacing egg white with whole eggs will result in a dry, tough muffin unless the formula is adjusted to increase the amount of fat. The fat in the yolk acts as an emulsifier and contributes to the sensation in the mouth and preservation qualities [33].

The improvement of the functionality of egg substitutes can be applied in some situations, especially when these egg alternatives give better functionality. For example, some egg substitutes give better foaming abilities, binding properties, and taste enhancement. Meanwhile, when it comes to nutrition and health, plant-based ingredients can contribute to or replace some healthier components, for example, these egg substitutes can replace the unhealthy components that eggs provide, such as cholesterol [34].

According to Charles *et al.* [35], the term arrowroot refers to any plant of the genus Marantha, but the term is most commonly used to describe the easily digestible starch from *Maranta arundinacea* rhizomes. Arrowroot starch has a binding temperature above 70 °C and the amylose content can range from 16 to 27 % [36]. Arrowroot starch can also be used in various bakery products, gels, special binders, stabilizers for ice cream, and others, as a substitute for other types containing gluten [37].

Flaxseed and arrowroot are emerging as potential functional foods. The present work deals with the effect of soaked ground flaxseed/sticky flaxseed gel and arrowroot starch on the evaluation of muffin quality due to its nutritional and functional properties and increases the potential use of flaxseed as a food ingredient.

The study aimed to formulate muffins with flaxseed and arrowroot starch gel and evaluate their nutritional, physicochemical, and sensory quality.

MATERIALS AND METHODS

Materials

To produce muffins, the dough used the following materials from some retail chains in Bulgaria: wheat flour (Good mills, Sofia, Bulgaria), eggs, sugar, flaxseed (ZoyaBG, Bulgaria, origin Egypt), and arrowroot starch (ZoyaBG, Bulgaria, origin India). Flaxseed had the following parameters (according to manufacturer's data): 20.90 g of protein,

50.70 g lipids, 7.90 g of saturated, 22.04 g omega-3, 5.12 g omega-6, 10.20 g carbohydrates, 27.22 g total dietary fiber. Arrowroot starch has the following chemical composition per 100 g (according to the manufacturer): 0.06 g fat, 84.80 g carbohydrates, 0.3 g protein and 5.24 g total dietary fiber.

Preparation of flaxseed and arrowroot gel

The substitute for eggs, flaxseed and arrowroot starch is prepared by grinding whole flaxseed into fine particles in a mill (model IKA Tube Mill control, Germany) sieving in a sieve with a mesh size of 60 μm and then adding together with arrowroot to water at 100 °C homogenizing for 5 minutes in a ratio of 1:1:10 ($g \cdot mL^{-1}$). The mixture is then cooled at room temperature for 2 h, after which a gel is obtained by separating the flaxseeds.

Preparation of muffins

Flaxseed gel and arrowroot (50, 100 %) were added to the formula separately, replacing the eggs. The sample containing only egg white and yolk is called the control. The compositions of the muffin samples are given in Table 1.
The muffin control dough was prepared by splitting egg yolks and whites. The egg yolks were mixed with 1/3 of the amount of sugar and whipped with a mixer at a minimum speed in laboratory conditions until a thickened fluffy mass of light cream color was obtained, i.e. until their initial volume increased 2 - 2.5 times. The egg whites are broken with the remaining 2/3 of the amount of sugar at a minimum, medium and maximum speed of the mixer until a snow-white fluffy mass is obtained, i.e. until their initial volume increases 6 - 7 times. The foamed whites and yolks were mixed in a common container and the specified amount of sifted flour was added to them, stirring the mixture until dough was obtained.
The dough was dozed in forms containing 45 g of dough and baked in an oven for 30 minutes at 180 °C. The baked muffins were cooled for 30 min at 25 °C, and then stored at room temperature.

Table 1. *Formulations of muffins*

Sample	Wheat flour [g]	Sugar [g]	Egg yolk [g]	Egg white [g]	Flaxseed [g]	Arrowroot [g]
Control	155	130	68	150	0	0
50 % FA gel*	155	130	34	75	30	30
100 % FA gel	155	130	0	0	60	60

*FA gel = flaxseed and arrowroot gel

Methods

Determination of a water absorption index of flaxseed and arrowroot
The water absorption index (WAI) of arrowroot and flax seeds was determined according to a method described by Choi *et al.* [38]. A 3 g sample was mixed with 30 mL of distilled water and kept in a water bath at 60 °C for 1 h. The sample was then centrifuged at 4000 rpm for 15 minutes using a centrifuge (BIOBASE, model BKC-TL4B, China) and the resulting precipitate was weighed. The water absorption index of the samples is calculated according to equation (1).

$$\text{WAI}\ (g \cdot g^{-1}) = \frac{\boldsymbol{wt.\ of\ water\ uptake\ in\ hydrated\ residue}}{\boldsymbol{wt.\ of\ flour/powder}} \quad (1)$$

Muffin height
The muffin product was taken out from the paper baking case, and the muffin height was measured as the vertical distance from the bottom to the top (highest point) of the muffin center using vernier calipers [39].

Muffin volume
The volume of the muffins, measured by the rapeseed displacement method, was described by Raeva *et al.* [40]. Each muffin was placed in a plastic beaker of known volume, the remaining space in the plastic beaker will be then filled with rapeseed; the

volume of the rapeseed required will be then determined by a graduated cylinder. Muffin volume was calculated as the difference between the total volume and volume of rapeseed.

