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Sensory and Lipid Profile Optimization of Functional Brownies Through Cold-Pressed Nut Oil Substitution for Butter

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Abstract: This study evaluated the effects of replacing butter, rich in saturated fats, partially (50%) and totally (100%) with nut oils (almond, pistachio, and walnut) on the physical, nutritional, and sensory properties of chocolate brownies. By replacing butter with nut oils, the brownies became softer and more elastic, particularly with walnut oil. This change could make the brownies more appealing to consumers who prefer a softer, chewier product. The increased cohesiveness in the brownies containing almond and walnut oils (50% substitution) suggests better structure and consistency, which could contribute to a more pleasant eating experience. The reduction in gumminess and chewiness, particularly in the 100% nut oil formulations, indicates a potentially improved texture, making the brownies easier to bite into and consume. Regarding color, the analysis showed that the luminosity of the brownies was quite similar across all samples, although small differences were noticed between the dough and the baked product. The colorimetric parameters a* and b* indicated that the baking process had an intensifying effect on the color, making the final product more uniform across all samples. In terms of nutritional composition, it was observed that the moisture content decreased as the proportion of nut oil increased. The fat content rose in all nut oil-replaced brownies, with the highest increase noted in the almond and pistachio oil formulations. As a result, the energy content also increased due to the higher fat content. The protein content showed only slight differences, with a slight decrease compared to the control (butter-based) brownies. When examining the fatty acid profile, the study found that the palmitic acid (saturated fatty acid) levels were significantly reduced in the brownies with 100% nut oil substitutions, especially in those made with almond and walnut oils. Oleic acid (monounsaturated fatty acid) increased significantly, particularly in almond and pistachio oil formulations. Linoleic acid (polyunsaturated fatty acid) also increased in all reformulated brownies, with the highest levels found in the walnut oil-based brownies. Additionally, the levels of Vitamin E were higher in the 100% nut oil substitutions, offering potential health benefits. The sensory evaluation of the brownies showed that consumers preferred the reformulated versions, with higher scores for flavor, texture, and overall acceptability compared to the traditional recipe. The brownies with nut oil replacements were favored for their softer, moister texture and improved flavor, which contributed positively to the overall consumer experience. These findings suggest that replacing butter with nut oils not only enhances the nutritional profile of the brownies, making them healthier, but also results in a product that is more appealing to consumers in terms of taste and texture. The study concluded that the substitution of butter with nut oils is a viable approach for improving both the nutritional content and sensory properties of baked goods.

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1. Introduction

Bakery products include items such as cakes or cookies, and they are consumed daily in large quantities. The main issue is that these types of ultra-processed foods are filled with saturated fats, refined flours, and sugars [1]. One of the most popular products worldwide is chocolate brownies, which are made from butter, sugar, flour, chocolate, and eggs. Specifically, much of the brownie formulation consists of butter, which is a saturated fatty acid (SFA). In recent years, the baking industry has increasingly embraced healthier and more sustainable ingredients, with a particular interest in replacing butter with vegetable oils, as they are rich in unsaturated fats [2]. Studies have shown that these oils can enhance the lipid profile of baked goods by lowering the saturated fat content, which is linked to LDL cholesterol and cardiovascular risk [3]. This shift aligns with the growing demand for functional foods, a sector experiencing immense growth with annual growth rates between 8% and 14%, and global market estimates of approximately USD 167 billion [4].

As the incidence of obesity, type 2 diabetes, and cardiovascular diseases rises, food industries around the world produce foods whose packaging contains unattractive labels due to high levels of salt, sugar, and fats, especially saturated fats [5]. The dietary intake of saturated fats, such as butter, has been associated with an increased risk of cardiovascular diseases as they tend to raise low-density lipoprotein cholesterol. Randomized clinical trials testing the effects of reducing saturated fats on cardiovascular risk have generally replaced saturated fats with polyunsaturated fats, monounsaturated fats, or carbohydrates [6]. Despite the well-documented risk of excessive saturated fat consumption, these fats remain prevalent in many diets due to the wide availability of foods rich in them and a lack of public awareness about their dangers.

According to [7], the main cardiovascular diseases (CVDs) arise due to excessive consumption of fats, especially saturated fats. The consumption of monounsaturated fatty acids found in vegetable oils and Omega-3, present not only in animal-derived foods like salmon or tuna but also in plant-based sources such as nuts, helps to prevent these types of diseases by reducing cholesterol levels, triglycerides, and blood pressure. Moreover, the consumption of products rich in polyphenols, vitamins, and minerals, which are also found in nuts, and which have antioxidant, anti-inflammatory, anticancerogenic, and cardiovascular protective effects, has been shown in epidemiological studies to have the potential to reduce the risk of cardiovascular diseases [8].

Saturated fats are used in baked goods because they contribute to mouthfeel, tenderness, structure, moisture, flavor, texture, and overall acceptability [9]. Additionally, the role of fats is to trap air in the dough during mixing, which provides structure for the leavening gases. They also affect the final product's volume and interfere with the protein matrix, adding lubricity to the texture by coating starch and protein particles [10].

