JSAES
Journal of Sustainable Agricultural and Environmental Sciences

Print ISSN : 2735-4377
Online ISSN : 2785-9878
Homepage: https://jsaes.journals.ekb.eg/

Research Article

Development of Functional Ice Cream Fortified with Spirulina (*Arthrospira platensis*): Improvements in Nutritional and Antioxidant Properties

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Article info: -

- **Received:** 8 August 2025
- **Revised:** 7 September 2025
- **Accepted:** 27 September 2025
- **Published:** 5 October 2025

Keywords:
Dairy product; physical properties; antioxidant activity

Abstract:

This experimental study aimed to evaluate the incorporation of Spirulina powder *Arthrospira platensis* as a functional and nutritional enhancer in ice cream. Ice cream was manufactured and divided into four batches as follows: (C), ice cream without any addition, Control, (T1) ice cream with 0.5% spirulina powder, (T2) ice cream with 1% spirulina powder, (T3) ice cream with 1.5% spirulina powder. The physicochemical properties, antioxidant activity (total phenolic content (TPC), DPPH radical scavenging activity, and ferric reducing antioxidant power (FRAP)), rheological properties, melting characteristics, and sensory attributes were assessed. The results revealed that the addition of Spirulina powder significantly improved the antioxidant activity of the ice cream, with higher concentrations of Spirulina. The nutritional profile also showed a marked increase in protein and ash content, confirming the fortified effect of Spirulina powder. Furthermore, functional properties such as melting resistance, viscosity, and overrun were positively influenced, indicating improved stability and texture of the product. However, the fortifying samples acquired a noticeable green color due to the natural pigments in Spirulina powder. The consumer acceptance was not negative, and sensory evaluation results indicated an increase in overall acceptability.

1. Introduction

In recent years, growing consumer awareness of health and nutrition has increased the demand for functional foods with added health benefits. One key area of interest is the enhancement of antioxidant levels in food products using natural sources, due to concerns over the potential health risks associated with synthetic additives. Spirulina powder, a natural microalga rich in bioactive compounds, offers a promising alternative for improving the antioxidant capacity of dairy products.

Ice cream, the most widely consumed frozen dairy dessert, is a complex colloidal system made from a blend of dairy and non-dairy components such as fat, milk solids-not-fat, sugars, stabilizers, emulsifiers, and water (Goff and Hartel, 2013; Goff, 2006). Its composition and production involve homogenization, aeration, and freezing processes that create a structure of air bubbles, fat droplets, and ice crystals. Historically, ice cream has evolved through centuries of technological and cultural advancements, spreading from the Mediterranean to global popularity (Goff and Hartel, 2013). Despite varying types and definitions worldwide, its formulation consistently aims to balance texture, flavor, and consumer appeal. Ingredient selection depends on functional, legal, and economic factors that directly influence product quality (Goff, 2006).

Spirulina (*Arthrospira platensis*) is a filamentous cyanobacterium, commonly referred to as blue-green algae, that grows in both freshwater and marine environments. It has long been consumed as a nutrient-dense food source, containing 60–70% protein by dry weight and providing all essential amino acids, thus classifying it as a complete and highly digestible protein. Spirulina is also rich in B vitamins, iron, magnesium, potassium, and zinc, in addition to potent antioxidants such as phycocyanin, chlorophyll, and β-carotene, which contribute to reducing oxidative stress. Furthermore, it provides γ-linolenic acid (GLA), a rare fatty acid with anti-inflammatory properties. Owing to its balanced composition, Spirulina is widely recognized as a valuable dietary supplement and a promising option to combat protein malnutrition (Prasetyo et al., 2024; Ai et al., 2023).

From a health standpoint, Spirulina provides a wide range of benefits. It contributes to cardiovascular health by reducing LDL cholesterol, triglycerides, and blood pressure, while increasing HDL cholesterol. It also enhances immune function by stimulating immune cells and strengthening antioxidant defenses. Moreover, Spirulina promotes gut health through the growth of beneficial bacteria and shows neuroprotective potential by reducing inflammation linked to neurodegenerative disorders. Its role in diabetes management is also significant, as it helps regulate glucose metabolism and improve insulin sensitivity. In addition, regular intake of Spirulina has been associated with anemia prevention, anticancer effects, and better overall metabolic health (AlFadhly et al., 2022).

