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Evaluation of Physicochemical and Microbial Properties of Phycocyanin-Enriched Sugar Candy

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ABSTRACT

Growing consumer preference for natural over synthetic colorants has promoted the use of *Spirulina*, a rich source of protein and the pigment phycocyanin, in the food and health industries. In this study, *Spirulina* was cultivated in Roulik culture medium at 28 ± 2 °C and pH ~8 under white light with an intensity of 6000 lux. After 14 days, phycocyanin was extracted using the freeze–thaw method. Phycocyanin was incorporated into sugar candy at concentrations of 0, 0.5, 1, and 1.5%, and the physicochemical and microbial properties of the samples were evaluated during storage periods of 0, 10, 20, and 30 days. Results showed that increasing phycocyanin concentration enhanced antioxidant activity, ash content, and phenolic compounds, while reducing moisture content and water activity. The sample containing 0.5% phycocyanin achieved the highest sensory acceptance, and no microbial growth was observed in any of the samples. These findings suggest that phycocyanin can serve as a natural colorant with functional properties in the production of sugar candy.

1- INTRODUCTION

Recently, the use of natural plant-based compounds has gained more attention, especially in areas such as nutrition, medicine, and cosmetic products. Many studies have shown that adding plant-derived compounds, particularly phenolic compounds, to food products can have protective effects against different types of diseases. At the same time, with the increasing world population and the growing demand for protein, aquaculture has become one of the important sources for supplying protein. In this context, dried microbial cells, known as single-cell proteins, are considered suitable and sustainable protein sources [1]. Unlike land plants, the production of microorganisms such as microalgae, bacteria, fungi, and yeasts does not require agricultural land, which makes microalgae a viable option for protein production [2].
Spirulina is a filamentous blue-green microalga (cyanobacteria) lacking heterocysts, occurring in shallow alkaline habitats such as lakes and seas. It has been traditionally used as a food in Mexico and Africa. Spirulina is composed of approximately 62% amino acids and has a decent level of vitamin B12. It also contains xanthophylls and carotene, photosynthetic pigments [3]. Algae have been studied for many biological functions, including antioxidant, antibacterial, antifungal, antiviral, and even anticancer activity. The health benefits and high antioxidant activity of Spirulina are mainly due to its bioactive pigments [4].
Phycocyanin is a blue-colored pigment–protein complex that can be found in cyanobacteria and microalgae. This natural water-soluble pigment has attracted attention because of its various beneficial properties, such as immune system stimulation and antioxidant and anti-inflammatory effects, as well as antiviral, anticancer, and cholesterol-lowering activities. Because of these properties, phycocyanin has good potential for use in the food, pharmaceutical, cosmetic, and biotechnology industries. In general, microalgae are rich sources of nutrients and natural pigments, which makes them suitable for use in human food products [5, 6].

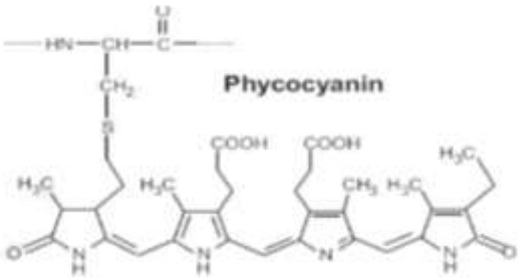

Figure (1). Phycocyanin structure[6]

Nikan Iri et al. (1401) investigated the effect of phycocyanin pigment on physicochemical, sensory, microbial and antioxidant properties of cheese. The results of the experiments showed that the fat, moisture, pH and 1,1-diphenyl-2-picrylhydrazyl (DPPH) content of fortified cheeses decreased significantly compared to the control sample. Also, the protein, beta-carotene, iron reduction assay power (FRAP) and nitric oxide capture increased significantly compared to the control sample. Sensory evaluation also showed a significant increase in satisfaction, except for the sense of smell, compared to the control sample. In addition, Escherichia coli and Staphylococcus aureus were not found during different days. However, the presence of coliform bacteria was evident from days 7 to 21 in fortified cheeses and the control sample. Furthermore, the results of volatile compounds obtained from the MS-GC test in the control sample and cheese enriched with 1% phycocyanin pigment indicate the presence of compounds with antimicrobial properties that play an important role in the shelf life and quality of cheese [7].
Kashi et al. (1403) studied the industrial application of phycocyanin, a natural edible pigment extracted from cyanobacterium Spirulina in ice cream production in terms of microbial and antioxidant properties. The results of the experiments showed that the

amount of fat and total sugar, melting point, ABTS, and DPPH of enriched ice creams decreased significantly compared to the control. Also, the amount of protein, aeration, and FRAP increased significantly compared to the control sample. Sensory evaluation also did not show any significant difference in the taste, flavor, color, and consistency of ice cream compared to the control sample. In addition, no signs of the presence of Escherichia coli, Staphylococcus aureus, and Salmonella were observed during the storage period. However, the presence of coliform bacteria was observed from days 42 to 56 in enriched ice creams and the control sample, and the presence of mold and yeast was observed only in the control ice cream from days 28 to 56. The amount of psychrophilic bacteria decreased from week 2 to week 8. The MS/GC test results of volatile compounds in ice cream enriched with 2% phycocyanin pigment indicate the presence of compounds with antimicrobial and antioxidant properties that play an important role in the shelf life and quality of ice cream [8].