Nuts are a potential source of unsaturated fatty acids, protein, dietary fiber, minerals such as potassium and magnesium, vitamin E, folate, and other bioactive compounds such as phenols and phytosterols [11]. Many of the nutritional components of nuts have been studied due to their multiple health benefits [12]. Pistachios have a high content of unsaturated and monounsaturated fats; specifically, they are rich in linoleic acid (13.1 g/100 g) and oleic acid (23.9 g/100 g). This oil can be used by the food industry as a condiment or a substitute for saturated fats, due to its flavor, aroma, and color, creating new culinary perspectives. It can also be used in the cosmetic and pharmaceutical industries due to its emollient properties and vitamin content [13]. Walnut is very rich in monounsaturated fatty acids. It is a perfect source of Omega-3 and arachidonic acid. Additionally, it contains many phytochemicals that have antioxidant effects, such as melatonin, ellagic acid, vitamin E, carotenoids, and polyphenols [14,15]. These mentioned compounds have shown potential health benefits, such as delaying aging, preventing cancer, reducing inflammatory processes, and protecting against neurological diseases [16]. Almonds stand out for their low content of saturated fatty acids (<0.1–4.1%) and their high content of monounsaturated fatty acids (31–33%). Additionally, almonds are a source of polyphenols, with a high presence of hydrolyzable tannins, proanthocyanidins, and flavonoids, regardless of the nature of the almond (roasted or raw) [17]. It has been reported that incorporating almonds into the diet reduces the risk of colon cancer, increases HDL cholesterol, and reduces LDL cholesterol levels. Furthermore, powerful free radical scavenging capacities have been observed, due to the presence of flavonoids and other phenolic compounds [18].

There have been other attempts to provide healthier alternatives to bakery products. For instance, the authors of [19] studied the effects of replacing commercial margarines for rice bran oil emulsions in chocolate brownies. The new formulas exhibited texture and sensory properties similar to commercial brownies, but with a significant reduction in saturated fatty acids and lower hardness. The authors of [20] carried out an essay where butter was totally replaced by seeds and nut oil emulsions. The new formulas presented better texture parameters, which were appreciated by consumers, and the lipid profile was enhanced, with a higher proportion of unsaturated fatty acids and vitamin E. The authors of [21] used structured emulsions as butter substitutes in shortbread cookies. They found that structured emulsions represent a good solution to produce nutritionally improved cookies, but the texture and color are compromised. They also received promising scores in the sensory analysis in terms of texture and overall acceptability, despite the butter product still being the preferred sample.

Replacing butter with nut oils like pistachio, walnut, and almond oils offers a powerful upgrade to traditional brownies, improving both their nutritional profile and flavor. These oils are rich in heart-healthy monounsaturated fats and antioxidants, making them an excellent choice for consumers looking for a healthier dessert option without compromising the taste. These oils not only enhance the brownies' flavor with their unique, rich profiles but they also support long-term health benefits, such as improved cholesterol levels and reduced inflammation. As consumer demand grows for functional, nutritious foods, this study aims to provide valuable insights into how replacing butter with nut oils can create a more accessible and health-conscious dessert, contributing to the development of innovative, better-for-you bakery products that meet the evolving needs of today's market. This study aims to demonstrate how such simple ingredient swaps can help meet the growing consumer demand for functional, nutritious foods, making it easier for people to incorporate functional foods into their everyday diets.

2. Materials and Methods

2.1. Raw Materials

Nuts were obtained from local providers in the Castilla-La Mancha region (Spain). The nuts used were almond (*Prunus dulcis* 'Marcona'), pistachio (*Pistacia vera* 'Kerman'), and walnut (*Juglans regia* 'Nerpio'). The choice of these cultivars was primarily driven by their availability in our autonomous community, and also what they had in Castilla-La Mancha. Walnuts were used in fresh form, while pistachios were roasted at 100 °C and almonds at 150 °C, both for 30 min in a conventional oven. Before extraction, the seeds and nuts were ground for two 20 s cycles at 10,000 rpm using a blade mill (RETSCH modelo

GM 20, Verder Scientific GmbH & Co., KG., Haan, Germany) and were placed in cotton cloths, weighing 200 g each.

Oils were obtained in the pilot plant of the Higher Technical School of Agronomic and Forestry Engineering and Biotechnology (ETSIAMB, Albacete, Spain) using a hydraulic press (MECAMAQ modelo DEVF, El Palau D'Anglesola, Spain) under the conditions of 10 min extraction at 200 bars of pressure [13].

Once the oil was obtained, and due to the turbidity caused by sediments which could interfere with subsequent analytical measurements, the oils were subjected to a centrifugation process. A CENTRONIC-BL centrifuge (J.P. Selecta, Abrera, Spain) was used at a speed of 12,000 rpm for 5 min. The oils were stored in opaque glass bottles under refrigeration at 4 °C to avoid degradation.

2.2. Product Reformulation

The butter in the brownies was partially (50%) and fully (100%) replaced with oils from pistachio, walnut, and almond cold-pressed oils. Additionally, a control sample was made with butter (Figure 1). The ingredients used were 100 g of fat, 240 g of eggs, 180 g of sugar, 100 g of flour, and 100 g of chocolate.

