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Nutritional and Sensory Optimization of Functional Crackers with the Incorporation of *Arthrospira platensis*

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Abstract: *Arthrospira platensis*, which is known as the most important food supplement of the future due to its high nutritional value, was the focus of this study. The main objective of this study was to develop a functional cracker enriched with proteins, essential amino acids, and polyunsaturated fatty acids with the incorporation of *A. platensis*. Therefore, this research aimed to improve the texture (including moisture and firmness) and sensory properties (such as color, taste, and smell) of crackers by adding *A. platensis* at three different levels (0%, 2.5%, and 5.0%). The sensory attributes of crackers were evaluated by twenty taste testers and thirty consumers, assessing color, odor, taste, crispness, and overall preference. The highest hardness value among the studied trials was observed in trial 14, which contained 5% *A. platensis* with 577 N. According to the results of the panel test, among the crackers with 5% *A. platensis* addition, trial 14 had the highest color value. To obtain the optimum formula, dough with 50 mg/g *A. platensis*, 625 mg/g flour, and 220 mg/g water was recommended. The addition of *A. platensis* has great potential to improve the nutritional, textural, and sensory properties of crackers.

Keywords: *Arthrospira platensis*; cracker; functional food; food enrichment

1. Introduction

Technological developments, industrialization, and cultural change constantly increase the amount of saturated fat added to foods in Australia, Mexico, and the U.S.A., reaching extremely high values [1]. People suffer from many diseases, such as obesity, diabetes, cardiovascular disease, etc., due to a combination of factors such as unhealthy diet, habits of people, genetics, and adverse environmental factors. To overcome these problems, people tend to consume functional or enriched foods, a relatively new category, and claim health benefits after consumption beyond plain nutrition [2]. Functional foods, which contain bioactive compounds that provide health benefits beyond essential nutrition without synthetic ingredients, have indeed gained popularity in recent years since more individuals have sought safe, wholesome, and nutritious foods [3,4]. These foods are designed to support health and reduce the risk of some diseases by including ingredients that positively impact physiological functions [3,4]. The market for functional foods containing microalgae has increased significantly globally and may continue to grow [5]. Investors are looking for opportunities related to microalgae production. Research on microalgae cultivation is developing processes in competitive markets [5]. There are two primary categories of microalgae-based foods: microalgae-based nutrients and microalgae-based complete microalgae biomass. It is used in human nutrition not only because of its high protein content (up to 70% w/w) but also because of its desirable amino acid profile regarding the amount of essential amino acids and good digestibility, making it a potential alternative protein source [6–8].

The nutritional and functional properties of microalgae are fundamental. Microalgae are recognized as natural products that have essential bioactive substances such as vitamins, vital amino acids, minerals, pigments, fibers, polyunsaturated fatty acids, and polysaccharides [9]. In some

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microalgae, long-chain polyunsaturated fatty acids (PUFAs) and pigments are functional foods' most notable and beneficial components [10]. Microalgal biomass is widely produced as it can be used in various applications such as food, feed, nutraceuticals, pharmaceuticals, and cosmetics [11]. Some studies have shown that microalgae proteins may be more competitive with commercial emulsifiers, like sodium caseinate, whey protein, and soy protein [6,12,13].

Microalgal biomasses are used in processed foods such as crackers, bread, biscuits, spaghetti, and fruit drinks [14] to improve foods' nutritional or functional properties. In some foods, microalgal biomass is highly preferred for coloring purposes. Some packaged foods on the market especially have insufficient protein content to increase their protein or amino acid levels, and microalga can be used.

Arthrospira platensis has been historically used in the human diet according to various records. It has been consumed as a daily food in Chad for many years. The Aztecs also used *A. platensis* to produce cakes, known as tecuitlat [15]. It has the potential to modify foods or be utilized in creating functional foods due to the numerous health advantages linked to its consumption. The production of food products enriched with *A. platensis* has increased with greater awareness of the relationship between diet and health. The orientation towards healthy eating is due to increased innovations within the food sector [16].