Muffin density
It was calculated as the ratio of the weight of the muffin to the volume of the muffin [41].

Baking loss
Baking loss is the weight loss (WL %) during baking was calculated by using the following equation 2 [42]:

$$WL\,[\%] = (W_{batter} - W_{muffin}/W_{batter}) \times 100 \quad (2)$$

where: W is weight in g.

Color parameters
instrumentally measure the colors on the crust and the crumb on the muffins, with a colorimeter for quality control, model PCE-CSM 5, Germany on the CIELab system where: L* - lightness (L=0-black; L=100-white); a* (+a=red; -a=green); b*(+b=yellow; -b=blue); C* (Chroma); H* (Hue).

Moisture content
Moisture content (total), expressed as a percentage (respectively dry matter) of the cake (two hours after its final baking) by standard AACC method 44-15A) [43]. A sector of size 1/4 or 1/2 to 1/4 symmetrical parts of at least 5 samples shall be cut from the article. The sample is cut and 3 g is weighed into a weighing glass, placed in an oven at 105 °C and dried to constant weight. The difference between two parallel measurements must not exceed 0.125 %.

Water absorption capacity of muffins
From the average sample not less than 3 samples are taken and with a brush are cleaned of adhering particles. In a container filled with water at 20 °C, the empty cell is immersed, removed, wiped the outer sides with filter paper, and weighed to the nearest 0.01 g. The samples are placed in the cell and weighed. Then, altogether they are immersed in the bath and left for exactly 120 seconds. Later, the cell is removed from the bath and held at a slope for about 30 seconds to drain the water. Again, it is wiped with filter paper (the outer walls) and the wetted cage is reweighed.
The swelling H (%) is calculated using the formula:

$$H = \frac{M - M_1}{M_2 - M_1} .100$$

where: M - the weight of a bowl with hydrated products, g;
M_1 – the weight of the empty bowl, g;
M_2 – the weight of a bowl with dry products.

Microbiological characteristics of muffins
The total number of microorganisms and the number of molds and yeasts in muffins were determined according to the AACC method [43]. The results of the microbiological analysis are expressed as log $cfu \cdot g^{-1}$.

Antioxidant activity
The antioxidant activities of muffins were determined by using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging modified method, as described by Brand-Williams [44] and Taneva [45]. In methanol, DPPH in oxidized form gives a deep violet color. However, antioxidant compounds usually denote an electron to DPPH, thus causing reduction. In reduction form, DPPH turns yellow. A 0.002 % DPPH solution was prepared in methanol and measured at 517 nm. Sample extracts (50 µL) were mixed with 3 mL of the DPPH solution and kept for 15 min in the dark. Then the absorbance was measured again at 517 nm.

Sensory evaluation
A quantitative descriptive sensory profiling test was used to determine the sensory parameters (shape, color, smell, size and uniformity of the pores, sweet taste, residual taste (aftertaste), and softness of the muffins) of the muffins six hours after firing according to ISO 6564 and ISO 6658 method. The samples were prepared one hour before evaluation. The middles of each sample type were cut pieces measuring 1.5 cm x 1.5 cm x 1.5 cm. A panel of ten trained sensory assessors was selected to ensure the accuracy of the assessment. The intensity of each sensory indicator was recorded on a nine-point linear scale after one-hour orientation sessions with sensory evaluators, where they specified terminology and scored points on the scale. The coded samples are presented simultaneously and evaluated in random order between sensory estimators.

Nutritional profile
The proximate analysis of muffins was determined by using the guidelines and methods of AOAC (Association of Official Analytical Chemists): moisture content - method 950.46; crude protein - 981.10; crude fat - 922.06; crude fiber - 978.10 [46].
Nutritional value - the nutritional value has been calculated using conversion factors according to EU Regulation 1169/2011 on the provision of nutrition information to consumers:
- Carbohydrates: 4 $kcal \cdot g^{-1}$;
- Protein: 4 $kcal \cdot g^{-1}$;
- Fats: 9 $kcal \cdot g^{-1}$;
- Fiber: 2 $kcal \cdot g^{-1}$.

Statistics

All the results obtained were analyzed using IBM SPSS Statistics software version 23 by using a one-way ANOVA test. While comparing the means, we were using the Tukey test at a 5 % significant level. The data were presented as mean values of three replicates with standard deviation.

RESULTS AND DISCUSSION

Water absorption index (WAI) of flaxseed and arrowroot

The WAI values of flaxseed and arrowroot were set at 4.55 and 8.23 $g \cdot g^{-1}$, respectively (Table 2).
In the literature, water absorption indices (WAI) of flax seeds have been defined as 5.10 $g \cdot g^{-1}$ [47, 48]. It is believed that the use of flaxseed and arrowroot gels in the muffin formula causes a change in structure by influencing the water absorption indices of the samples. In this study, it was revealed that arrowroot gel has a good ability to absorb water.

Table 2. *Water absorption index (WAI) of flaxseed and arrowroot*

Sample	WAI [$g \cdot g^{-1}$]
Flaxseeds	4.55±0.05^a
Arrowroot	8.23±0.05^b

**Different uppercases in columns and lowercases in rows indicate a significant difference (P ≤ 0.05)*

Physical properties for the muffins

These analyses are of great importance as they determine the quality of final products (Table 3).
The water retention capacity of the new products is lower than that of the control. The pores of the control are therefore smaller and almost equal in size, evenly distributed in the middle and at the same time thinner. The increasing substitution of eggs in the muffin reduces their volume, which ranges from 210.00 ± 10.00 cm^3 to 160.00 ± 9.00 cm^3.

