

Effects of *Spirulina platensis* enrichment on the quality properties of traditional kesik cheese*

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Summary

This study evaluated the effect of incorporating *Spirulina platensis* (*S. platensis*, SP) into traditional kesik cheese on the physicochemical and microbiological quality of this rennet-free acid-coagulated Turkish dairy product. Four cheese groups were produced from raw cow's milk: a control group and three experimental groups supplemented with 0.25%, 0.50%, and 0.75% (m/m) SP. Samples were stored at +4°C for 21 days. Yield and proximate composition were determined after production, while pH, titratable acidity, and microbiological parameters (total viable count, total psychrophilic count, lactic acid bacteria, as well as yeast and mold counts) were analyzed on days 0, 7, 14, and 21. *S. platensis* incorporation significantly increased cheese yield ($p < 0.001$) and protein content ($p = 0.007$). The pH values of the SP-treated groups were significantly higher than those of the control group ($p < 0.001$). The highest LAB count was observed in the 0.75% SP group on day 21 ($5.05 \log_{10}$ cfu/g), while TPC and YM counts remained generally lower in the SP-treated groups. Microalgal enrichment of kesik cheese with 0.50-0.75% *S. platensis* represents a promising strategy for improving nutritional composition and selected technological properties of this traditional dairy product.

Keywords: dairy product, kesik cheese, microalgae enrichment, *Spirulina platensis*, storage stability

With increasing consumer awareness, the food industry has shifted toward products that provide physiological benefits beyond basic nutrition. In this context, functional foods are also referred to by terms such as nutraceuticals, therapeutics, and enriched foods (13, 50), and dairy products account for approximately 70% of this market (48).

Kesik is a traditional fresh cheese widely consumed in rural regions of Anatolia and produced by long-established methods. The production process is based on the coagulation of milk by natural or added acids, placing it among the limited number of cheeses produced without the use of rennet. This production method is considered one of the oldest milk processing techniques and represents a practical approach to milk utilization (35, 44). Kesik occupies an important place among traditional dairy products because of its low production cost, rapid manufacturing process, and fresh consumption. In addition, the presence of both

casein and whey proteins enhances its nutritional value (15, 36, 40). Known by different names across various regions of Türkiye (e.g., kesik, minci, sürk, and cacık), this type of cheese varies in its sensory characteristics depending on the local production techniques and milk type. Due to its traditional production methods, kesik generally has a short shelf life and is consumed fresh because its quality parameters change rapidly during storage (15, 23). Therefore, enrichment strategies aimed at improving both nutritional value and quality characteristics have recently attracted increasing research interest (25).

Spirulina platensis (*S. platensis*) is a filamentous blue-green microalga whose dry matter consists of approximately 60-70% protein (7, 10). It is notable for its rich content of essential amino acids, vitamins, minerals, and various bioactive compounds. Due to these properties, it has been classified as „Generally Recognized as Safe” (GRAS) by the Food and Drug Administration (20). The antioxidant, antimicrobial, and antiviral properties of *S. platensis* have been reported in numerous studies, and its application as

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a functional ingredient in dairy products has gained increasing attention in recent years. Accordingly, *S. platensis* has been incorporated into yogurt, kefir, ice cream, and various cheese types at different concentrations, and its effects on nutritional, microbiological, and sensory properties have been investigated (2, 8, 9, 11, 27, 39, 41). Although *S. platensis* has been used at various inclusion levels in previous studies, lower concentrations, particularly below 1%, have generally been associated with more favorable sensory outcomes (11, 22, 24). To the best of our knowledge, however, *S. platensis* has not previously been investigated in traditional kesik. Therefore, the aim of the present study was to evaluate the effects of different inclusion levels on the production yield, physicochemical properties, and microbiological quality of kesik during 21 days of storage at 4°C.

Material and methods

Fresh raw bovine milk with approximately 4% fat content, originating from an officially certified disease-free herd, was obtained from a local dairy establishment and used for cheese production. *S. platensis* powder was obtained from AlgBU (Boğaziçi University, İstanbul, Türkiye). The proximate composition of the microalgae is presented in Table 1.