Crackers remain a versatile snack food that is highly consumed, according to various reviews, thanks to their distinctive taste, long shelf life, and reasonable price [17]. Crackers are among the most consumed foods by children and older people due to their low production costs, simplicity, long shelf life, and inclusion of essential nutrients [17]. Incorporating 4% *A. platensis* significantly enhances the nutritional content of biscuits [18] and ayran [4,19]. In previous studies, positive results have been obtained by adding *A. platensis* to foods, usually between 1% and 5% [20]. No studies have been found regarding the improvement of functional crackers by adding *A. platensis*. Algal biomass at three concentrations (0%, 2.5%, and 5.0%) was preferred according to the results of previous studies [20] and our preliminary studies. The objective of this study was to enhance the nutritional (like protein and amino acids), textural (like moisture and hardness), and sensory (like color, taste, and odor) characteristics of crackers by incorporating *A. platensis* (0%, 2.5%, and 5.0%). Besides, it was tested the suitability of *A. platensis* for adding the crackers to be a functional food.

2. Materials and Methods

2.1. Materials

Arthrospira platensis produced in *Spirulina* medium [12] in the Hydrobiology Laboratory of the Department of Biology of Gaziantep University was used in cracker production. Şölen Food Company supplied the raw materials for the crackers with food and safety system standards. Protein concentration and fatty acid composition of *A. platensis* were determined to characterize its biomass. *Arthrospira platensis* biomass was examined separately for biochemical content, fatty acids, and protein using the TS EN ISO 12966-2 technique [21] and the Kjeldahl method [15].

2.2. Manufacturing of Functional Crackers

Samples of crackers were manufactured in the accredited Research and Development Laboratory of Şölen Food Company (Figure 1).

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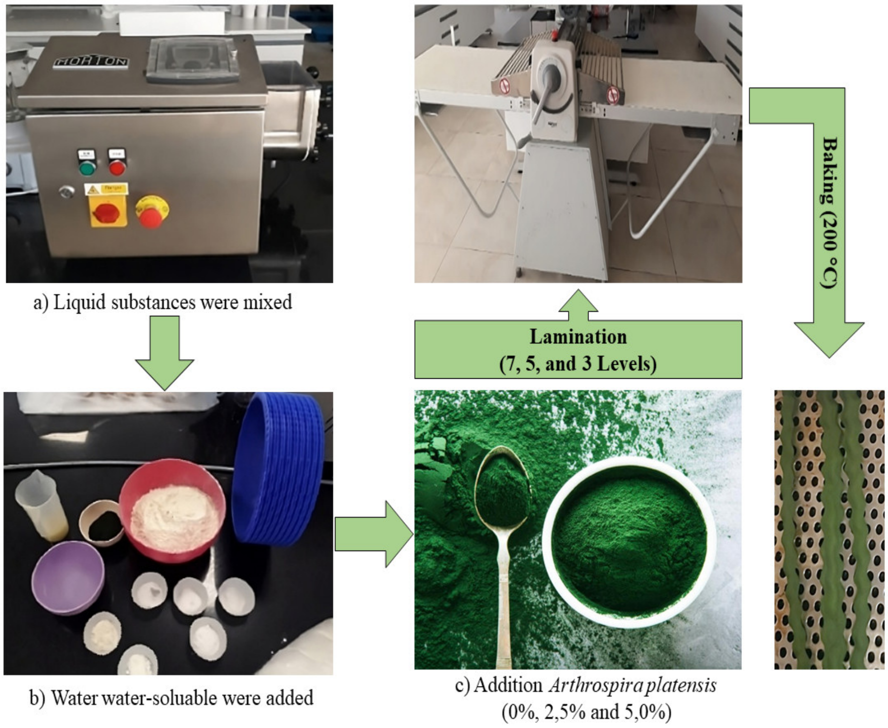

Figure 1. Trial of functional crackers.

The Design Expert package program (Stat-Ease Inc., U.S.A.) was used to determine the cracker trials, and 17 distinct formulations were produced.