In a different work, Devi et al. [40] studied the application of microencapsulated phycocyanin in gummy candy, where the main idea was the use of this pigment as a safe natural blue colorant. The samples were analyzed for moisture, ash, water activity and color and the presence of phycocyanin was confirmed using infrared spectroscopy. The drying process was conducted at about 80°C. Different levels of phycocyanin (0, 1, 3 and 5%) were used and a bright blue sample for comparison. The results showed that changing the concentration had an effect on moisture, water activity and color intensity. The IR results confirmed that phycocyanin was still present in the product and among the samples, PL was considered the best one [9].

In general, natural pigments are important for food and pharmaceutical applications because they are considered safer and more acceptable by consumers. Still, one of the main challenges is their low stability. Jasmer et al. studied stability of C-phycocyanin in gelatin candies with addition of trehalose and citric acid Their results showed that trehalose may have a protective effect on phycocyanin, especially in digestion when it is exposed to gastric juice and enzymes such as pepsin. It also helped improve the stability of the pigment over time. Another point was that gelatin candies can act as a suitable carrier for delivering phycocyanin to the intestine [10].

In another research, hard candy was produced using blue phycocyanin extracted from *Spirulina platensis* as a natural color. In that study, first the pigment was extracted by freeze–thaw method and then it was encapsulated using maltodextrin (1:1 ratio). After that, the candy was prepared using two different processing methods, and finally the samples were analyzed. The experimental design was a completely randomized design with two factors. The products were evaluated based on color, taste, and texture. Based on panel opinions, the formulation containing 80 g sucrose and 3 g phycocyanin gave better results. Chemical analysis also showed values for antioxidant activity (IC50), reducing sugar, sucrose, moisture, ash, and protein content. Also, the blue color of the candy stayed relatively stable for about 28 days [11].

Even though these studies exist, most of them are focused on dairy products or gelatin candies. There is still not much information about using phycocyanin in traditional sweets, especially Iranian ones. Sugar candy is a traditional sweet that is widely consumed in Iran, but usually it does not contain natural pigments or antioxidant compounds. Therefore, the incorporation of phycocyanin may improve not only the color but also the nutritional and functional properties of Sugar candy.

However, until now, there has not been a detailed study about the physicochemical, antioxidant, sensory, and microbial changes in Sugar candy enriched with phycocyanin.

Therefore, this study aimed to evaluate the physicochemical, antioxidant, sensory, and microbial properties of Sugar candy enriched with phycocyanin extracted from Spirulina and to investigate its potential as a natural colorant in traditional confectionery products.

2-Materials and Methods

Commercial phycocyanin powder (Xi'an Huilin Bio-Tech Co., China) was purchased and used as a reference standard for spectrophotometric comparison.White sugar and food-grade citric acid (Kimia Gostar, Iran) as well as all other chemicals used in the assays were purchased from Merck, Germany.(Phycocyanin used to enrich sugar candies was extracted from laboratory-cultured Spirulina using the freeze-thaw method)

1-2. Production of Phycocyanin The Spirulina was cultured in Zarrouk medium at 28 ± 2°C, pH 8, under white light of 6000 lux. The microalgae reached their maximum growth in the logarithmic phase after approximately 14 days. At this point, the cells were harvested to be used in the experiments. Phycocyanin was extracted using a freeze–thaw method in a buffer solution. For this, 0.1 g of dried biomass was dissolved in 15 mL of 0.05 M sodium hydrogen phosphate buffer. The solution was frozen at -20°C (Pars freezer) and then thawed in a water bath at 10°C (AASHTO T245-97, ASTM D5581). This freeze–thaw cycle was repeated five times. The solution was then centrifuged at 4000 rpm for 20 min (Anke, model TDL80-2B) and the upper phase containing phycocyanin was collected [12,13]. The absorption spectrum of phycocyanin was recorded by a spectrophotometer (Specord 210, Analytik Jena). The peaks in the absorption spectrum represent the pigment's ability to absorb light of particular wavelengths. This gives important information about the optical and chemical properties of the pigment. Figure 2 shows the absorption spectra: Panel A corresponds to the standard phycocyanin powder purchased from Xi'an Huilin Bio-Tech Co., Ltd (CAS No. 20298-86-6) and Panel B refers to the liquid phycocyanin obtained from the laboratory-cultured Spirulina.