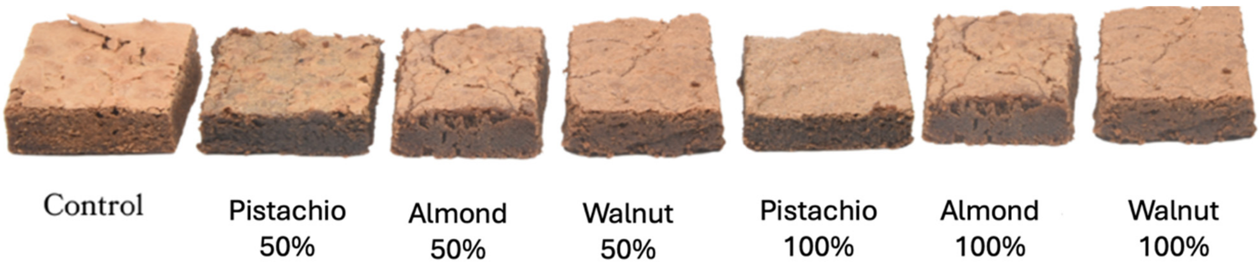

Figure 1. External appearance of the control and the reformulated brownies with nut oils.

The formulation and the method were based on [22] with some modifications. First, butter or oil and chocolate were melted using a double boiler method and cooled to room temperature. Then, eggs and sugar were mixed in a bowl. The mixture was then combined with the previous chocolate mixture. Then, wheat flour was added and mixed. The final mixture was placed in a baking tin and was oven-baked at 180 °C for 25 min. After baking, it was removed from the baking tin and left to cool for 1 h to avoid wetting the samples with the contained steam. Physical and sensory analysis was carried out on freshly baked brownies. The rest were sealed to 60% in polyamide and polytene bags and stored at 14 °C until used for further chemical analysis.

2.3. Physical Parameters

Brownies were evaluated for color using a Minolta CR-200 colorimeter (Minolta Camera Co., Ltd., Osaka, Japan) with a D_{65} illuminant. The color values were measured using a CIE L* a* b* scale in 4 random zones of 4 different doughs and baked brownies (3 × 3 × 3 cm) that were randomly selected, and the means were recorded as L* = lightness (0 = black, 100 = white), a* (−a* = greenness, +a* = redness), and b* (−b* = blueness, +b* = yellowness).

A texture profile analysis (TPA) was selected as a method to evaluate the texture of the brownies. Brownies were cooled at room temperature for 3 h and sequentially analyzed. Measures were taken using 4 pieces of each brownie formulation (3 × 3 × 3 cm) for two-cycle compression using a texture analyzer TA-TX Plus (Stable Micro Systems, Godalming, UK), equipped with a 50 mm round diameter probe at 3.3 mm/s, a 30 kg load cell, and 60% of compression.

2.4. Chemical Analysis

Moisture, fat (Ankom XT10), protein (Kjeldahl), dietetic fiber (Weende), and carbohydrate analyses were carried out according to AOAC standardized methods. The total energy was calculated from proteins, carbohydrates, and fats based on 100 g of sample [23].

Methyl esters of fatty acids were obtained through cold transesterification with methanolic potassium hydroxide, adding 2 mL of n-hexane to 0.02 g of oil previously extracted from samples by Soxhlet extraction with petroleum ether for 3 h.

Then, 200 μL of a methanolic potassium hydroxide solution (2 mol L^{-1}) was added and mixed vigorously. Once the supernatant was transferred to a glass vial, it was analyzed by gas chromatography on a Shimadzu GC-2010 Plus gas chromatograph equipped with a split–splitless injector, a flame ionization detector, and an automatic sampler (AOC-20i, Shimadzu, Tokyo, Japan).

A CPSil 88 capillary column (Varian, Middelburg, The Netherlands; 50 m × 0.25 mm internal diameter, 0.20 μm film thickness) was used, with helium as the carrier gas (120 kPa). The program used was the following: 5 min at 140 °C, followed by a 5 °C min^{-1} increase from 140 to 220 °C, and held at 220 °C for 15 min. The injector and detector temperatures were 250 and 270 °C, respectively, and the split ratio was 1:50 with a 1 μL injection volume. Each fatty acid methyl ester (FAME) was identified by direct comparison with a standard mixture (FAME 37, Supelco, Bellefonte, PA, USA). The analyses were performed in triplicate for each formulation, and the results were expressed as the relative percentage of each fatty acid, based on the relative peak areas.

Vitamin E was determined after extracting the fat from the food matrix, in the same manner as for the fatty acid profile determination, but in this case, using an HPLC system (Jasco, Tokyo, Japan) equipped with an automated injector (AS-2057), a PU 2089, and a multi-wavelength diode array detector (DAD) MD-2018, coupled with a fluorescence detector (FP-2020). The components were determined by comparing them with commercial standards.

Lipid oxidation was evaluated based on changes in thiobarbituric acid-reactive substances (TBARs) during cold storage. The resulting color was measured at 532 nm using a UV/VIS spectrophotometer (Perkin-Elmer Lambda 15, Boston, MA, USA). The results were expressed as mg of malondialdehyde per kg of sample.

All analysis was carried out in triplicate from 3 samples (3 × 3 × 3 cm) selected randomly from each formulation.