In each trial, crackers were prepared in three proportions (0 control, 2.5%, and 5.0% *A. platensis* added). The samples were prepared with water, *A. platensis*, flour, salt, and oil. Each trail was prepared as 1000 g in total (Table 1). Raw materials such as salt, lecithin, ammonium bicarbonate, sodium bicarbonate, protease enzyme, and cornstarch were kept constant in each trial batch. Samples of crackers were cooled at 24–25 °C. The crackers were then sealed in vacuum packages and kept at a temperature of 18±2 °C until analysis.

Table 1. Production trials of crackers.

Trials	*Arthrospira platensis* (g/kg)	Flour (g/kg)	Water (g/kg)	Raw Materials (g/kg)
1	0	670	180	125
2	0	625	260	115
3	25	625	220	130
4	25	670	260	45
5	0	580	220	200
6	25	625	220	130
7	50	670	220	60
8	25	625	220	130
9	0	670	220	110
10	0	625	180	155
11	50	580	220	150
12	25	625	220	130
13	25	580	180	215
14	50	625	260	165
15	50	625	180	145
16	25	580	260	135
17	25	625	220	130

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First, liquid ingredients were added to the mixer, and the mixture was mixed for 90 seconds at 48 rpm. In the second stage, solids were added and mixed at 100 rpm for 15 minutes until the dough became elastic. After obtaining the dough, it was folded in 2 using a Rondo brand laminator. The thickness of the rolled dough was determined to be 1 mm. The laminator was opened in 7, 5, and 3 stages to receive a puffier product and to ventilate the dough.

The same process was repeated, but this time, the dough in the laminator was cut with a chisel. Since air bubbles were formed in the dough thinned by the laminating process, it is possible to obtain crispier crackers due to the high degree of swelling and the thinner surface. The next step was to cut the cracker dough into long, jagged shapes using a wheel-shaped bar cutter. The next step was to cut the cracker dough into long, serrated shapes using a wheel-shaped bar cutter.

The baking temperature of the cracker samples and the dough placed in trays was kept constant at 200 °C, and the cooking time was 5 min (Figure 1). The cooking was performed in an electric stone oven (Wiesheu, Germany). The crackers were kept in hermetically sealed packages at 18±2 °C and analyzed. The ideal crackers were selected by choosing among the crackers tasted by the expert tasters of Şölen Food Company.

The Design-Expert Program (Stat-Ease Inc.), a statistical package program dedicated to performing experimental design, was used for optimization based on desirability values. The cracker dough was prepared according to the AACC method [22] using a laboratory mixer (Morton, UK).

2.3. Sensory Analyses

Twenty taste testers, aged 20 to 45, nearly half of them women, were engaged by the R&D Department of Şölen Food Company and were responsible for evaluating the different types of crackers. They had the sensory evaluation certificates. Besides, the sensory evaluation trial was conducted with an additional 30 consumers, aged 18 to 46. Each panel test took place in a separate room. The panel cabinets are separated from the rest of the room by a glass divider, preventing them from touching any other tester. To reduce the likelihood of visual illusions and misunderstandings, the room housing the taste panel contains daylight lighting with sound diffusion.

The method of EN ISO 8589 [23] was used. The tasting panel assessments are based on ratings from 1 (very weak) to 5 (very like) established under the categories of color, crispness, odor, fragrance, and general flavor. The samples were applied by separating them into various days because the panelists' margin of error grew with subsequent testing [18,24].

2.4. Physicochemical Analysis

Protein analysis was performed using the Kjeldahl method [25], which states that protein analyses were carried out using the Kjeldahl technique (with a factor of 5.75). An ion exchange Chromatography method was used to determine the amino acid content (I.E.C.) in the cracker with the Technician Sequential Multiple Sample (T.S.M.) Amino Acid Analyzer (Technician Instruments Corporation, New York, U.S.A.) used for determination of amino acid content declared by [26]. It was degreased, hydrolyzed, and evaporated in an evaporator device before being put into the amino acid analyzer to determine the amino acid profiles. It was determined by taking the net height of each peak that the T.S.M. chart recorder produced. The amino acid values were the mean of analyses performed in triplicate. The internal standard was nor-leucine.