Recent studies have demonstrated the potential of Spirulina platensis as a functional ingredient in various food products. (Donato et al., 2019) reported improved protein and mineral content in cookies fortified with up to 15% Spirulina, with 5% addition maintaining consumer acceptability. Similarly, Agustini et al. (2016)

evaluated the incorporation of Spirulina platensis in soft cheese and ice cream, focusing on sensory and physicochemical properties. Their findings indicated that the highest acceptable concentrations were 1% in soft cheese and 1.2% in ice cream. The addition of Spirulina significantly increased the β-carotene content and influenced the water, fat, protein, and texture of the soft cheese. In ice cream, it affected total sugar, overrun, melting point, total solids, fat, and sensory characteristics. Other studies have confirmed that Spirulina exhibits dose-dependent antioxidant activity (Anbarasan et al., 2011; Kamble et al., 2013) and a positive impact on fermentation, texture, and acceptability in dairy products such as yogurt and cheese (Barkallah et al., 2017).

This study aims to develop functional ice cream enriched with Spirulina powder to enhance its antioxidant activity while maintaining desirable quality characteristics.

2. Materials and Methods

2.1. Raw materials and chemicals

Fresh whole milk with (3% fat and non-fat solids content of 8.25%), cream with 33% fat was used to adjust the fat content (Juhayna, Egypt). whole milk powder was added as a source of milk solids (Nido, Nestlé, Switzerland).

Guar gum was used as a stabilizer, and mono- and diglycerides of fatty acids were used as emulsifiers. Both were obtained from Palsgaard Food Ingredients, Denmark.

Spirulina powder was obtained from Spirulina 91 farms in Wadi El-Natrun, Egypt. Sucrose and vanilla were purchased from the local market. DPPH (2,2-Diphenyl-1-picrylhydrazyl) and other chemicals were purchased from El-Naser company, Egypt.

2.2. Methods

2.2.1. Preparation of ice cream fortified with Spirulina powder (Arthrospira platensis)

As shown in Table 1, the ice cream base was prepared by heating milk and cream to 75°C, followed by the gradual addition of milk powder, sugar, stabilizer, and emulsifier with constant stirring. The mix was heat-treated at 80°C for 10 minutes and aged overnight at 5°C. Spirulina powder was then added at 0.5% (T1), 1.0% (T2), and 1.5% (T3), (C) containing no Spirulina powder. The final mixture was frozen using a batch freezer (YKF-618 Hard ice cream machine) and stored at −18°C to −23°C (Goff and Hartel, 2013).

Table 1. Ingredients of Spirulina powder ice cream samples

Ingredients	*Treatments			
	C	T1	T2	T3
Cow milk (%)	77.5	77.5	77.5	77.5
FCMP (%)	2.5	2.5	2.5	2.5
Cream (%)	5	5	5	5
Sugar (%)	14.5	14.5	14.5	14.5
Stabilizer (%)	0.2	0.2	0.2	0.2
Emulsifier (%)	0.3	0.3	0.3	0.3
Spirulina powder (%)	-	0.5	1	1.5
Vanilla (%)	0.1	0.1	0.1	0.1

2.2.2. Chemical characterization of ice cream

Fat and protein contents were analyzed using the Gerber (ISO, 2008) and Kjeldahl methods (AOAC, 2005), respectively. pH was measured using a digital pH meter, while moisture, ash, and titratable acidity were determined according to AOAC (2005).

2.2.3. Antioxidant activity

2.2.3.1. DPPH Radical Scavenging Activity

10 g of sample was extracted with 90 mL of 80% methanol under magnetic stirring, followed by 20 hours of dark incubation. The extract was centrifuged and filtered. 0.1 mM DPPH solution in methanol was prepared, and 3.9 mL of it was mixed with 0.1 mL of the sample extract. The mixture was kept in the dark at 20 °C for 30 minutes. Absorbance was measured at 517 nm using a UV–Vis spectrophotometer. The scavenging activity was calculated using the formula:

$$\text{Inhibition (\%)} = (A_0 - A_1) / A_0 \times 100,$$

where A_0 is the absorbance of the control and A_1 is the absorbance of the sample (Szmejda et al., 2018).