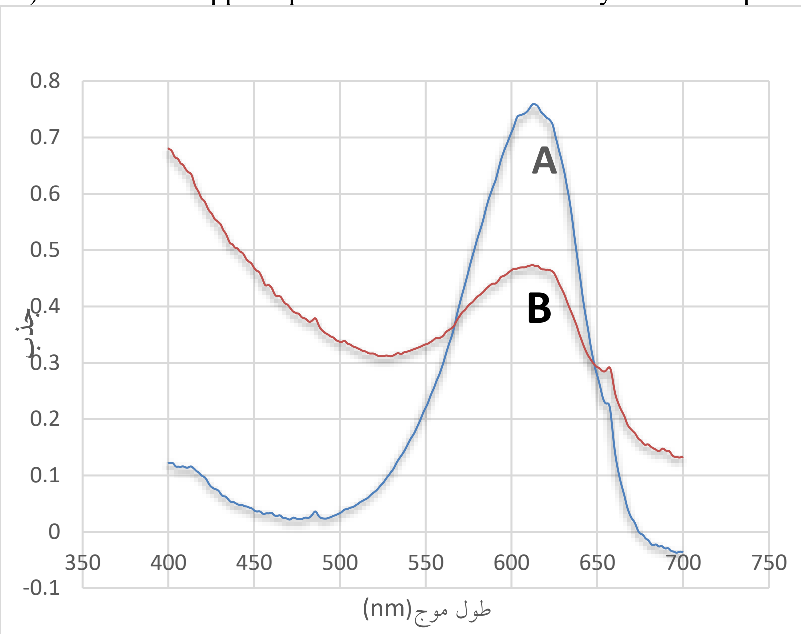

Figure (2). Graph of phycocyanin absorption rate

Preparation of Phycocyanin-Enriched Sugar Candy.۱-۳.

The water was heated in a pot, and the temperature was brought up to about 60-70°C. Then sugar was added slowly and mixed until dissolved. Egg white was then used to help remove impurities from the sugar. When the solution started boiling, some foam appeared on the surface, and it was removed. The temperature was then raised to about 110°C and held there for about 10 minutes. Then a small amount of citric acid (about 0.02%) was added. Heating was continued until the temperature reached nearly 135°C. At this stage, the syrup was ready, so it was moved onto a cooling table. After that, phycocyanin was added in different concentrations (0.5%, 1%, and 1.5%). The mixture was then kneaded for a while until the texture became more flexible.

In the next step, the dough was shaped using molds. It was also put into a rotating mixer to get a better form. A little syrup was sprayed on the surface for the pieces not to stick to each other. Finally, after cooling to about 25°C, the samples were packed in plastic bags and sealed.

2-3. Chemical and Microbial Tests

2-3-1. DPPH Radical Scavenging Activity

For measuring antioxidant activity, DPPH was used as a stable radical. In this test, 2 mL of methanolic extract with different concentrations was mixed with 2 mL of DPPH solution (0.004% in methanol).

Then the mixture was kept in dark conditions at room temperature for about 90 min. After that, the absorbance was read at 517 nm using a spectrophotometer (T70+, PG Instruments,

China). The results were compared with the control sample.
At the end, the scavenging activity was calculated by this equation [14]:

$$\text{Absorbance} = \frac{\text{Sample absorbance} - \text{Control absorbance}}{\text{Control absorbance}} \times 100$$

٢-٣-٣. Total Phenolic Content

The total phenolic content was measured using the Folin–Ciocalteu method. For the standard curve, gallic acid was used. The results were reported as the amount of phenolic compounds per gram of extract [15].

٢-٣-3. Moisture

Moisture content was determined based on the Iranian national standard (No. 16113). For this an oven (Memmert, Germany), a balance (AND, Japan) and a desiccator were used. The samples were dried and weighed before and after drying.

$$\text{Moisture (\%)} = \frac{(\text{weight of wet sample} - \text{weight of dry sample})}{\text{initial sample weight}}$$

2–3**-4. Ash Content**

Ash content was measured according to Iranian standard No. 2554 using an electric furnace (model 2-16KC, Germany). The results were expressed as percentage using the following equation:

$$\text{Ash (\%)} = \frac{M_0}{M_1} \times 100$$

where M_0 is the weight of ash remaining after the test (g) and M_1 is the initial weight of the sample (g) [17].

2-3-5 Water Activity

Water activity was measured using a water activity meter (Novasina LabMaster). The sample was kept at 25°C until it reached equilibrium. Then the vapor pressure of the sample was compared to the vapor pressure of pure water at the same temperature. The obtained value was reported as water activity (aw) [18].