The TS EN ISO 2171 technique was used to calculate the cracker's total ash [27]. The Color Flex lab tool was used to determine Hunter Color analyses. Hunter colors L* (whiteness and brightness), a* (greenness and redness), and b* (blueness and yellowness) are used to describe color parameters [28]. A texture analyzer (TA-XT plus Tissue Analyzer, Stable Micro Systems, Surrey, UK) with a 20 mm diameter, mechanically conditioned forward to cover 50% of the sample, and mechanically maximum computed and estimated in Newton was used to test the hardness of the cracker (N).

2.5. Statistical Analysis

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The quadratic polynomial problem generated by Design-Expert software version 7.0 was analyzed using the Response Surface Technique (R.S.M). Multiple regression was used to fit the coefficient of the response polynomial model to link the response variable to the independent factors [29]. The optimization, done by the Desing-Expert program with desirability value, was based on the desirability value, using sensory ratings (i.e., color, aroma, crispiness, hardness, flavor, and overall taste scores) as the response variables [30]. The best cracker was determined to have the highest desirability value.

Analysis of variance (ANOVA) was used to compare experimental data at a significant level ($p<0.05$). To compare the data from several groups, the Tukey multiple test was employed. An application of the Design Expert program was used to optimize the process.

2.6. Shelf Life

The shelf life of the best cracker was performed as accelerated shelf-life tests were carried out at 18-28 °C cycle for 12 weeks. Sensory (crispness, color, taste, odor, and moisture amount) analyses were considered as quality criteria.

3. Results and Discussion

3.1. Composition of Arthrospira Platensis

On a dry basis, the biomass of *A. platensis* contained 27% carbohydrates and 59% protein. The amount of linoleic acid was 38.8 g per 100 g, together with 0.16 g of gamma-linoleic acid, 0.1 g of arachidonic acid, 9.3 g of palmitoleic acid, and 30.6 g of palmitic acid.

3.2. Sensory, Physical, and Chemical Structure of the Crackers

The effects of *A. platensis* and flour on the color scores of cracker products are shown in Figure 2. The color scores of crackers varied between 3.7 and 4.6. The lowest color score was obtained in trial 16, which contained 2.5% *A. platensis*, a relatively low flour content (580 g/ kg), and water (260 g/kg). The highest ($p<0.05$) color value was observed in trial 14. This trial design contained 5% *A. platensis*, 625 g/kg flour, and 260 g/kg water. According to sensory evaluation, the cracker with the best color ($p<0.05$) was trial 14, which contained 5% *A. platensis*. The increase in the amount of flour and *A. platensis* positively affected the preferability of the crackers. Following the incorporation of *A. platensis* biomass, many food items have been developed, including soups, sauces, snacks, drinks, sweets, chocolates, biscuits, bread, cakes, and flour-based foods [31,32]

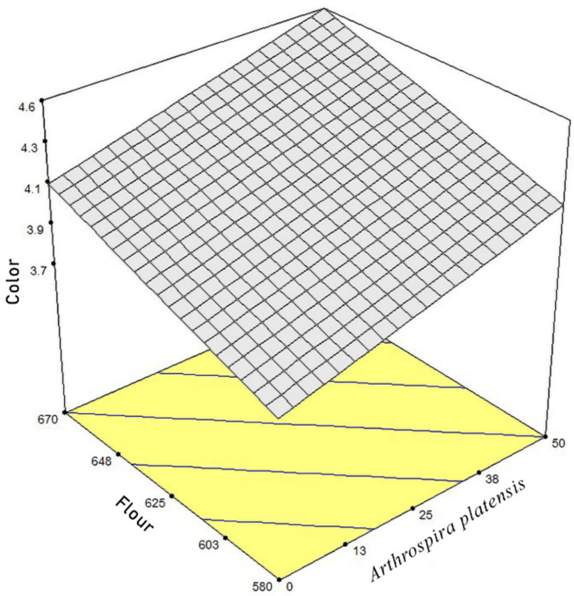

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Figure 2. Effects of *Arthrospira platensis* and flour on the sensory color of cracker products.