2.2.3.2. Total phenolic content (TPC)

10 g of sample was extracted with 90 mL of 80% methanol under magnetic stirring, followed by 12 hours of dark incubation. The extract was centrifuged and filtered. An aliquot of 0.2 mL was reacted with Folin–Ciocalteu reagent and sodium carbonate, then incubated at 20 °C for 20 minutes. Absorbance was measured at 760 nm, and TPC was calculated using a gallic acid standard curve. Results were expressed as mg GAE/g (Szmejda et al., 2018).

2.2.3.3. Ferric reducing antioxidant power (FRAP)

10 g of sample was extracted with 90 mL of 80% methanol under magnetic stirring, followed by 12 hours of dark incubation. The extract was centrifuged and filtered.

A 100 µL portion of the extract was mixed with 3 mL of FRAP reagent and incubated in the dark at 37 °C for 30 minutes. Absorbance was measured at 593 nm using a UV–Vis spectrophotometer. Antioxidant capacity was determined from a Trolox standard curve and expressed as µmol TE/g (Benzie and Strain., 1996).

2.2.4. Overrun determination

Overrun (%) was measured manually by comparing the volume of 250 mL of hardened ice cream to the volume of the same sample after melting at room temperature without stirring. The overrun was calculated using the formula:

Overrun (%) = [(Volume of ice cream – Volume of mix) / Volume of mix] × 100 (Farhah et al., 2020).

2.2.5. Viscosity

The apparent viscosity of the ice cream mix was measured using a digital viscometer (NDJ-8S, China) at 20 ± 1°C and a constant speed of 60 rpm. The appropriate spindle was selected based on the sample's consistency, and the instrument was calibrated before use. Viscosity values were recorded in centipoise (cP) after stabilization. All measurements were done in triplicate and reported as mean ± standard deviation. (ATO Analytical Instruments, n.d.)

2.2.6. Melting properties

The melting behavior of ice cream samples was evaluated at 25 ± 1 °C using a 100 g portion placed on a wire mesh screen. The time until the appearance of the first melted drop was recorded as an indicator of melting resistance. For the melting rate, the volume of melted ice cream was collected in a graduated cylinder at fixed intervals (15 and 30 min) starting from the first drop. All measurements were performed in triplicate, and results were expressed as mean ± standard deviation (Farhah et al., 2020).

2.2.7. Sensory evaluation

Sensory evaluation was performed by a panel of 15 untrained individuals using a weighted scoring system. Attributes included color (10 points), flavor (45), texture (30), melting in the mouth (15), and overall acceptability (100). Samples were coded and served under standardized conditions, and water was provided between samples (Gabbi et al., 2018). Results were reported as mean ± standard deviation.

2.2.8. Statistical analysis

Data were analyzed using SPSS software (version 22). Results from triplicate measurements were expressed as mean standard deviation. One-way ANOVA was used to assess significance ($p < 0.05$), and Duncan's multiple range test was applied to compare means.

3. Results and Discussions

3.1. Effect of Spirulina powder on chemical characteristics of ice cream

3.1.1. Protein Content of Fortified Ice Cream

As presented in Table 2 and Figure 1, a significant increase ($p < 0.05$) with rising levels of Spirulina powder. It ranged from 2.53% in the C to 3.35% in the T3. This increase reflects the high protein concentration of Spirulina powder, which contains approximately 57% protein. Spirulina powder is well recognized for its high-quality protein content, including both essential and non-essential amino acids, with phycocyanin contributing to its nutritional value (Beneihadj et al., 2016). Although levels of cysteine and lysine are slightly below FAO reference values, Spirulina powder still provides a complete amino acid profile, supporting its role in addressing protein-energy malnutrition (Aiello et al., 2019). These findings align with previous research that reported significant improvements in protein levels in dairy and functional foods enriched with Spirulina powder (Malik et al., 2013; Jadhav et al., 2022).