2-3-6. pH Measurement

The pH of the samples was measured based on Iranian standard No. 2852 using a pH meter (model SP-701, Switzerland) [19].

2-3-7. Enterobacteriaceae Count

To check contamination, VRBD culture medium was used. The samples were cultured using the pour plate method and incubated at 37 °C for about 24–48 hours [20].

2-3-8. Mold and Yeast Count

Mold and yeast counts were determined using YGC culture medium. The plates were incubated at 25 °C for about 5 days, and then the results were recorded [21].

2-3-9 Sensory Evaluation

Sensory evaluation of sugar candy was carried out based on Iranian standard No. 4938 using a 5-point hedonic scale (1 = very bad, 5 = very good). The test was done by 15 trained panelists, and the samples were evaluated for taste, texture, color, and overall acceptance [22].

2-4. Statistical Analysis

Different levels of phycocyanin (0, 0.5, 1, and 1.5%) and storage times (0, 10, 20, and 30 days) were evaluated, along with a control sample without phycocyanin. The experiment was conducted as a factorial arrangement based on a completely randomized design (CRD) using SAS software. Mean comparisons were performed using Duncan's multiple range test at a significance level of 5%. All treatments were carried out in triplicate.

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3- Results and Discussion

3-1. Effect of concentration and time on DPPH radical scavenging activity

The results of analysis of variance for the interaction of concentration and time on antioxidant activity are shown in Figure (2). As can be seen, with increasing time and concentration, DPPH radical scavenging activity increased. On day 30, the antioxidant activity was about 3.25 times higher than that of the control sample.

In general, increasing the concentration of phenolic compounds leads to an increase in DPPH radical scavenging activity, which is considered as antioxidant activity. This is because DPPH radicals are very sensitive to hydrogen-donating compounds (e.g., phenols), then these compounds are reduced to a non-radical form, resulting in a decrease in absorbance at 517 nm.

Therefore, in this method, antioxidant activity is expressed as the percentage reduction in DPPH absorbance compared to the control. Also, at higher phenolic concentrations, due to the presence of more hydroxyl groups, the hydrogen-donating ability increases, which leads to stronger radical scavenging activity [23]. Ahmadi et al. (2024). Effect of phycocyanin and phycoerythrin on antioxidant and antimicrobial activity of low-fat yogurt and cream cheese. Their results showed that antioxidant activity was higher in fortified samples at the end of storage. Also, the addition of these compounds had a significant effect on all antioxidant-related parameters ($p<0.01$) [24]. In another study, Liu et al. [25] investigated the effects of phycocyanin on bacterial population and antioxidant activity of alfalfa silage and found that the addition of 5% phycocyanin could maintain dry matter, crude protein and water-soluble carbohydrates and improve fermentation quality by increasing the amount of lactic acid and reducing pH and undesirable compounds. In addition, antioxidant capacity and phenolic content significantly increased and were positively correlated with silage quality.

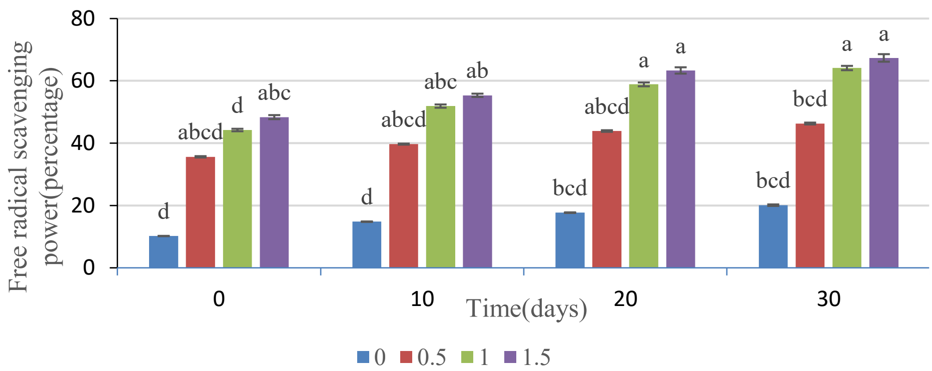

Figure (2).Interaction of concentration and time on antioxidant properties of phycocyanin-containing sugar candy. The averages in each column that have the same letters are not statistically significant at the 0.05 level

3-2. Total Phenolic Compounds of Sugar Candy Containing Phycocyanin

The results related to the interaction effect of concentration and storage time on phenolic compounds are shown in Figure (3). As it can be seen, with increasing time and also higher concentrations of phycocyanin, the total phenolic content increased. This increase also led to higher antioxidant activity. The increase in total phenolic content may be related to the bioactive compounds present in the Spirulina extract. It is also possible that some compounds associated with phycocyanin contributed to the Folin–Ciocalteu assay, resulting in higher measured phenolic values.