Effects of the inclusion of *A. platensis* and flour amount on the flavor of crackers are given in Figure 3. The flavor score was the closest to the optimum in trial 14, having the highest desirability value, where the amount of *A. platensis* was 50 g, the flour content was 625 g, the water content was 220 g, and the overall taste was high. An increase in the amount of *A. platensis* increased the desirability. It has been observed that the incorporation of brown algae in baked foods can enhance their nutritional profile, texture, and antioxidant properties owing to their elevated mineral content and dietary fiber composition [33–35].

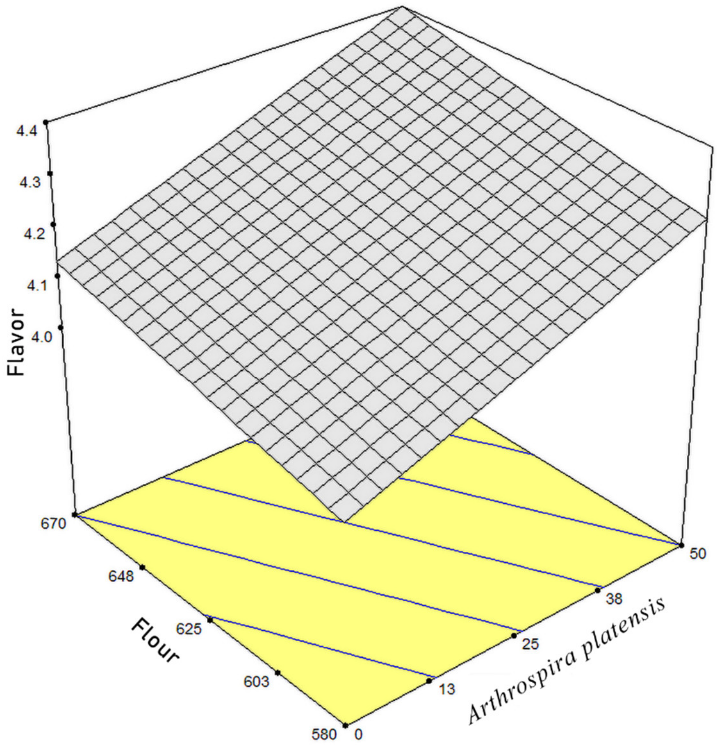

Figure 3. Effects of the *Arthrospira platensis* and flour of sensory flavor of crackers.

3.3. Hunter Color, Moisture, and Hardness of Cracker Samples

The color factor ranks first among consumers' preferences for food products. The color characteristics of crackers are found to vary based on the substances they include, such as the addition and ratio of *A. platensis*, as demonstrated in the current study.

Hunter color parameters, moisture, water activity (aw), and performance level results of functionalized crackers are given in Table 2. In the Hunter color analysis, trial 10 without *A. platensis* had the highest (L*) value (83.76), while trial 15 containing 5% *A. platensis* had the lowest value (33.60). The high algal concentration (5%) and water (180 g/kg) with low flour (625 g/kg) lead to decrease L* (brightness) value in trial 15. Increasing the incorporation of *A. platensis* decreased the lightness of the crackers (dark green), which is in agreement with a previous study [36]. Similar results were obtained in the addition of *Isochrysis galbanato* into cookies, which decreased the brightness of products [37]. Another factor is cooking temperature, which could cause a degradation in pigments, which decreases the brightness of samples. In pigment products in cooked products such as snack microalgae cookies, the reaction kinetics of pigment degradation, i.e., green, appears to occur and the amount of chlorophylls after high-temperature cooking may depend on the initial pigment concentration [35,38].

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Table 2. Hunter color values, moisture, water activity (aw), and hardness levels of crackers test trials. L* is lightness and darkness, a* is greenness and redness, and b* is blueness and yellowness. Data is mean ± standard deviation.