2.5. Sensory Analysis

A hedonic test was carried out in the ETSIAMB (Albacete, Spain) to determine the degree of overall liking for brownies using a scale of 9 points (0 = dislike extremely and 9 = like extremely). Overall, 105 untrained consumers were selected among students and staff, ranging from 18 to 55 years old, with the majority (65%) being between the ages of 18 and 30, representing the younger student population. The remaining participants (35%) were staff members aged 31 and above. The panel was composed of 52% female participants and 48% male participants, ensuring a balanced representation of gender. The panel included a mix of participants from diverse cultural backgrounds, with approximately 15% of the participants having an international background. This diversity allowed for the evaluation of texture preferences across various cultural and regional contexts.

They were given four squared samples (1 × 1 × 1 cm) from the midsection of the brownies to avoid the crust that is formed on the sides after baking. The parameters analyzed were external appearance, flavor, texture, and overall acceptability. In this study, the 105 untrained participants were informed about the substitution of butter with different vegetable oils prior to the sensory evaluation. This information was provided to ensure participant safety, particularly due to the potential allergens in some of the oils used, which could trigger allergic reactions in sensitive individuals.

Despite this prior information, the sensory evaluation focused on assessing the sensory attributes of the brownies without bias. To reduce the possibility of bias, the evaluation was conducted in a controlled environment with randomized sample presentation and blind testing, where the participants were not aware of which sample corresponded to which ingredient. This methodology aimed to ensure that participants focused solely on the sensory attributes without preconceived notions or preferences regarding the specific oils used.

The index of acceptability was calculated according to [22] following the equation below.

$$IA\ (\%) = \frac{Score \times 100}{9}$$

2.6. Statistical Analysis

The results are presented as means and their corresponding standard deviations. Statistical differences were estimated using the ANOVA test at a 5% significance level and the Duncan test ($p \leq 0.05$). All statistical analyses were performed using SPSS software, version 23.0 for Windows. The results were expressed from three replicates, unless stated otherwise.

3. Results and Discussion

3.1. Physical Parameters

All texture parameters were statistically different when butter was replaced with seed oil. The results are shown in Table 1. The hardness of the brownies decreases as the butter content is reduced, with the control sample showing the highest values [24]. This is because butter is rich in saturated fatty acids, which are responsible for its solid texture. In contrast, when non-emulsified oils, which have a liquid texture at room temperature, are used, a softer texture is obtained. However, as observed in other studies, consumers do not give negative scores for texture when they try the product [25]. This could be minimized by using oleogels, as depending on the type of emulsion developed, the hardness may not be affected [26].

Table 1. Texture parameters analyzed in brownie samples with a replacement of 50 and 100% butter with nut oils.

Parameter	Control	Almond 50%	Pistachio 50%	Walnut 50%	Almond 100%	Pistachio 100%	Walnut 100%
Hardness	74.23 ± 2.97 a	49.41 ± 1.82 b	46.02 ± 1.81 bc	42.59 ± 1.48 c	36.71 ± 1.40 d	26.11± 3.25 e	20.96 ± 2.64 e
Elasticity	0.27 ± 0.06 b	0.18 ± 0.02 c	0.40 ± 0.11 a	0.12 ± 0.01 c	0.35 ± 0.05 ab	0.24 ± 0.01 b	0.43 ± 0.02 a
Cohesiviness	0.67 ± 0.1 b	0.72 ± 0.07 ab	0.49 ± 0.02 c	0.88 ± 0.1 a	0.61 ± 0.06 b	0.65 ± 0.04 b	0.56 ± 0.05 c
Gumminess	48.68 ± 1.05 a	35.63 ± 1.21 b	14.62 ± 1.07 c	19.11 ± 1.91 de	24.04 ± 1.56 c	21.01 ± 0.54 d	24.91 ± 0.62 c
Chewiness	17.53 ± 0.74 a	6.79 ± 0.72 c	10.24 ± 0.46 b	10.62 ± 0.52 b	4.45 ±0.39 d	4.55 ± 0.55 d	2.54 ± 0.16 e

The numbers represent the mean ± standard deviation. Different letters in the same row for each attribute indicate significant differences ($p < 0.05$).

The elasticity decreased by 33.3% and 55.5% after replacing 50% of the butter with almond and walnut oils, respectively, and increased after replacing 100% of the butter with nut oils, particularly by 59.2% for walnut oil. Regarding cohesiveness, it increased by 31.3% and 7.4% in the almond and walnut oils replaced at 50%, respectively, while it decreased by 16.4% and 26.8% in the pistachio oil at 50% and walnut oil at 100%, respectively. As for gumminess, calculated as the product of hardness and cohesiveness, it decreased in all cases, with a maximum reduction of 70% for the brownie made with 50% pistachio oil.

Regarding chewiness, which is the energy required to chew solid foods, the lowest values were obtained in the case of 100% replacement with nut oils. In general, the values for hardness, gumminess, and chewiness showed a similar trend, with the control sample having the highest values, meaning it requires more energy to chew until complete swallowing [27]. Additionally, the studies by [27,28], which used fat substitutes for the preparation of cakes and brownies, respectively, showed similar results to those obtained in this study.