Table 2. Effect of using spirulina powder on the chemical characteristics of ice cream

Treatment	Protein (%)	Ash (%)	Fat (%)	T.S (%)	Acidity (%)	PH
C	2.53±.02[a]	.5847±.001[a]	4.5±.057[a]	26.5±.01[a]	.155±.0006[a]	6.49±.01[a]
T1	2.83±.01[b]	.6487±.0281[b]	4.6±.057[a]	27±.06[b]	.163±.001[a]	6.47±.01[b]
T2	3.09±0.021[c]	.7263±.003[c]	4.8±.1[b]	27.46±.15[c]	.21±.01[b]	6.42±.01[c]
T3	3.35±0.02[d]	.8193±.01[d]	5±.06[c]	28±.06[d]	.223±.01[b]	6.4±.01[d]

C (without Spirulina powder addition), T1, T2, T3: Ice cream samples supplemented with Spirulina powder at 0.5%, 1%, and 1.5%, respectively.

3.1.2. Ash content of fortified ice cream

The addition of Spirulina powder to ice cream showed affected the ash content as presented in Table 2 and Figure 1. There was a significant ($p < 0.05$) increase in ash content across all ice cream treatments with rising Spirulina powder levels. The ash content rose from 0.5847% in the C to 0.819% in T3 (1.5% Spirulina powder), confirming that Spirulina powder fortification enhances the mineral composition of the product. Similar findings were previously reported by Malik et al. (2013) and Jadhav et al. (2022). This increase is attributed to Spirulina powder's naturally high mineral content, which ranges between 7–13% ash (Jung et al., 2019). It provides a wide spectrum of essential minerals, including iron, calcium, magnesium, potassium, phosphorus, and trace elements like zinc and selenium (Nawal et al., 2022). Even at relatively low inclusion levels, Spirulina powder can notably boost the mineral and nutritional profile of food products.

3.1.3. Fat content of fortified ice cream

The influence of Spirulina powder addition on the fat content of ice cream was observed in Table 2 and Figure 1. A slight significant increase ($p < 0.05$) in fat content due to Spirulina powder. Fat levels rose from 4.5% in the C to 5.0% in the T3, due to the contribution of Spirulina powder to fat enrichment (Bajestanial, 2024).

The Spirulina powder had approximately 4–8% fat, which is consistent with the typical lipid content reported for this microalga (Becker, 2007). These lipids include glycerol esters and fatty acids (C14–C22), along with essential fatty acids like linoleic and linolenic acids, which enhance the product's nutritional value. This supports the role of Spirulina powder as a functional ingredient in improving both fat content and the nutritional profile of ice cream (Sajilata et al., 2008).

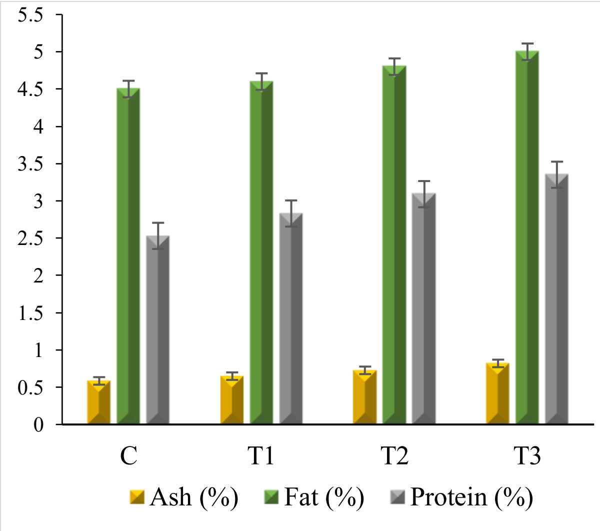

Figure 1. Chemical composition of Spirulina powder ice cream samples. C: (without Spirulina powder addition), T1, T2, T3: Ice cream samples supplemented with Spirulina powder at 0.5%, 1%, and 1.5%, respectively.