Trials	Hunter Color			Moisture	aw	Hardness (N)
	L*	a*	b*	%		
1	48.58	-1.40	26.37	1.71	0.03	463
2	80.84	3.09	25.84	3.57	0.08	395
3	47.95	-3.56	26.03	2.32	1.80	425
4	47.59	-1.98	25.38	2.30	1.70	421
5	79.72	1.97	24.13	3.50	1.96	306
6	47.28	-0.18	23.20	4.56	2.60	421
7	39.37	-0.88	20.79	1.80	2.30	516
8	46.47	-2.39	25.67	2.20	1.60	357
9	83.35	1.04	20.92	3.67	1.96	320
10	83.76	0.93	20.84	4.60	2.80	356
11	35.62	0.69	20.16	2.80	1.96	404
12	47.18	-2.23	26.20	2.60	1.25	335
13	48.25	-2.68	26.18	0.23	0.12	291
14	34.60	-3.78	20.53	1.60	0.20	577
15	33.60	-0.80	20.91	2.35	0.38	244
16	43.19	0.48	27.05	1.30	0.57	148
17	43.65	-2.10	25.60	1.87	0.63	287

Among the crackers with adding *A. platensis*, the highest a*(+) (redness) level was observed in trial 2 without *A. platensis* with 3.09. The a*(-) (greenness) was observed in trial 14, including 5% *A. platensis* with 3.78. Fresh pasta with free and microencapsulated *A. platensis* exhibited a green hue tendency, indicated by parameter a*, which can be positive (redness) or negative (greenness), respectively, while microencapsulation reduced this green hue [39]. Besides, cooking temperatures could affect the redness-greenness color of samples in the present study, which is in agreement with a previous study [36]. Moreover, the type and properties of flour in biscuits/cookies could change the color of the products [40].

The moisture content ranged from 0.23 in trial 13 with *A. platensis* to 4.60 in trial 10 without the algal biomass. The high moisture content was not preferred in crackers because shortenings limited the shelf life. The addition of *A. platensis* caused to decrease in the moisture content of crackers, and this effect extended the shelf life. The Turkish Standards Institute (TSI 2383 2010) has declared the maximum allowable moisture content for crackers at 7%. The moisture level observed in this study for trail patterns fell within the permitted limit.

The highest hardness value was measured as 577 N in trial 14, incorporating 5% *A. platensis* and 625 g flour (Table 2). The increase in the amount of flour and *A. platensis* caused an increase in the hardness of the cracker. This may be attributed to the capacity of *A. platensis* and flour to undergo a reaction with water, resulting in a powdery consistency. The increase in hardness observed in dark chocolate with *A. platensis* compared to the control without *A. platensis* is attributed to the low water content.

Higher hardness values with the addition of *A. platensis* than the control dark chocolate without the addition of *A. platensis* were determined due to the low amount of water [41].

The change in the amount of *A. platensis* and flour was very effective on the hardness level. When flour was 670 g/kg, and *A. platensis* was 5%, there was an increase in the cracker crunchiness level. [42] Reported that cracker dough, especially the flour raw material, is effective on the baked product quality and that hard and thin snacks are obtained from hard and non-sticky dough, while thick and sticky snacks are obtained from snacks with soft and sticky dough. On the other hand, the textural properties of crackers made with different proportions of ground almond and corn flour, and it was observed that the hardness value decreased with the increase in the amount of ground almond flour in the recipe [41,43] revealed that the increase in the amount of *A. platensis* increased the hardness and durability of chocolate.

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3.4. Optimization

The result of the Design-Expert analysis indicated that optimization, done by having the highest desirability value, identified the best formula as having 5% *A. platensis*, 260 g/kg water, and 670 g/kg flour. The inclusion of *A. platensis* in the production process of crackers results in an optimal product that possesses desirable health attributes. This particular cracker variant exhibits a high protein content and good textural properties, making it a favorable choice for producers and consumers alike.

Biochemical analyses of the produced optimum recipe with *A. platensis* and control without the alga are given in Table 3. The incorporation of 5% *A. platensis* increased the protein and amino acid content of the crackers with the highest protein content. The amino acid content of the cracker increased with the addition of 5% *A. platensis* (e.g., alanine, lysine, glutamic acid, aspartic acid, arginine, serine, threonine, tryptophan, and valine). Considering the total amount of amino acids, essential amino acids are very important for the human body. Because essential amino acids are so vital to our health, it may be better to enrich foods with high levels of them [44]. In comparison to chickpea and mung bean proteins, the digestibility of essential amino acids *in A. platensis* protein was about 85% in humans [45].