The colorimetric parameters, both for the dough and the baked brownies, are shown in Figures 2 and 3. In the case of brownies made with dark chocolate, it is unlikely that the natural color of the oil significantly impacts the colorimetric parameters of the final product because the dark, intense color of the chocolate dominates over any potential contribution from the oil's natural pigments such as carotenoids. However, in the dough prior to baking, the oil may have a slightly more noticeable effect, as the chocolate color is not yet fully distributed or transformed by heat. During and after baking, chemical reactions such as Maillard reactions and caramelization, combined with the homogenization of the ingredients, further reinforce the dominance of the dark chocolate color, minimizing any perceptible influence of the oil on color parameters [29].

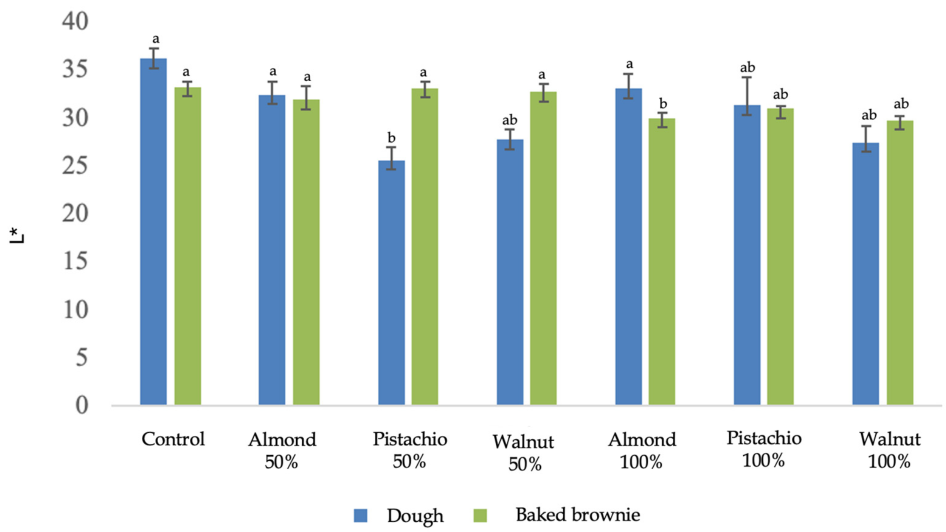

Figure 2. Luminosity analyzed both in the dough and the baked brownies reformulated with nut oils. Different letters indicate significant differences.

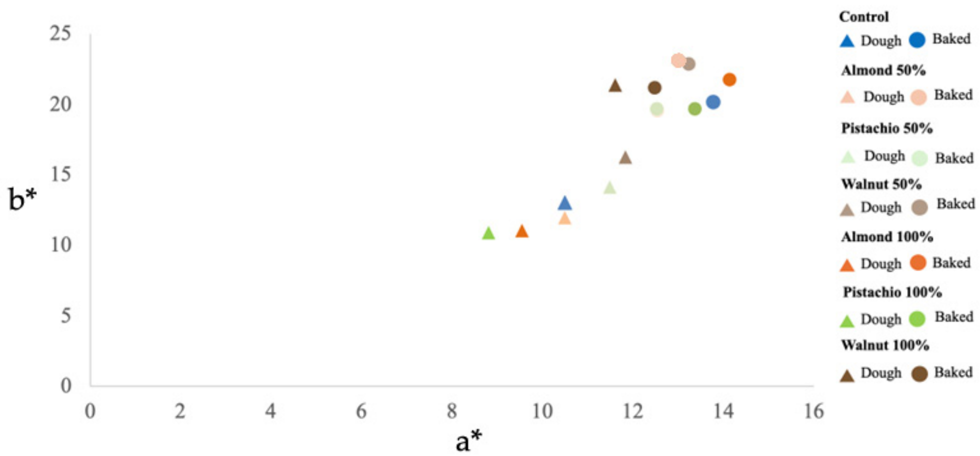

Figure 3. a* and b* parameters analyzed both in the dough and the baked brownies reformulated with nut oils.

For brightness, there were minimal significant differences between the samples, with the differences being more noticeable in the dough than in the baked brownies. These results are consistent with those obtained in gluten-free cookies with seed oils or in all the meat products developed in this study, where replacing animal fat with seed or nut oils decreased the brightness of all the reformulated samples.

For the parameters a* and b*, the situation is similar. Two clearly differentiated groups can be observed: on one side, there is the dough, with lower a* and b* values, and on the other, there is the baked brownie, which increases both values [30]. Additionally, it is seen that the baking process of the brownies makes the group more homogeneous. Also, after baking, the a* and b* values increase, indicating that the brownie becomes more intense, as represented by both the red/green and blue/yellow axes. The change could be due to several factors during baking, such as Maillard reactions or caramelization, both of which occur as the sugars and amino acids react. These color changes could be linked to sensory attributes such as the external appearance of the texture of the brownies.

3.2. Nutritional Composition

Table 2 presents the results of the nutritional analysis of the evaluated brownie samples. Significant differences were observed in several parameters, which were attributed to the physicochemical composition of the ingredients used, specifically the butter and the nut oils. These findings align closely with extensive research on the health benefits associated with nuts and their derived oils [31–33].

Table 2. Nutritional composition of the different formulations of brownie with nut oil. The results are expressed in % and the energy value in kcal/100 g.