3.1.4. Total solids of fortified ice cream

The contribution of Spirulina powder to changes in the Moisture and Total Solids of ice cream was shown in Table 2. Increasing Spirulina powder levels led to a slight decrease in moisture content and an increase ($p < 0.05$) in total solids, from 26.5% in the C to 28% in T3. This inverse trend aligns with previous research by Agustini et al. (2016).

The rise in total solids is mainly due to the cumulative increase in protein, fat, and ash resulting from the incorporation of Spirulina powder. Since Spirulina powder is rich in these components, its addition naturally boosts the dry matter content (Koli et al., 2022). The mild reduction in moisture can be attributed to the displacement of water by the added dry powder, which leads to a higher concentration of solids (Agustini et al., 2015).

3.1.5. Titratable Acidity and pH of fortified ice cream

Table 2, displayed the changes in acidity and PH of ice cream as a result of spirulina fortification; titratable acidity increased ($p < 0.05$) with the addition of Spirulina powder, rising from 0.155% in C to 0.223% in T3. Meanwhile, PH levels decreased slightly from 6.48 to 6.40. These changes are consistent with the observations of (Malik et al.,2013; Jadhav et al., 2022).

The increase in acidity may be related to Spirulina powder's chemical makeup, particularly its high protein and mineral content, which contribute to the acidic nature of the product. In dairy systems, acidity is influenced by proteins, minerals, and SNF content (Arbuckle, 1986). Thus, Spirulina powder, as a nutrient-rich additive, can shift the physicochemical balance and lead to slight but significant changes in pH and titratable acidity.

3.2. Antioxidant activity of fortified ice cream

The impact of incorporating Spirulina powder in ice cream on the antioxidant activity was demonstrated in Table 3. The DPPH radical scavenging activity increased significantly ($p < 0.05$) from 24.5% in the C to 45.4% in T3 (1.5% Spirulina powder), indicating improved radical neutralization capacity with Spirulina powder addition. This enhancement is attributed to its high content of phycocyanin and phenolic compounds, known for their antioxidant action. Other phytochemicals such as sterols, flavonoids, reducing sugars, and tannins may have also contributed (Shalaby et al., 2013; Bajestanial., 2024). Similarly, the FRAP assay showed a significant increase in ferric-reducing power, rising from 0.18 to 0.376 mmol Fe^{2+}/g as Spirulina powder concentration increased (Bajestanial., 2024). This is linked to the dose-dependent reducing effect of phycocyanin and the contribution of other antioxidant compounds (Punampalam et al., 2018).

Table 3. Antioxidant activity ice cream samples with different levels of spirulina powder.

Treatment	DPPH (%)	FRAP (mmol Fe^{2+}/g)	TPC (mg GAE/g)
C	24.5±.06^{a}	.18±.01^{a}	3.41±.01^{a}
T1	34.8±.12^{b}	.2500±.01^{b}	3.91±.01^{b}
T2	36.4±.17^{bc}	.3100±.01^{c}	4.05±.012^{c}
T3	45.4±.15^{d}	.3767±.01^{d}	4.45±.02^{d}

C sample (without Spirulina powder addition), T1, T2, T3: Ice cream samples supplemented with Spirulina powder at 0.5%, 1%, and 1.5%, respectively. DPPH% %: (2,2-Diphenyl-1-picrylhydrazyl); FRAP: ferric reducing antioxidant power.; TPC, total phenolic content.

The (TPC) also showed a marked rise from 3.41 mg GAE/g (C) to 4.45 mg GAE/g in T3, confirming the enrichment of phenolic compounds in Spirulina powder-fortified samples. This result is in line with previous studies showing Spirulina powder's potential as a source of phenolics, which vary according to cultivation and processing conditions (Boyanova et al., 2022; Ranga Rao et al., 2010). Overall, the findings indicate that incorporating Spirulina powder significantly enhanced the antioxidant profile of the ice cream.