Table 3. *Physical characteristics of muffins*

Samples	Volume [cm^3]	Density [$g \cdot cm^{-3}$]	Height [mm]	Baking loss [%]	Water absorption capacity [%]
Control	210.00±10.00^c	0.24±0.02 ^{c}	7.54±1.22^b	14.33±0.05^b	331.21±5.22^c
50 % FA gel*	190.00±8.00^b	0.26±0.02 ^{b}	6.34±1.04^a	12.22±0.05^a	280.12±6.11^b
100 % FA gel	160.00±9.00^a	0.31±0.01 ^{a}	6.11±1.07^a	12.63±0.03^a	220.51±5.65^a

**Different uppercases in columns and lowercases in rows indicate a significant difference (P ≤ 0.05)*

However, because the density is inversely proportional to volume, the muffin with 100 % egg substitution has the greatest density. This means that the product is less aerated and dense. The muffin control height was the highest; it decreased as the proportion of flaxseed egg substitutes in the formulation increased. The height of the control was 7.54 ± 1.22 mm and varied up to 6.11 ± 1.07 mm in 100 % FA gel. In a similar study, muffin height decreased from 4.133 ± 0.25 cm to 1.300 ± 010 cm when fully replacing eggs with soaked ground flaxseed [34]. In this study, baking loss decreased with the partial substitution of flaxseed egg substitute, which was attributed to the water-binding ability of flaxseed gum.

Color parameters

It is evident from the data presented in Figures 1 and 2 that the values of the indicator L* characterizing the brightness of the color of the bark and the media of test and control samples are significantly reduced. It is noteworthy that for all samples the maximum values for color brightness outstrips those of the control samples. The maximum values for the L* indicator for the bark and the media were found to be recorded in the control sample. The experimental results obtained for the influence of flaxseed and arrowroot gel on the indicator a*, reflecting the participation of the red component in the color of the bark and the crumb of the studied muffins show a tendency to significantly reduce the values of this indicator in the samples 50 % FA and 100 % FA.

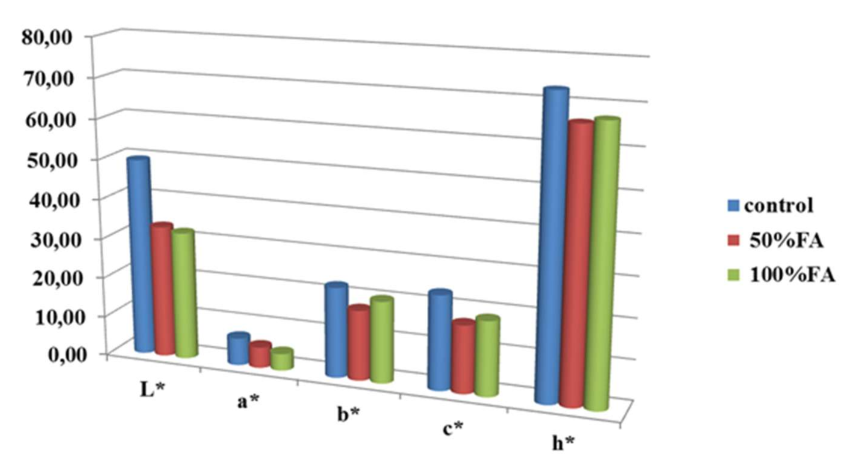

Figure 1. *Color parameters of crumb muffins*

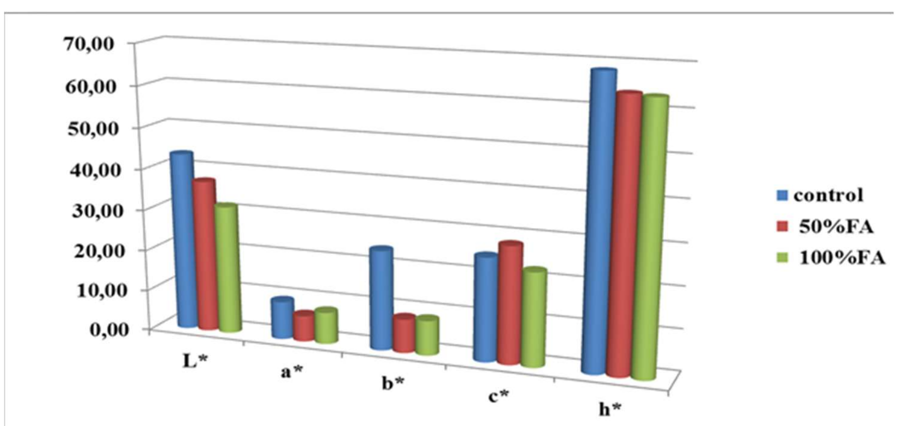

Figure 2. *Color parameters of crust muffins*

The results reflect the changes in the yellow color b* of the color of the rind and the middle of the muffins examined tended to decrease their values recorded in the product mid during the technological process, both for the new and the control samples of the two assortments. However, significantly lower values for this indicator were found in the test samples for the bark of marshes with 15 % elderberry flour. The higher values can be explained by the ongoing Mayard reactions and caramelization of sugars, as well as the influence of the gel. It should be noted that the values of indicator b* for the bark of marshes with new products are 3 times lower compared to the control ones. Likely, the plant-based hydrogel has a positive effect on color formation in new samples. The C* saturation of color is an indicator determining the visual perception of color by which color quality is characterized. The hue H* can usually be represented quantitatively by a single number, often corresponding to an angular position around a central or neutral point or axis of a diagram with color space coordinates. Different shades are reported in the crumb of the muffins containing gel, which correlates with the brightness and saturation shown.