Parameter	Control	Almond 50%	Pistachio 50%	Walnut 50%	Almond 100%	Pistachio 100%	Walnut 100%
Moisture	25.60 ± 0.34 ^{a}	22.90 ± 0.98 ^{ab}	20.50 ± 0.12 ^{ab}	22.20 ± 0.34 ^{ab}	18.10 ± 0.07 ^{b}	19.40 ± 0.12 ^{b}	17.60 ± 0.34 ^{b}
Ashes	0.77 ± 0.34	0.77 ± 0.45	0.75 ± 0.14	0.72 ± 0.56	0.76 ± 0.11	0.71 ± 0.14	0.72 ± 0.56
Protein	7.44 ± 0.21 ^{a}	7.31 ± 0.33 ^{a}	7.13 ± 0.22 ^{ab}	7.04 ± 0.19 ^{b}	6.75 ± 0.34 ^{c}	6.94 ± 0.22 ^{c}	6.94 ± 0.19 ^{c}
Carbohydrates	56.18 ± 0.98 ^{a}	53.00 ± 1.02 ^{b}	52.94 ± 0.23 ^{c}	55.39 ± 0.21 ^{ab}	51.33 ± 0.61 ^{c}	51.43 ± 0.23 ^{c}	54.30 ± 0.21 ^{b}
Fiber	0.95 ± 0.18	0.94 ± 0.45	0.91 ± 0.34	0.89 ± 0.30	0.93 ± 0.36	0.91 ± 0.34	0.94 ± 0.30
Fat	35.61± 0.16 ^{e}	38.92 ± 0.34 ^{c}	39.09 ± 0.45 ^{b}	34.75 ± 0.28 ^{d}	41.16 ± 0.12 ^{a}	40.92 ± 0.45 ^{a}	38.04 ± 0.28 ^{c}
Energy	575.00 ± 0.32 ^{e}	592.00 ± 0.24 ^{b}	592.00 ± 0.28 ^{b}	579.00 ± 0.17 ^{d}	603.00 ± 0.34 ^{a}	602.00 ± 0.28 ^{a}	587.00 ± 0.17 ^{c}

The numbers represent the mean ± standard deviation. Different letters in the same row for each attribute indicate significant differences ($p < 0.05$).

Regarding protein content, the observed differences were mainly since butter contains a small amount of protein (0.9 g/100 g). However, these differences were less than 1% of the total protein content. The protein content of the brownies could be significantly increased if, in addition to the oil, flours from oilseed cakes were added. These flours are high in protein and fiber, which would enhance the product's nutritional profile [34] and may also have a positive effect on consumer acceptance.

The fat content changes when butter is replaced with nut oils, except for the 50% walnut oil, which does not show significant differences compared to the traditional brownie. Replacing butter with oil increases the total fat content and, therefore, the energy value. This is because of the nutritional composition of butter and oils. Butter contains around 80% fat and 16–18% water, with the rest being milk solid [35]. The higher energy density in foods can lead to overconsumption, as individuals may consume more calories without realizing it, especially when larger portions of high-energy-dense foods are consumed [36]. This can contribute to weight gain and an increased risk of obesity and related metabolic diseases. The goal was to substitute butter with oil in its liquid state, as this is a product that allows for such a replacement, resulting in more natural products without the need for any additives to formulate emulsions. These emulsions would have reduced the fat content of the samples, as seen in previous studies [20]. Another alternative would be to add dietary fiber to the formulation using products such as inulin or psyllium, as dietary fiber reduces the energy value of food because it is not fully digested in the body, limiting calorie absorption. Additionally, fiber can slow digestion and increase satiety, leading to a reduced overall calorie intake [37]. It has been proved in products such as bread [38], cupcakes [39], or cake [40].

The brownies reformulated with nut oils have a nutritional composition similar to benchmark brownies in terms of moisture, carbohydrates, and fiber. On the other hand, the reformulated brownies have a higher fat content (34.75–41.16%) and calories (575–603 kcal/100 g). While this increase in calories could be a downside for those looking to control their calorie intake, the healthy fats may offer benefits for cardiovascular health. Overall, the nutritional profile of these reformulated brownies is competitive with commercial products, but could be further improved with the addition of fiber or other functional ingredients.

3.3. Fatty Acid Composition

Table 3 shows the improvements in the fatty acid profile achieved in the reformulated samples, due to the substitution of butter, which mainly contains palmitic acid, with nut oils, which are sources of unsaturated fatty acids.

Table 3. Fatty acid, vitamin E, and TBA profile of brownies reformulated with pistachio, almond, and walnut oils.