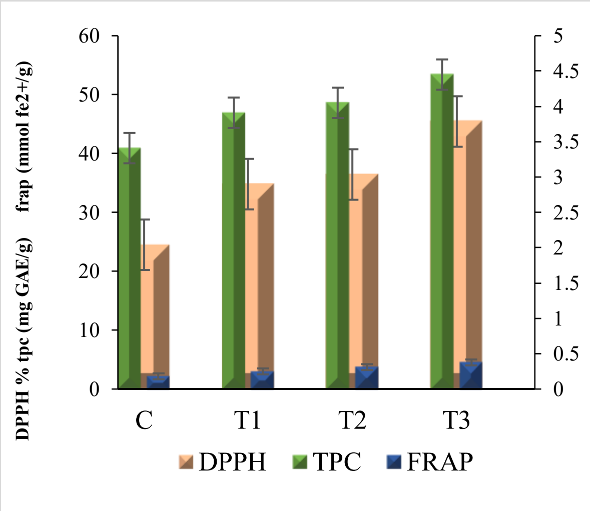

Figure 2. TPC, DPPH, and FRAP of Spirulina powder-fortified ice cream. C sample (without Spirulina powder addition), T1, T2, T3: Ice cream samples supplemented with Spirulina powder at 0.5%, 1%, and 1.5%, respectively.

3.3. Physical properties

3.3.1. Overrun of fortified ice cream

Overrun refers to the volume increase in ice cream resulting from air incorporation during freezing, which plays a critical role in determining texture and quality (Syed et al., 2018). The role of Spirulina powder incorporation in increasing the Overrun of ice cream was revealed in Table 3 and Figure 3. Overrun values increased significantly ($p < 0.05$) with the addition of Spirulina powder, rising from 25.3% in C to 58.4% in T3 sample (1.5% Spirulina powder). These findings are consistent with those reported by (Boyanova et al., 2022).

The enhancement in overrun may be attributed to the functional components of Spirulina powder particularly proteins and lipids which possess notable emulsifying and foaming properties. Previous studies have shown that Spirulina powder offers an emulsifying capacity of 1.13 mL fat/g protein, a foaming capacity of 207%, and foam stability of 27%, all of which contribute to improved air incorporation and retention during freezing Boyanova et al. (2022).

3.3.2. Viscosity of fortified ice cream

Viscosity is a critical physicochemical property of ice cream mix that ensures the homogeneity of the product by preventing phase separation (Malik et al., 2013). The effect of fortifying ice cream with Spirulina powder on the viscosity was shown in table 3 and Figure 3, the addition of Spirulina powder significantly ($p < 0.05$) increased the viscosity, from 307 mPa·s in the C to 399 mPa·s in the sample fortified with 1.5% Spirulina powder. These findings are consistent with prior research highlighting the thickening effects of Spirulina powder components (Rasouli et al., 2017).

Table 4. Physical properties of spirulina powder-enriched ice cream

Treatment*	Overrun (%)	Viscosity (mpa ⁄s)	Melting resistance (min)	Melted volume after 15 min (ml)	Melted volume after 30 min (ml)
C	25.3±.17[a]	307.67±.88[a]	13 ±.29[a]	16 ±.12[a]	35 ±.58[a]
T1	33.43±.23[b]	339.3±1.45[b]	15.5±.28[b]	12.± .58[b]	27± .58[b]
T2	45.467±.26[c]	378.67±2.027[c]	16.± .29[b]	10 ±0.29[c]	24 ±.58[c]
T3	58.43±.23[d]	399.3±1.76[d]	17 ±.29[c]	8 ±.58[d]	19 ±.58[d]

*C (without Spirulina powder addition), T1, T2, T3: Ice cream samples supplemented with Spirulina powder at 0.5%, 1%, and 1.5%, respectively

The observed increase is mainly due to Spirulina powder's rich content of proteins and polysaccharides, which contribute to building a stable, three-dimensional network that enhances texture and flow resistance. Furthermore, Spirulina powder exhibits a high water-binding capacity up to 1.45 g water/g protein Boyanova et al. (2022). which reduces free water and improves the mix's overall consistency. Additionally, the presence of natural fibers in Spirulina powder supports structural integrity and moisture retention in the ice cream formulation.