Microbiological characteristics of muffins

The data showed that the total number of muffin microorganisms was influenced by the replacement of eggs with and gel of flaxseed and arrowroot, respectively (Figure 3). Namely, the results of the addition of the functional ingredients showed a significant decrease in the total bacterial counts in muffins (1.08 - 1.10 log cfu·g^{-1} in 50 % FA gel and 100 % FA gel) compared to the control sample (2.24 log cfu·g^{-1}) which had the highest bacterial count.

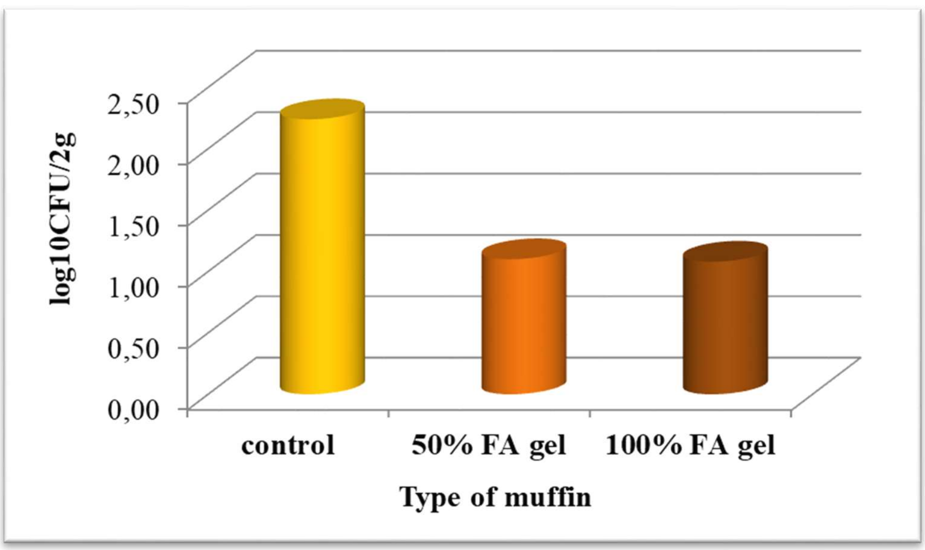

Figure 3. *Total plate count of muffins*

The small difference in the total number of microorganisms between all muffins can be due to the difference in the level of the main and additional ingredients. Dried fruits contain a very high sugar content, which is attributed to hygroscopic behavior, extracting water from the product and inserting sugar molecules inside, so there is much less water for microbial activity. Microorganisms are mostly neutrophils and cannot grow at less than 4.5 *p*H and 0.8 water activity (a_w). Water stress increases with lower water activity, and these processes help prevent the proliferation of microorganisms. Various factors affect mold growth, including water activity, relative humidity, temperature, *p*H, and storage time. Molds can easily survive with an a_w of 0.80, but no mold growth can occur when a_w is equal to or less than 0.62 [49]. Mold growth occurs more frequently at a_w from 0.62 to 0.85. Mold survival at lower a_w also depends on oxygen retention, nutrient availability, solute concentration, temperature, and *p*H. At lower a_w with high osmotic pressure, spores, and vegetative cells cannot survive [50].

Antioxidant activity

The free radical trapping activity of the muffin extracts with and without eggs was evaluated and the results are shown in Table 4.

Table 4. *Antioxidant activity of muffins*

Sample	DPPH (inhibition %)
Control	15.22±0.02[a]
50% FA gel*	32.51±0.12[b]
100% FA gel	40.11±0.08[b]

**Different uppercases in columns and lowercases in rows indicate a significant difference (P ≤ 0.05)*

A DPPH assay was conducted to evaluate free radical trapping to assess the extent of antioxidant activity. The control showed the least DPPH clearing activity, while the cake with 100 % gel (100 % FA gel) provided the best inhibition of DPPH (40.11 %). The increase in the antioxidant activity of hydrogel muffins is due to the inclusion of flaxseed, which contains high antioxidant activity (46 %).

It has also been suggested that high amounts of flax seed bioactive substances remain stable during the roasting process and impart antioxidant properties to muffins.

Sensory evaluation

Sensory analysis is a combination of techniques and methods to evaluate sensory properties such as the shape, color, smell, taste, residual aftertaste, and texture of sponge cakes. These properties are crucial for the overall perception of products. For this reason, it is extremely important to determine how potential users (sensor evaluators) evaluate muffins with different functional components and which have the closest sensory characteristics to those of the control product. Odor, taste, and residual taste are important sensory characteristics necessary for the next analysis of products with a functional component.

After conducting a sensory analysis, it was found that the control and the devices with functional components had differences in shape, but in the control, the bark was softer and greater elasticity was found for its crumb to the egg-free muffins (Figure 4).