The highest amount was observed at day 30 with 1.5% concentration, while the lowest value was related to the control sample.

Sabetghadam et al. (2021) also reported that the lowest phenolic content was found in the control sample, and by increasing the extract concentration, the amount of phenolic compounds increased. This increase results in higher antioxidant activity. In general, higher phenolic content improves the ability of extracts to scavenge free radicals, mainly because of the higher number of hydroxyl groups that can donate hydrogen. As a result, the scavenging power becomes stronger. Also, this activity depends on the structure and molecular weight of phenolic compounds, since in lower molecular weight compounds, hydroxyl groups are more easily available [26].

It has also been reported that the antioxidant activity of fennel seed extract increases with increasing concentration [27].

Recent studies on Iranian propolis ethanolic extracts have shown a positive relationship between phenolic and flavonoid contents and antioxidant activity. Samples with higher phenolic content showed stronger DPPH radical scavenging activity, which confirms the important role of these compounds. These findings are in line with the present study and indicate that increasing phycocyanin concentration in **Sugar Candy** can enhance phenolic content and consequently improve antioxidant activity. This also highlights the potential use of natural bioactive compounds in traditional confectionery products [28]

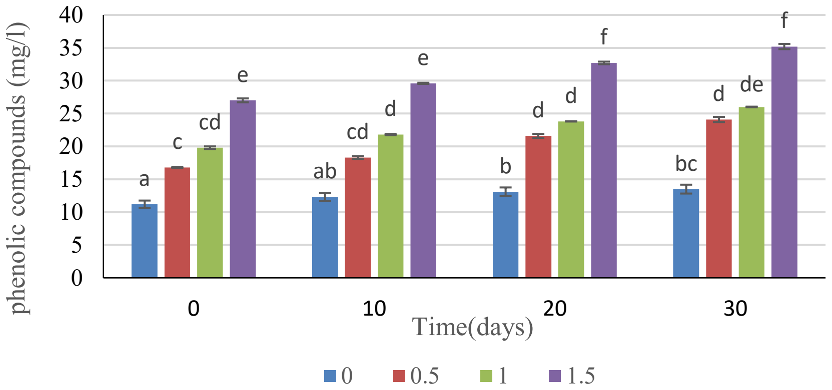

Figure (3). Interaction diagram of concentration and time of phenolic compounds of sugar candy containing phycocyanin. The averages in each column that have the same letters are not statistically significant at the 0.05 level

۳-۳. Effect of Time and Concentration on Moisture Content of Sugar Candy

The results related to the effect of time and phycocyanin concentration on moisture content are shown in Figure (4). As it can be seen, with increasing phycocyanin concentration, the moisture content showed an increasing trend. However, during storage time, the moisture decreased significantly ($p < 0.05$). This reduction is probably due to moisture loss from the surface of **Sugar Candy** over time.

Also, the highest moisture content was observed at 1.5% concentration, while the lowest value was related to the control sample (5.68 and 4.56, respectively).

Water absorption is considered one of the most important physical properties of proteins. This property not only affects the structure and processing characteristics of food products, but also plays an important role in food spoilage because of its effect on water activity. Water binding in proteins mainly happens through hydrogen bonds. Since Spirulina contains more than 60% protein, it seems that in this formulation, water is absorbed by protein chains, especially during heating processes such as mixing and drying. After cooling, hydrogen bonds are formed between chains, and water becomes trapped within the protein network [29].

Mardiani et al. (2013) reported that increasing phycocyanin concentration led to a decrease in moisture content in cheese [30]. Also, Bosnea et al. (2021) showed that higher levels of Spirulina powder reduced moisture content in traditional Greek cheese [31].

In another recent study on feta cheese enriched with Spirulina (Arthrospira platensis), it was observed that moisture content decreased, while other physicochemical properties and microbial stability improved [32]. These findings are generally in agreement with the present study, suggesting that increasing phycocyanin concentration in **Sugar Candy** during storage can reduce moisture and improve product stability.

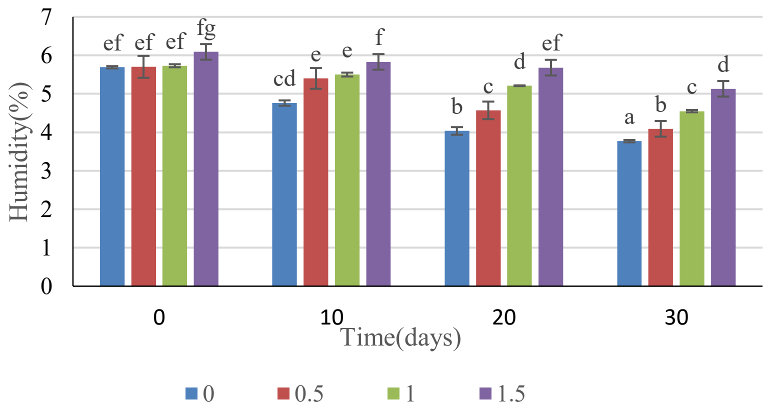

Figure (4). Interaction diagram of concentration and time on the moisture content of phycocyanin-containing sugar candy. The averages in each column that have the same letters are not statistically significant at the 0.05 level