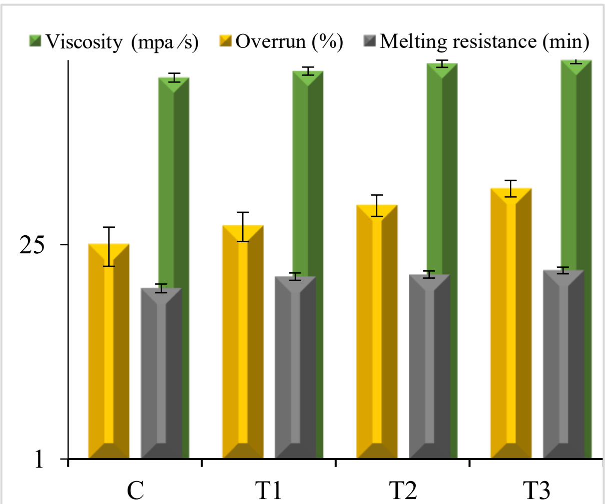

Figure 3. Physical properties of ice cream fortified with spirulina powder. C (without Spirulina powder addition), T1, T2, T3: Ice cream fortified with Spirulina powder at 0.5%, 1%, and 1.5%, respectively.

3.3.3. Melting properties of fortified ice cream

Melting behavior is a key quality parameter in ice cream, typically assessed through two aspects: melting resistance and melting rate. Melting resistance refers to the time the product maintains its structure, while melting rate reflects the amount of melt over time both critical for evaluating product stability during consumption (Warren & Hartel, 2018).

The impact of incorporating Spirulina powder into ice cream on the melting properties was demonstrated in Table 4. In addition Spirulina powder significantly ($p < 0.05$) enhanced the melting resistance of the samples (Figure 4), increasing the melting time from 13 in C to 17 °C in T3 minutes. Concurrently, the melting rate decreased markedly; after 15 minutes, melted weight dropped from 16 g in the C to 8 g in the Spirulina powder-enriched sample, and after 30 minutes, from 35 g in C to 19 in T3 g (Figure 4). These findings are consistent with those reported by Boyanova et al. (2022).

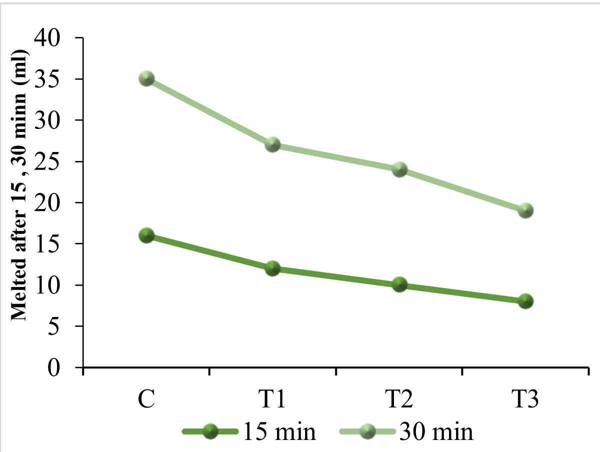

Figure 4. Melting rate of spirulina powder-fortified ice cream samples after 15 and 30 minutes at room temperature. C (without Spirulina powder addition), T1, T2, T3: Ice cream samples supplemented with Spirulina powder at 0.5%, 1%, and 1.5%, respectively.

This improvement is largely attributed to Spirulina powder's high water-binding capacity and protein content, which reinforce the structural integrity of the ice cream matrix (R. P. Sofijan et al., 2004). Spirulina powder proteins serve as natural emulsifiers, enhancing the stability of fat globules and air cells, and thus slowing down melting (El-Rahman et al., 1997). Additionally, the increased overrun observed in fortified samples further contributes to a stable microstructure capable of withstanding temperature-induced collapse.

3.4. Sensory evaluation of fortified ice cream

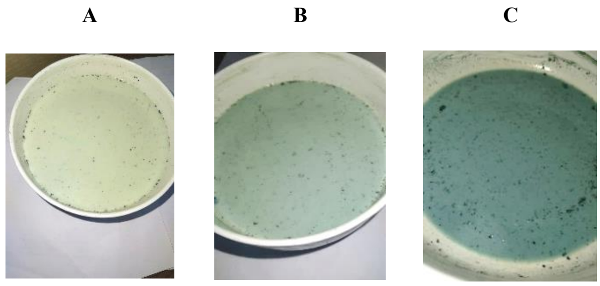

Figure 5. Ice cream samples containing spirulina 0.5% (A), 1% (B), 1.5% (C).