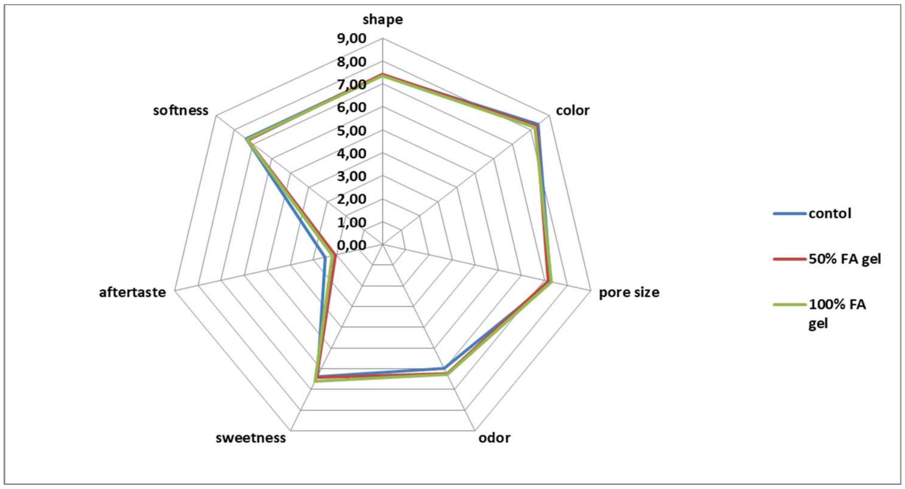

Figure 4. *Sensory profile of muffins*

The sensory analysis revealed specific improvements in the texture and flavor of the muffins with flaxseed and arrowroot gel. The muffins with functional components had a noticeable improvement in texture, with a more uniform crumb structure. The texture of the egg-free muffins was slightly denser compared to the control, but still, their overall mouthfeel was softer and moister due to the higher water retention capacity of flaxseed and arrowroot.

Regarding flavor, the muffins with flaxseed and arrowroot gel exhibited a more pronounced aroma compared to the control, with a slightly nutty and earthy flavor. Although the sweetness was less intense, likely due to the reduced sugar content from egg replacement, the overall flavor profile was still balanced and acceptable. The residual aftertaste of the muffins with functional ingredients was more noticeable but pleasant, contributing to a unique flavor experience.

The elasticity of the cake is a superficial response to its microstructure. The pores of the muffin without eggs are thicker-walled, larger, and equal in size. The bark and crumb of the control were of a pronounced light-yellow color, due to the presence of dye components in the egg yolk (carotenoids) (Figures 5 and 6). The color of the bark and crumb of the gel muffins is grayish-brown, with a gray color prevailing in the brim. This color is uncharacteristic of pastry confectionery, but appraisers perceive it. The smell of new products is more pronounced, and specific, compared to the smell of the control. They had a less pronounced sweet taste than that of the control. It is reported that the greater content of flaxseed gel and arrowroot masks the sweet taste. Gel-added muffins had a strong residual aftertaste but were pleasant compared to the control.

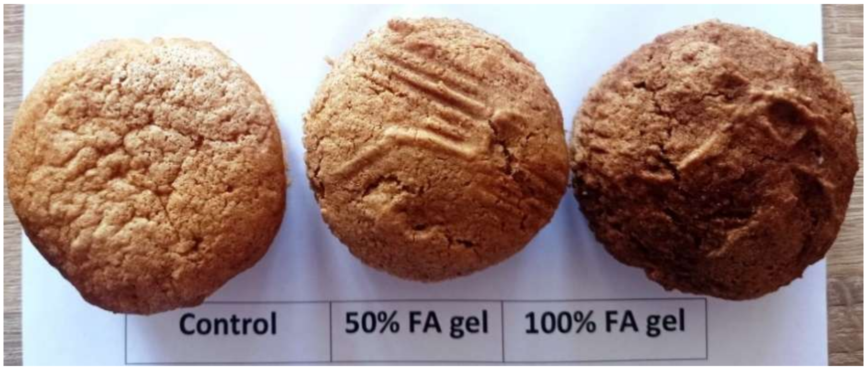

Figure 5. *Visualization of crust muffins*

Figure 6. *Visualization of crumb muffins*

Nutritional profile

The results of the chemical composition and energy value of the muffins are presented in Table 5. In terms of moisture content, the highest values were reported in flaxseed and arrowroot gel muffins (25.75 - 27.35 %), compared to the control (22.50 %). It has been shown that the flaxseed gel that was added to the muffin dough, as an egg substitute, has a water-binding function [51].

Table 5. *Nutritional profile of muffins without and with flaxseed and arrowroot gel*

Nutritional properties	Samples		
	Control	50 % FA gel	100 % FA gel
Moisture [%]	22.50±0.10	25.75±0.05	27.35±0.90
Carbohydrates [%]	59.60±0.20	45.83±1.40	38.50±0.30
Fiber [%]	2.01±0.20	4.56±0.10	5.08±0.20
Protein [%]	11.58±0.10	8.90±0.11	6.22±0.10
Lipids [%]	6.32±0.03	7.42±0.12	6.84±0.27
Energy value [kcal]	335.00	294.83	250.62

The control sample was characterized by the highest protein content (11.58 %), while the lowest protein content was found in a muffin with 100 % flaxseed gel and arrowroot (6.22 %). The highest fat content was determined in sample 50 % FA (7.42 %) and the lowest content was in control (6.32 %) while the highest percentage of carbohydrates was determined in the control (59.60 %), with the lower carbohydrate content of the

new products. According to the results obtained, the carbohydrate content decreases with the replacement of eggs. Moreover, the results showed that there was a significant increase in the dietary fiber content of muffins containing functional ingredients.
The highest amount of dietary fiber was contained in the muffin 100 % FA (5.08 %), while the content in the control was 2.01 %. By forming a viscous solution, dietary fiber slows intestinal transit, slows down gastric emptying, and reduces glucose and sterol absorption from the intestine. The energy value of muffins is from 250.62 kcal/100 g to 335.00 kcal/100 g product, with a 100 % FA muffin having the lowest energy value, the control has the highest carbohydrate and protein content and therefore has the highest energy value.