٤-٣. Effect of Time and Concentration on Ash Content of Sugar Candy

The results of the interaction between time and phycocyanin concentration on ash content are shown in Figure (5). As can be seen, ash content increased with increasing concentration and also over storage time. On day 30, the ash content was about 3.33 times higher compared to the control sample.

The highest ash value was observed at 1.5% concentration on day 30. This increase can be related to the naturally high mineral and ash content of Spirulina [34]. The results of this study are also in agreement with the findings reported by Mehraban Sang Atash (2013) [35].

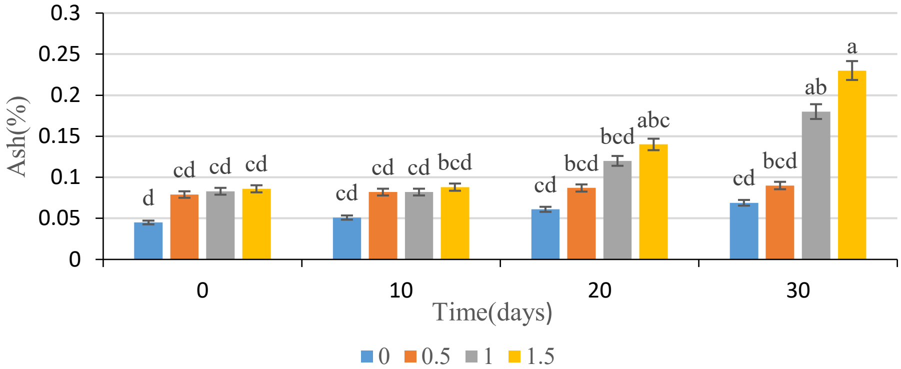

Figure (5). Interaction diagram of concentration and time on the ash content of sugar candy containing phycocyanin.
The averages in each column that have the same letters are not statistically significant at the 0.05 level

٥-٣. Effect of Time and Concentration on Water Activity of Sugar Candy

The results related to water activity (aw) are shown in Figure (6). By adding phycocyanin, water activity increased significantly, which can be due to its ability to absorb and hold water, leading to higher moisture in the samples.

However, during storage time, water activity decreased significantly ($p < 0.05$). This might be due to drying of the samples and also moisture exchange with the surrounding environment.

In general, a large part of water in food systems is bound to functional groups like hydroxyl groups in polysaccharides and carbonyl or amino groups in proteins through hydrogen bonding. Since Spirulina has a high protein content, it seems that these interactions play an important role in binding water molecules, which explains the increase in water activity with higher phycocyanin concentration.

On the other hand, over time, changes such as breaking of hydrogen and carbonyl bonds, along with environmental effects, may lead to a reduction in water activity during storage.[٣٦]

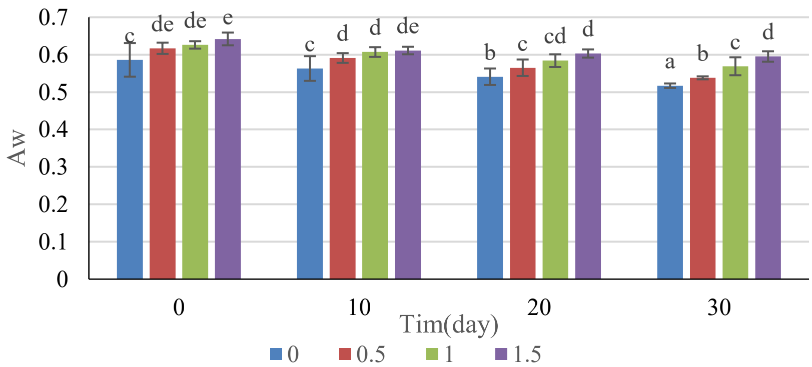

Figure (6). Interaction plot of time on water activity properties of sugar candy containing phycocyanin
The averages in each column that have the same letters are not statistically significant at the 0.05 level

3-6. Effect of Time and Concentration on pH of Sugar Candy

Some previous studies have shown that adding Spirulina powder to dairy products can reduce pH, while at the same time improving their nutritional composition. For example, in one study, yogurts enriched with 0.25 to 1% Spirulina powder showed a decrease in pH, coagulation time, and syneresis, while fat, protein, and total solids increased [7]. These findings are more or less similar to the results of the present study. In this work, a slight and non-significant decrease in pH was observed in **Sugar Candy** containing phycocyanin. This change may be related to some reactions between ingredients and the formation of acidic compounds during storage. It could also help improve the microbial stability of the product.