Table 5 shows that supplementing ice cream with Spirulina platensis powder (0.5–1.5%) led to clear improvements in most sensory attributes. Overall acceptability scores rose significantly ($p < 0.05$), from 86.3 in the control to 91.8, 90.4, and 94.3 for T1, T2, and T3, respectively. Flavor scores remained high, with T3 achieving 42.1/45, indicating that the characteristic marine notes of Spirulina were well balanced by the product's sweetness and creaminess. Texture and melting quality also improved markedly, texture rising from 24.6 in the control to 28.48 in T3, while melting quality increased from 10.5 to 13, reflecting enhanced structural stability. Although color scores decreased slightly due to the natural green pigment of Spirulina (from 8.4 in the control to 5.6 in T3), but remained within an acceptable range.

Table 5. Sensory evaluation of spirulina powder-supplemented ice cream.

Treatment	Color (10)	Flavour (45)	Melting (15)	Texture (30)	Overall (100)
C	8.4±.31^{a}	40.2±1.39^{a}	10.5±.5^{a}	24.64±.68^{a}	86.3±1^{a}
T1	8.16±.39^{b}	40.2±1.3^{a}	12.5±.5^{ab}	26.3±.5^{a}	91.8±1.9^{b}
T2	7.26±.35^{b}	40.6±.53385^{a}	11.66±.84^{b}	25.04±.704^{a}	90.4±1.503^{b}
T3	5.64±.50^{b}	42.1±1.07703^{a}	13.06±.38^{b}	28.48±.19^{b}	94.3±.54^{b}

C (without Spirulina powder addition), T1, T2, T3: Ice cream samples supplemented with Spirulina powder at 0.5%, 1%, and 1.5%, respectively.

These findings can be explained by the functional properties of Spirulina platensis, which contains proteins and polysaccharides that act as natural stabilizers and emulsifiers, improving body, texture, and melting resistance in frozen desserts. Moreover, sensory evaluation principles emphasize that consumer acceptance depends primarily on flavor, texture, and mouthfeel, while moderate color changes are often tolerated when the overall eating quality is improved (Drake et al., 2023). Consequently, Spirulina fortification—particularly at 1.5% enhanced the sensory quality and consumer acceptability of ice cream despite a slight color change.

4. Conclusions

In conclusion, the incorporation of Spirulina powder platensis into ice cream at levels of 0.5%, 1.0%, and 1.5% resulted in significant improvements in its nutritional and functional properties. Spirulina powder-enriched samples showed higher protein, ash, and total solid contents, as well as enhanced antioxidant activity as evidenced by increased DPPH scavenging, FRAP values, and total phenolic content. The addition of Spirulina powder also positively influenced rheological and physical properties, including overrun, viscosity, and melting resistance. Despite a slight reduction in visual appeal due to the natural green color of Spirulina powder, consumer acceptability was not negatively affected—in fact, flavor, texture, and overall acceptability were improved. These findings suggest that Spirulina powder can be used as a natural, functional ingredient in frozen dairy products to enhance their health-promoting potential without compromising sensory quality.

Author Contributions: The following statements should be used "Conceptualization, Mohamed El-Hawary, Sameh Awad and Mona Moharam; methodology, Mona Moharam; Dina Amer investigation, Mona Moharam and, Sameh Awad; resources, Dina Amer and Mona Moharam; writing—original draft preparation, Mona Moharam; writing—review and editing, Sameh A. Awad and Dina Amer; supervision, Mohamed El-Hawary, Sameh Awad and, Dina A. Amer. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: I would like to extend my sincere gratitude to my esteemed professors for their continuous guidance and valuable support throughout this research. My appreciation also goes to Tanta University and Alexandria University for providing the academic environment, facilities, and resources essential for the completion of this work. Their contributions have been fundamental to the success of this study.

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

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