Table 3. Biochemical analyses of control without *Arthrospira platensis* and optimum recipe with the addition of *Arthrospira platensis*.

Constituents	Control	Optimum recipe	Difference %
Protein (g/100 g)	13.34	16.60	24.7
Carbohydrate	73.5	71.3	-3.0
Fatty Acid	6.0	7.0	16.7
Total amino acid (mg/100g)	11052	15949	53.83
L-Isoleucine	418	758	81
L-Leucine	888	1272	43.2
L-Methionine	178	298	67
L-Threonine	223	467	109
L-Phenylalanine	670	891	33
Tryptophan	90	187	107
L-Valine	473	792	67
L-Alanine	318	694	118
L-Arginine	250	633	153
L-Aspartic Acid	353	903	156
L-Phenylalanine	670	891	33
L-Glutamic Acid	3618	4268	18
L-Histidine	183	319	74
L-Methionine	178	298	67
L-Proline	1.755	1973	12
L-Serine	415	623	50
L-Tyrosine	355	529	49

Bold amino acids are essential.

The biochemical analyses suggested that *A. platensis* has a high protein biomass, consistent with other research [13,17,47] and fatty acids such as gamma-linoleic acid. Leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine are among the most important amino acids [47]. Essential amino acids are so vital to human health. Therefore, foods that are enriched with them are favored [45]. The essential amino acid in the protein of *A. platensis* was found to be approximately 85% digestible by humans, which is higher than the digestibility of chickpea and mung bean protein [21].

On cracker samples, sensory analyses (color, crispness, odor, fragrance, and general flavor analysis) were done. The algal biomass containing pigments, such as chlorophyll-a, phycocyanin, and phycoerythrin, caused the colors of the crackers to alter when *A. platensis* was added. The degree and general acceptability of the goods' sensory qualities (color, odor/aroma, taste, and texture) were greatly improved (p<0.05) in this study by the addition of *A. platensis*. The addition of *A. platensis* was an important factor in the color parameters of the crackers, which varied based on the ingredient. According to results obtained from a study by Kumar et al. [48], this reaction also happened in a biscuit product that contained marine collagen peptide. According to [49] study, adding 2.5% *A. platensis* into extruded food products did not modify its color, but adding 5.0-12.5% *A. platensis* considerably altered the products' color. Additionally, the color score increased when *A. platensis* was added to ayran [19], a dairy product and sourdough "crostini" [50].

The level of color appreciation was highest at the level where *A. platensis* is 5%, and the amount of water is 26%. It was observed that the increase in the amount of *A. platensis* increased the color liking in crackers. Moreover, the increase in the amount of water and *A. platensis* caused an increase in the amount of crackers color. Similarly, [51] examined the effect of adding water to pumpkin powder on bakery products in their study.

In their results on color, they observed a decrease in the L* value and an increase in the a* and b* values. According to the color values obtained, increasing the proportion of pumpkin powder decreased the brightness of the product and increased its redness and yellowness. In similar studies, microalgae biomass was added to various foods to add color and functional properties.

4. Conclusions

The results of our study indicated that adding *A. platensis* has a favorable impact on the cracker constituents. It was found in preliminary studies that the samples having more than 5% *A. platensis* caused a darker green color and unpleasant flavor. The trail 14 containing 5% *A. platensis* had the best sensory color score with4.4 and it achieved the best flavor score and a cracker hardness of 577 N. Adding 5% *A. platensis* in the crackers resulted in an increase in protein content from 24.7%. According to the panel test result, the highest color scores were obtained with the addition of 5% *A. platensis*. The results of sensory and biochemical analysis showed that biochemical components of *A. platensis* can be used in crackers by increasing their nutritional value. The findings of this research showed that the use of *A. platensis* in crackers is beneficial for health.

Author Contributions: AÇ, DG, and HB designed the overall research work and performed the experiments.

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Informed Consent Statement: No conflicts, informed consent, human or animal rights were applicable to this study.

Data Availability Statement: The data supporting this study's findings are available from the corresponding author declared upon reasonable request.

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