Parameter	Control	Almond 50%	Pistachio 50%	Walnut 50%	Almond 100%	Pistachio 100%	Walnut 100%
Pamitic acid (%)	36.10 ± 0.23 [a]	21.60 ± 0.98 [c]	23.40 ± 0.12 [b]	21.20 ± 0.34 [c]	10.00± 0.77 [e]	14.30 ± 0.12 [d]	11.40 ± 0.67 [e]
Stearic acid (%)	14.10 ± 0.36 [a]	9.65 ± 0.45 [b]	9.08 ± 0.14 [b]	9.94 ± 0.56 [b]	6.34 ± 0.11 [c]	5.59 ± 0.14 [d]	6.74 ± 0.56 [c]
Oleic acid (%)	28.70 ± 1.23 [c]	49.50 ± 0.45 [c]	42.20 ± 0.22 [d]	25.01 ± 0.19 [cd]	65.80 ± 0.34 [a]	51.70 ± 0.22 [b]	21.00 ± 0.19 [d]
Linoleic acid (%)	4.74 ± 0.53 [f]	11.50 ± 1.02 [e]	17.30 ± 0.23 [d]	31.30 ± 0.21 [b]	16.60 ± 0.61 [d]	26.30 ± 0.23 [c]	50.20 ± 0.21 [a]
Linolenic acid (%)	0.43 ± 0.22 [c]	0.21 ± 0.45 [c]	0.40 ± 0.34 [c]	5.56 ± 0.31 [b]	0.10 ± 0.36 [c]	0.42 ± 0.34 [c]	9.71 ± 0.3 [a]
SFA (%)	63.82 ± 0.18 [a]	37.35 ± 0.31 [b]	38.40 ± 0.32 [c]	36.98 ± 0.56 [b]	16.75 ± 0.21 [c]	20.25 ± 0.15 [b]	18.60 ± 0.65 [c]
MUFA (%)	30.99 ± 1.12 [c]	50.84 ± 0.28 [b]	43.89 ± 0.45 [c]	26.15 ± 0.61 [d]	66.52 ± 0.78 [c]	53.04 ± 0.37 [b]	21.49 ± 0.54 [d]
PUFA (%)	5.17 ± 0.22 [c]	11.71 ± 0.31 [c]	17.70 ± 0.28 [c]	36.86 ± 0.12 [c]	16.70 ± 0.34 [c]	26.72 ± 0.88 [c]	59.91 ± 0.36 [c]
Vitamin E (mg/kg)	<2.50 ± 0.12 [d]	<2.50 ± 0.24 [d]	<2.50 ± 0.28 [d]	4.43 ± 0.17 [c]	6.74 ± 0.34 [ab]	5.3 ± 0.28 [b]	8.35 ± 0.17 [a]
TBA (mg MDA/kg)	0.91 ± 0.21	0.79 ± 0.34	0.88 ± 0.45	0.91 ± 0.28	0.81 ± 0.12	0.82 ± 0.45	0.91 ± 0.28

The numbers represent the mean ± standard deviation. Different letters in the same row for each attribute indicate significant differences ($p < 0.05$).

As expected, the highest value of palmitic acid, a saturated fatty acid (SFA), was found in the control sample. This value decreased as the percentage of oils increased. Notably, the samples with 100% almond and walnut oil reduced the palmitic acid content by approximately 70%. Similarly, the research [41] achieved a reduction in palmitic acid by up to 2.74 times in cookies, where butter and margarine were replaced with olive oil. This fatty acid makes up a significant portion of the fatty acids in traditional brownies.

Ref. [42] managed to reduce this type of fatty acid by 74% in muffins by substituting butter with monoglyceride-based oleogels, which was very similar to the behavior observed in this study. Regarding SFAs, they have been of great interest in many studies due to their association with health, as they stimulate pro-inflammatory mechanisms through reactive oxygen species [43]. Additionally, a high consumption of saturated fats has been linked to an increased risk of cardiovascular disease, prompting regulatory bodies to recommend reducing their intake, specifically ensuring that these fats do not exceed 10% of daily intake [42].

As can be observed in the case of polyunsaturated fatty acids, the results are very positive in all cases, as their content increases in every sample. The case of monounsaturated fatty acids is different, as the use of walnut oil resulted in a decrease in content compared to the control sample. Regarding oleic acid, for the pistachio and almond samples, the content increased by 80% and 129.2%, respectively, making it the dominant fatty acid in these brownies. This fatty acid has health benefits, including inhibiting platelet aggregation, lowering serum LDL cholesterol, and reducing systolic blood pressure, all of which contribute to lowering the risk of certain cardiovascular diseases. However, negative effects related to endoplasmic reticulum stress have also been observed, which are still under investigation [44].

Regarding linoleic acid, the almond and pistachio samples contained at least three times more than the traditional brownie recipe, with this fatty acid being the predominant one in these samples. Linoleic acid is the major polyunsaturated fatty acid (PUFA) in the diet and has positive health effects, such as lowering blood cholesterol levels, specifically LDL cholesterol, and a positive impact on the inflammatory process, reducing the likelihood of many degenerative diseases [45]. Additionally, linoleic acid is an important component of the cell membrane and a key element for child development, brain function, and vision [46].

Another notable point is the increase in vitamin E content observed when butter was completely replaced with nut oils. This vitamin can improve tolerance to low oxygen pressure, myocardial efficiency, and peripheral capillary dilation [47]. It also has significant antioxidant power, as it inhibits the production of reactive oxygen species during the propagation of free radical reactions [48]. No significant differences were found for the TBA content.

3.4. Sensory Evaluation

It is well known that sensory properties are one of the most important factors influencing consumer purchasing decisions. Therefore, the food industry aims to design food products that fully meet consumer expectations to achieve product acceptability [49]. Table 4 shows the results obtained for the sensory evaluation of new healthy brownies. In general, the reformulated samples received higher scores for all evaluated parameters compared to the traditional formula, indicating that consumers highly accept the substitution of butter with nut oils in chocolate brownies, which was not the case for other products. These results were also found in a study on reformulated brownies with sweet potato flour and black cumin oil, which helped improve all sensory parameters [50].