CONCLUSIONS

In this study, flaxseed and arrowroot starch were selected as plant-based functional ingredients to replace eggs in muffins. The incorporation of flaxseed and arrowroot significantly enhanced the muffins' physicochemical, sensory, and nutritional characteristics. The results suggest that the combination of flaxseed and arrowroot starch is an effective egg replacer, improving texture, moisture retention, and antioxidant properties, while also enhancing the dietary fiber content. Muffins made with these functional ingredients demonstrate better overall quality, compared to the control, and could be considered a healthier alternative with preventive properties.
However, there are some limitations to the study. The effect of flaxseed and arrowroot gels on the shelf life and long-term stability of the muffins was not evaluated, and further research could investigate the optimal storage conditions for muffins containing these ingredients. Additionally, sensory acceptance among a larger, more diverse consumer group could provide more insights into the market potential of these egg-free muffins. Future studies could also explore the possibility of combining flaxseed and arrowroot with other functional ingredients, such as plant-based proteins, to further enhance the nutritional profile and texture of the muffins.
In conclusion, muffins made with flaxseed and arrowroot as egg substitutes represent a promising alternative for consumers seeking healthier, egg-free options, with the potential for further optimization in terms of texture, flavor, and shelf-life stability.

REFERENCES

1. Karaoğlu, M.M., Kotancilar, H.G.: Quality and textural behavior of par-baked and rebaked cake during prolonged storage, *International Journal of Food Science & Technology,* **2008**, **44** (1), 93-99;
2. Yang, S.C.; Baldwin, R.E.: Functional properties of eggs in foods, in: *Egg Science and Technology* 4th edition (Editors: Stadelman, W.J., Cotterill, O.J.), Boca Raton, CRC Press, **1995**, 405-463;
3. Murughar, A.D., Zaidi, Z., Kotwaliwale, N., Gupta, C.: Effect of egg-replacer and composite flour on physical properties, color, texture and rheology, nutritional and sensory profile of cakes, *Journal of Food Quality*, **2016**, **39** (5), 425-435;
4. Bozan, B., Temelli, F.: Chemical composition and oxidative stability of flax, safflower and poppy seed and seed oils, *Bioresource Technology*, **2008**, **99** (14), 6354-6359;
5. Morris, D.H.: Flax: *A Health and Hutrition Primer*, 4th edition, Flax Council of Canada, Winnipeg, MB, Canada, **2007**;