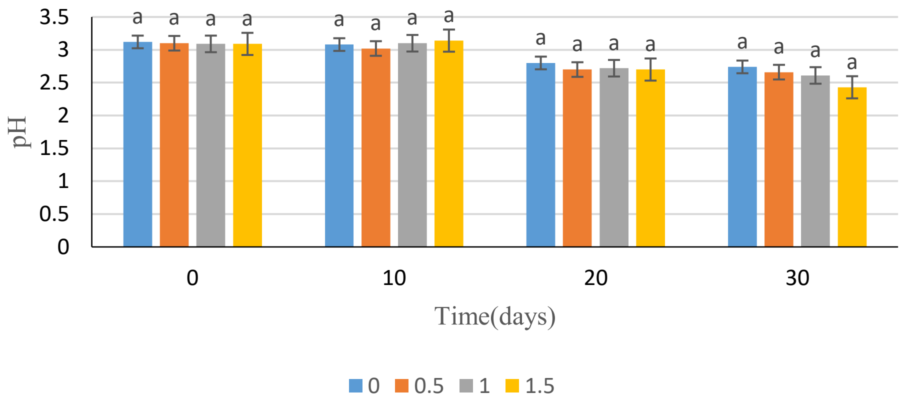

Figure (7). Interaction plot of time on pH changes of sugar candy containing phycocyanin averages in each column that have the same letters are not statistically significant at the 0.05 level

3-7. Microbial Properties of Sugar Candy Containing Phycocyanin

According to Table (1), all microbial tests were negative at different times and concentrations, which indicates that the samples were in good condition. Since no preservatives were used in this product, it can be said that **Sugar Candy** containing phycocyanin had acceptable microbial stability. It seems that phycocyanin extracted from *Spirulina platensis* may help reduce microbial growth [37]. Also, results from other studies have shown that Spirulina extracts and phycocyanin pigment have strong antimicrobial effects against pathogenic bacteria and fungi [38].

Table (1). Investigation of microbial properties of sugar candy containing phycocyanin

Time (days)	Concentration (ppm)	Mold(Cfu/g)	Yeast (Cfu/g)	Enterobacteriaceae(Cfu/g)	Acceptable limits	Execution method
0	0	<10	<10	<10	<100	Cultivation and counting
10	0	<10	<10	<10	<100	Cultivation and counting
20	0	<10	<10	<10	<100	Cultivation and counting
30	0	<10	<10	<10	<100	Cultivation and counting
0	0.5	<10	<10	<10	<100	Cultivation and counting
10	0.5	<10	<10	<10	<100	Cultivation and counting
20	0.5	<10	<10	<10	<100	Cultivation and counting
30	0.5	<10	<10	<10	<100	Cultivation and counting
0	1	<10	<10	<10	<100	Cultivation and counting
10	1	<10	<10	<10	<100	Cultivation and counting

20	1	<10	<10	<10	<100	Cultivation and counting
30	1	<10	<10	<10	<100	Cultivation and counting
0	1.5	<10	<10	<10	<100	Cultivation and counting
10	1.5	<10	<10	<10	<100	Cultivation and counting
20	1.5	<10	<10	<10	<100	Cultivation and counting
30	1.5	<10	<10	<10	<100	Cultivation and counting

٣-٨. Sensory properties of **Sugar Candy** containing phycocyanin

The results of the sensory evaluation for texture, color, taste, and overall acceptance are presented in Table (2). Among all samples, the one containing 0.5% phycocyanin received the highest scores in all sensory attributes. In fact, adding phycocyanin at this level showed the best acceptance compared to the other treatments ($p<0.05$). It seems that the blue color created by phycocyanin made the product more attractive and interesting for consumers. Overall, the panelists were generally satisfied with the samples containing phycocyanin. However, when the concentration increased beyond this level, the acceptance of the samples slightly decreased.

These findings are in agreement with the results reported by Fallah et al. (2021) and Barzegar et al. (2020.)[٣٩,٤٠]