Table 4. Sensory parameters analyzed in reformulated nut brownie samples.

Parameter	Control	Almond 50%	Pistachio 50%	Walnut 50%	Almond 100%	Pistachio 100%	Walnut 100%
External appearance	6.40 ± 0.93^{b}	7.07 ± 0.90^{ab}	7.30 ± 0.98^{ab}	7.70 ± 1.05^{ab}	7.42 ± 1.14^{ab}	8.13 ± 0.71^{a}	8.33 ± 1.07^{a}
Texture	5.93 ± 1.25^{b}	7.53 ± 1.07^{a}	7.53 ± 1.03^{a}	7.77 ± 1.07^{a}	7.77 ± 1.08^{a}	7.68 ± 1.01^{a}	7.59 ± 1.08^{a}
Flavor	7.07 ± 1.38^{b}	8.07 ± 0.94^{a}	8.13 ± 0.93^{a}	7.93 ± 1.04^{a}	7.87 ± 1.05^{a}	8.00 ± 1.06^{a}	7.83 ± 1.03^{a}
Overall acceptability	6.46 ± 0.48^{b}	7.67 ± 0.46^{ab}	7.79 ± 0.44^{a}	7.91 ± 0.49^{a}	7.72 ± 0.41^{ab}	8.01 ± 0.45^{a}	7.98 ± 0.40^{a}
Overall index (IA) (%)	71.77	85.55	86.55	87.88	85.77	89.00	88.66

The numbers represent the mean ± standard deviation. Different letters in the same row for each attribute indicate significant differences ($p < 0.05$).

Flavor is a key parameter in consumer acceptability. In this case, the reformulated brownies scored better compared to the traditional recipe. Ref. [51] found in their study on replacing saturated fat in muffins with avocado puree that substitutions up to 50% had very good acceptance, but as the replacement increased, the ratings became more negative. Our brownies received higher ratings than the control sample, both at 50% and 100% substitution.

The texture of baked goods is evaluated not only by its hardness but also by its softness, fluffiness, and ability to break down in the mouth. These factors influence the overall sensory perception. According to studies by [52], a softer and moister texture enhances the sensation of freshness, contributing to a more positive sensory experience. In particular, softness is associated with the perception of freshness and quality, characteristics that are especially appreciated by consumers of baked goods.

Consumer behavior and preferences are also influenced by cultural and psychological factors. In many Western cultures, softness and juiciness in baked goods like brownies are associated with higher quality and freshness. Consumers tend to perceive products with a harder texture as less fresh or even stale. This phenomenon is a key factor in the preference for a softer and juicier texture observed in the results of this research [53].

Regarding the sensory analysis of texture, the control sample, which was the hardest, received the lowest ratings from consumers. It seems that, according to the comments provided by the consumers, they prefer a softer texture. Nut oils, being a less saturated and more fluid ingredient compared to other oils or fats, help retain moisture within the brownie crumb. This moisture is crucial for achieving a juicier and softer texture, preventing the final product from becoming dry or hard, which can occur in recipes that do not incorporate enough fat or liquids [54]. The presence of moisture in the batter contributes to a lighter, less dense crumb that is easier to break down in the mouth, an especially desired characteristic in baked goods like brownies. A juicy, soft texture makes the brownie seem fresher and more pleasant to eat, while dryness tends to be associated with a firmer, less appealing texture [55]. This type of moist, soft texture is highly valued by consumers, as it not only improves the mouthfeel but also makes the brownie more indulgent and flavorful, giving it a sense of freshness that is key to a positive tasting experience.

In addition to the health motivation, emphasis is placed on the importance of sensory attributes in new foods, where taste, texture, and smell are respected. Ref. [56] concludes that taste is the most important attribute, valuing it above health-related characteristics.

Products should have a minimum score of 70% IA to be considered as acceptable in sensory properties. In our case, all the samples were above that percentage, although the reformulated samples obtained higher scores for both parameters [22].

4. Conclusions

Replacing butter with nut oils in chocolate brownies represents a significant innovation in bakery formulations, demonstrating a positive impact on both physical and nutritional properties. Increasing the proportion of oils in the recipe resulted in a lighter, smoother, and more cohesive texture, with reduced hardness and gumminess, especially in samples with 100% oil. This textural change highlights the potential of nut oils to enhance the sensory characteristics of baked goods.

From a nutritional perspective, the inclusion of almond, pistachio, and walnut oils improved the lipid profile by increasing unsaturated fatty acid content while reducing saturated fats, contributing to healthier product development. Additionally, the increased vitamin E content added value in terms of antioxidant properties and functional properties to maintain good cardiovascular health.

The sensory evaluation results indicate that consumers found the reformulated brownies enjoyable, with praise for the flavor and texture, suggesting that these oils not only provide nutritional benefits but also offer a viable and attractive alternative for the bakery industry by combining health, natural, and sensory quality.

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Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

FA, fatty acid; SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; FAME, fatty acid methyl ester; TPA, texture profile analysis; ANOVA, one-way analysis of variance.

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