6. Oomah, B.D.: Flaxseed as a functional food source, *Journal of the Science of Food and Agriculture*, **2001**, **81** (9), 889-894;
7. Teh, S.S., Bekhit, A.E.D., Carne, A., Birch, J.: Effect of the defatting process, acid and alkali extraction on the physicochemical and functional properties of hemp, flax and canola seed cake protein isolates, *Journal of Food Measurement and Characterization*, **2014**, **8** (2), 92-104;
8. Fedeniuk, R.W., Biliaderis, C.G.: Composition and physicochemical properties of flaxseed (*Linum usitatissimum L.*) mucilage, *Journal of Agricultural and Food Chemistry*, **1994**, **42** (2), 240-247;
9. Azmoon, E., Saberi, F., Kouhsari, F., Akbari, M., Kieliszek, M., Vakilinezam, A.: The effects of hydrocolloids-protein mixture as a fat replacer on physicochemical characteristics of sugar-free muffin cake: Modeling and optimization, *Foods*, **2021**, **10** (7), 1549, https://doi.org/10.3390/foods10071549;
10. Samakradhamrongthai, R.S., Maneechot, S., Wangpankhajorn, P., Jannu, T., Renaldi, G.: Polydextrose and guar gum as a fat substitute in rice cookies and its physical, textural, and sensory properties, *Food Chemistry Advances*, **2022**, **1**, 100058, https://doi.org/10.1016/j.focha.2022.100058;
11. Nieto-Mazzocco, E., Saldaña-Robles, A., Franco-Robles, E., Mireles-Arriaga, A.I., Mares-Mares, E., Ozuna, C.: Optimization of gluten-free muffin formulation with agavin-type fructans as fat and sucrose replacer using response surface methodology, *Future Foods*, **2022**, **5**, 100112, https://doi.org/10.1016/j.fufo.2021.100112;
12. Khatun, M., Ahmed, M.W., Hossain, M.M., Karmoker, P., Iqbal, A.: Utilization of Banana Peel Flour in Biscuit Making as Wheat Flour Substitute, *European Journal of Agriculture and Food Sciences*, **2021**, **3** (6), 32-35;
13. Binou, P., Yanni, A.E., Kartsioti, K., Barmpagianni, A., Konstantopoulos, P., Karathanos, V.T., Kokkinos, A.: Wheat biscuits enriched with plant-based protein contribute to weight loss and beneficial metabolic effects in subjects with overweight/obesity, *Nutrients*, **2022**, **14** (12), 2516, https://doi.org/10.3390/nu14122516;
14. Rabail, R., Sultan, M.T., Khalid, A.R., Sahar, A.T., Zia, S., Kowalczewski, P.Ł., Jeżowski, P., Shabbir, M.A., Aadil, R.M.: Clinical, nutritional, and functional evaluation of chia seed-fortified muffins, *Molecules*, **2022**, **27** (18), 5907, https://doi.org/10.3390/molecules27185907;
15. Donno, D., Fabro, M., Mellano, M.G., Gamba, G., Fioccardi, A., Beccaro, G.L.: Integrating traditional wheat-based foods with high health value flours: *Castanea* spp. agro-biodiversity in bakery products, *Agriculture*, **2022**, **12** (7), 946, https://doi.org/10.3390/agriculture12070946;
16. Mustafa, A.M., Abouelenein, D., Acquaticci, L., Alessandroni, L., Angeloni, S., Borsetta, G., Caprioli, G., Nzekoue, F.K., Sagratini, G., Vittori, S.: Polyphenols, saponins and phytosterols in lentils and their health benefits: An overview, *Pharmaceuticals*, **2022**, **15** (10), 1225, https://doi.org/10.3390/ph15101225;
17. Vilas-Boas, A.M., Brassesco, M.E., Quintino, A.C., Vieira, M.C., Brandão, T.R.S., Silva, C.L.M., Azevedo, M., Pintado, M.: Particle size effect of integral carob flour on bioaccessibility of bioactive compounds during simulated gastrointestinal digestion, *Foods*, **2022**, **11** (9), 1272, https://doi.org/10.3390/foods11091272;
18. Bangar, S.P., Sandhu, K.S., Rusu, A., Trif, M., Purewal, S.S.: Evaluating the effects of wheat cultivar and extrusion processing on nutritional, health-promoting, and antioxidant properties of flour, *Frontiers in Nutrition*, **2022**, **9**, 872589, https://doi.org/10.3389/fnut.2022.872589;
19. Hajas, L., Sipos, L., Csobod, É.C., Bálint, M.V., Juhász, R., Benedek, C.: Lentil (*Lens culinaris* Medik.) flour varieties as promising new ingredients for gluten-free cookies, *Foods*, **2022**, **11** (14), 2028, https://doi.org/10.3390/foods11142028;
20. Bokić, J., Kojić, J., Krulj, J., Pezo, L., Banjac, V., Tumbas Šaponjac, V., Travičić, V., Moreno, D.A., Bodroža-Solarov, M.: Bioactive, Mineral and antioxidative properties of gluten-free chicory supplemented snack: Impact of processing conditions, *Foods*, **2022**, **11** (22), 3692, https://doi.org/10.3390/foods11223692;
21. Galdeano, M.C., dos Santos Gomes, F., Chávez, D.W.H., Almeida, E.L., Moulin, L.C., de Grandi Castro Freitas de Sá, D., Tonon, R.V.: Lycopene-rich watermelon concentrate used as a natural food colorant: Stability during processing and storage, *Food Research International*, **2022**, **160**, 111691, https://doi.org/10.1016/j.foodres.2022.111691;
22. Egea, M.B., De Sousa, T.L., Dos Santos, D.C., De Oliveira Filho, J.G., Guimarães, R.M., Yoshiara, L.Y., Lemes, A.C.: Application of soy, corn, and bean by products in the gluten free baking process: A review, *Food and Bioprocess Technology*, **2023**, **16**, 1429-1450;