Table(2). Sensory evaluation of properties of sugar candy containing phycocyanin

30	20	10	0	Tim	
3.23±0.02^{b}	3.5±0.014^{ab}	3.7±0.01^{a}	3.77±0.02^{a}	0	
4±0. 22^{ab}	4.03±0.02^{ab}	4.17±0.23^{a}	4.23±0.012^{a}	0.5	texture
3.39±0.05^{c}	3.61±0.12^{b}	3.87±0.06^{ab}	4±0.014^{a}	1	
3 ±0.17^{bc}	3.44± 0.01^{b}	3.67±0.09^{ab}	3.89±0.12^{a}	1.5	
3.2±0.003^{a}	3.2±0.2^{a}	3.4 ±0.01^{a}	3.5±0.01^{a}	0	
4.5±0.03^{a}	4.48±0.6^{a}	4.42±0.033^{a}	4.4±0.03^{a}	0.5	color
4.4±0.02^{ab}	4.7±0.01^{a}	4.6±0.09^{a}	4.56±0.05^{a}	1	
4.3±0.04^{a}	4.45 ±0.04^{a}	4.4±0.05^{a}	4.36±0.002^{a}	1.5	
4±0.17^{a}	4±0.32^{a}	4±0.38^{a}	4±0.1^{a}	0	
3.16±0.07^{d}	3.53±0.12^{c}	3.75±0.28^{b}	4.23±0.15^{a}	0.5	test
3±0.32^{bc}	3.22±0.28^{ab}	3.3±0.3^{ab}	3.5±0.16^{a}	1	
2.63±0.4^{c}	2.8±0.41^{b}	3±0.15^{ab}	3.2±0.22^{a}	1.5	
4±0.23^{a}	4±0.25^{a}	4±0.19^{a}	4.2±0.1^{a}	0	
4.1±0.07^{ab}	4.1±0.07^{ab}	4.27±0.2^{ab}	4.46±0.15^{a}	0.5	accept
3.53±0.12^{c}	3.5±0.09^{bc}	3.77±0.27^{b}	4.12±0.16^{a}	1	
2.8±0.17^{d}	3±0.11^{c}	3.42±0.3^{b}	4±0.22^{a}	1.5	

4-Conclusion

The results of this study showed that adding phycocyanin from spirulina can have a positive effect on **Sugar Candy** quality. As the amount of phycocyanin increased, antioxidant activity, ash, and total phenolic content also increased. On the other hand, moisture and water activity decreased during the study. The pH did not change much and the differences were not significant

From the sensory results, the sample with 0.5% phycocyanin had the best overall acceptance. It seems that this level was more suitable in terms of color and taste compared to higher concentrations. When the amount was higher, the acceptance slightly decreased.

Also, no microbial growth was observed in any of the samples during storage. This shows that the product had good stability, even without using preservatives.

In general, phycocyanin can be used as a natural color with antioxidant properties in **Sugar Candy**. It can help improve the product and may be useful for making new types of traditional sweets. Since people are now more interested in natural ingredients, using this compound could be a good option in food production

- Suggestions for future work
- Study the stability of phycocyanin at different processing temperatures
- Check the effect of encapsulation on its stability against heat and light
- Investigate its effect on texture in similar products
- Evaluate production at industrial scale and economic aspects
- Study the product over longer storage time

Data Availability

Data from this study will be made available upon request.

Conflict of Interest

The author declares that there are no conflicts of interest related to this study.

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Authors Contributions

All activities in this study were carried out by the authors.

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ارزیابی ویژگی‌های فیزیکوشیمیایی و میکروبی شکرپنیر غنی‌سازی‌شده با فیکوسیانین

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چکیده

افزایش نگرش مصرف‌کنندگان به استفاده از رنگ‌های طبیعی به‌جای رنگ‌های سنتزی، موجب گسترش کاربرد ریزجلبک *اسپیرولینا* به‌عنوان منبع پروتئین و رنگ‌دانه فیکوسیانین در صنایع غذایی و بهداشتی شده است. در این پژوهش، *اسپیرولینا* در محیط کشت رودیک تحت دمای ۲۸±۲ °C ، pH حدود ۸ و نور سفید با شدت ٦۰۰۰ لوکس کشت شد و پس از ١٤ روز، رنگ‌دانه فیکوسیانین به روش ذوب ـ انجماد استخراج گردید. فیکوسیانین در غلظت‌های ۰، ۰/۵، ۱ و ۱/۵ درصد به شکرپنیر افزوده شد و تغییرات فیزیکوشیمیایی و میکروبی نمونه‌ها طی دوره نگهداری ۰، ۱۰، ۲۰ و ۳۰ روز مورد ارزیابی قرار گرفت. نتایج نشان داد با افزایش غلظت فیکوسیانین، فعالیت آنتی‌اکسیدانی، خاکستر و ترکیبات فنلی روند افزایشی و میزان رطوبت و فعالیت آبی روند کاهشی داشت. نمونه حاوی۰/۵ درصد فیکوسیانین بالاترین امتیاز پذیرش حسی را کسب کرد و در هیچ‌یک از نمونه‌ها رشد میکروبی مشاهده نشد. این نتایج نشان می‌دهد فیکوسیانین می‌تواند به‌عنوان یک رنگ‌دانه طبیعی با خواص عملکردی مطلوب در تولید شکرپنیر مورد استفاده قرار گیرد.