23. Soares, I.D., Cirilo, M.E.M., Junqueira, I.G., Vanin, F.M., Rodrigues, C.E.d.C.: Production of cookies enriched with bioactive compounds through the partial replacement of wheat flour by cocoa bean shells, *Foods*, **2023**, **12** (3), 436, https://doi.org/10.3390/foods12030436;
24. Mueed, A., Shibli, S., Korma, S.A., Madjirebaye, P., Esatbeyoglu, T., Deng, Z.: Flaxseed bioactive compounds: chemical composition, functional properties, food applications and health benefits-related gut microbes, *Foods*, **2022**, **11** (20), 3307, https://doi.org/10.3390/foods11203307;
25. Sangiorgio, P., Errico, S., Verardi, A., Moliterni, S., Tamasi, G., Rossi, C., Balducchi, R.: Bioactive lignans from flaxseed: Biological properties and patented recovery technologies, *Nutraceuticals*, **2023**, **3**, 58-74;
26. Chen, H.H., Xu, S.Y., Wang, Z.: Gelation properties of flaxseed gum, *Journal of Food Engineering*, **2006**, **77** (2), 295-303;
27. https://bakerpedia.com/ingredients/egg-replacement/, Bakerpedia. *Egg Replacement*. Retrieved from, **2022, 08.08.2024**;
28. Hussain, A.S., Oulabi, R.A.: Studying the possibility of preparing an egg-free or egg-less cake, *International Journal of Engineering & Technology*, **2009**, **1** (4), 324-329;
29. Yazici, G.N., Ozer, M.S.: A review of egg replacement in cake production: Effects on batter and cake properties, *Trends in Food Science & Technology*, **2021**, **111**, 346-359;
30. Khan, S., Shah, H., Kamal, S., Rehman, A., Shehzad, Q., Karamat, U., Karim, A., Hussain, M., Muneeb, M., Xia, W.: Preparation and quality attributes of egg-reduced pound cake incorporating grass carp (*Ctenopharyngodon idella*) protein concentrate, *Journal of Aquatic Food Product Technology*, **2022**, **31** (3), 242-258;
31. Daun, J.K., Barthet, V.J., Chornick, T.L., Duguid, S.: Structure, composition, and variety development of flaxseed, in: *Flaxseed in Human Nutrition*, 2nd edition (Editors: Thompson, L.U., Cunnane, S.C.), Champaign, Illinois, AOCS Press, **2003**;
32. Oomah, B.D.: Flaxseed as a functional food source, *Journal of the Science of Food and Agriculture*, **2001**, **81** (9), 889-894;
33. Cross, N.: Muffins and bagels, in: *Handbook of Food Products Manufacturing*, vol. 1 (Editor: Hui, Y.H.), John Wiley and Sons Inc, Hoboken, (New Jersey), **2007**, 279-305;
34. Kostor, S.N.S.B., Hammed, S.N.A., Rosli, S.N.N.N.S.: Effect of physical of aquafaba and flaxseed on basic muffin as an egg replacer, *Festival Agro Makanan dan Bioteknologi*, **2021**, 1-6;
35. Charles, A.L., Cato, K., Huang, T.C., Chang, Y.H., Ciou, J.Y., Chang, J.S., Lin, H.H.: Functional properties of arrowroot starch in cassava and sweet potato composite starches, *Food Hydrocolloids*, **2016**, **53**, 187-191;
36. Moorthy, S.N.: Physicochemical and functional properties of tropical tuber starches: a review, *Starch/Stärke*, **2002**, **54** (12), 559-592;
37. Jyothi, A.N., Sajeev Sreekumar, J.N.: Hydrothermal modifications of tropical tuber starches. Effect of heat–moisture treatment on the physicochemical, rheological and gelatinization characteristics, *Starch/Stärke*, **2010**, **62** (1), 28-40;
38. Choi, I., Han, O.K., Chun J., Kang, C.S., Kim, K.H., Kim, Y.K., Cheong, Y.K., Park, T.I., Choi, J.S., Kim, K.J.: Hydration and pasting properties of oat (*Avena Sativa*) flour, *Preventive Nutrition and Food Science*, **2012**, **17** (1), 87-91;
39. Lee, P., Oh, H., Kim, S., Kim, Y.: Textural, physical and retrogradation properties of muffin prepared with kamut (*Triticum turanicum Jakubz*), *Italian Journal of Food Science*, **2020**, **32** (1), 107-124;
40. Raeva, P.; Baeva, M.; Dimitrov, D.: Effects of mung bean flour on sponge cake quality, *Scientific Study & Research – Chemistry & Chemical Engineering, Biotechnology, Food Industry*, **2024**, **25** (3), 277-286;
41. Hera, E., Ruiz-París, E., Oliete, B., Gómez, M.: Studies of the quality of cakes made with wheat-lentil composite flours, *Lebensmittel-Wissenschaft und-Technologie*, **2012**, **49** (1), 48-54;
42. Rodríguez García, J., Puig Gómez, C.A., Salvador, A., Hernando Hernando, M.: Functionality of several cake ingredients: a comprehensive approach, *Czech Journal of Food Sciences*, **2013**, **31** (4), 355-360;
43. American Association of Cereal Chemists AACC: *Approved methods of the American Association of Cereal Chemists*, 10th edition, American Association of Cereal Chemists, Inc., St. Paul (MN) **2000**;
44. Brand-Williams, W., Cuvelier, M.E., Berset, C.: Use of a free radical method to evaluate antioxidant activity, *LWT – Food Science and Technology*, **1995**, **28** (1), 25-30;

45. Taneva, I., Zlatev, Z.: Antioxidant activity and physicochemical parameters of yogurt enriched with extracts of red hawthorn (*Crataegus Monogyna* Jacq.) and black (*Crataegus nigra* Waldst & Kit.), *Scientific Study & Research – Chemistry & Chemical Engineering, Biotechnology, Food Industry*, **2024**, **25** (3), 239-253;
46. AOAC (Association of Official Analytical Chemists), **2023**. 950.46; 981.10; 922.06; 978.10;
47. Hatamian, M., Noshad, M., AbdananMehdizadeh, S., Barzegar, H.: Effect of roasting treatment on functional and antioxidant properties of chia seed flours, *NFS Journal*, **2020**, **21**, 1-8;
48. Kumar, R.K., Bejkar, M., Du, S., Serventi, L.: Flax and wattle seed powders enhance volume and softness of gluten-free bread, *Food Science and Technology International*, **2019**, **25** (1), 66-75;
49. Rahman, M.S.: *pH in food preservation: handbook of food preservation*, 2nd edition, Taylor and Francis Press, New York, **2007**, 289-295;
50. Mohd-Zaki, Z., Bastidas-Oyanedel, J., Lu, Y., Hoelzle, R., Pratt, S., Slater, F., Batstone, D.: Influence of pH regulation mode in glucose fermentation on product selection and process stability, *Microorganisms*, **2016**, **4** (1), 2, https://doi.org/10.3390/microorganisms4010002;
51. Konecsni, J., Vidal, J., Kupper, C., Loutas, P., Reaney, M.: *US 2005/0249860 A1*, **2005**.