Tab. 1. Proximate composition of *S. platensis* used in the study

Parameter	Value (% , mean $\pm$ SD)
Dry matter	96.13 $\pm$ 0.18
Protein	55.92 $\pm$ 0.77
Fat	6.04 $\pm$ 0.20
Ash	7.01 $\pm$ 0.02

Kesik was produced using a modified version of the traditional method described by Denk et al. (15). Raw milk was heated at 85°C for 10 min, cooled to 45°C, and divided into four groups: a control group without *S. platensis* and three treatment groups supplemented with 0.25%, 0.50%, and 0.75% (m/m) *S. platensis*. Following the addition of *S. platensis*, coagulation was induced by adding a 5% citric acid solution at a level of 10% (v/m) of milk. After curd formation, the whey was drained, and the resulting curds were packed in airtight polyethylene containers and stored at 4°C for 21 days, consistent with the storage period previously used for *S. platensis*-enriched fresh Ricotta cheese (27). Yield and proximate composition were determined immediately after production, whereas pH, titratable acidity, and microbiological analyses were performed on days 0, 7, 14, and 21 of storage. The experiment was independently replicated three times, with the complete set of four cheese batches produced in each experimental replicate on separate days using different raw milk batches. All analyses were performed in duplicate (n = 6 per treatment at each sampling point).

Cheese yield was calculated based on the amount of cheese obtained from 100 L of milk (19). Dry matter and ash contents were determined by the gravimetric method according to ISO (31) and AOAC (5), respectively. Protein

content was determined by the Kjeldahl method according to ISO (33), and a conversion factor of 6.38 was used. Fat content was determined by the Van Gulik method according to ISO (30). The pH was measured using a digital pH meter (Adwa AD1030, Adwa Instruments, Szeged, Hungary) and titratable acidity was determined according to ISO/TS (34) and expressed as% lactic acid.

For microbiological analyses, 10 g cheese samples were homogenized with 90 mL of sterile peptone water (0.85% NaCl + 0.1% peptone), and serial dilutions were prepared accordingly. Total viable count (TVC) was determined on Plate Count Agar (PCA; Oxoid, UK) at 30°C for 48-72 h (28). Total psychrophilic count (TPC) was determined on PCA at 4°C for 7 days (26). Lactic acid bacteria (LAB) were enumerated on MRS agar (Oxoid, UK) at 30°C for 72 h (29), and yeast and mold (YM) counts were determined on acidified Potato Dextrose Agar (Oxoid, UK) at 25°C for 5 days (32). The results were expressed as log₁₀ cfu/g.

Data were analyzed using IBM SPSS Statistics (version 22.0, IBM Corp., USA). Descriptive statistics are presented as mean $\pm$ standard deviation. Normality and homogeneity of variance were assessed using the Shapiro-Wilk and Levene tests, respectively. One-way ANOVA was applied for parameters measured at a single time point, while two-way ANOVA was used to evaluate the effects of storage time and treatment groups. Post hoc comparisons were performed using Tukey's HSD or Games-Howell tests depending on variance homogeneity. For TPC and YM counts, where a high number of observations were below the detection limit, only descriptive statistics are presented. Statistical significance was set at $p < 0.05$ (21, 43).

Results and discussion

The addition of *S. platensis* had a statistically significant effect on cheese yield ($p < 0.001$). Yield values increased from 13.13 $\pm$ 0.42% in the control group to 15.32 $\pm$ 1.38% in the 0.75% SP group (Fig. 1), with both the 0.50% and 0.75% SP groups showing

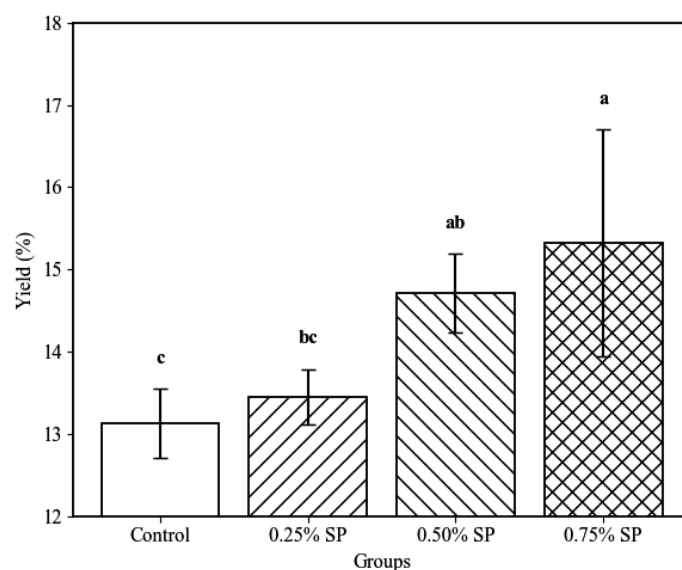


Fig. 1. Effect of *S. platensis* addition on cheese yield (%)

Explanations: Error bars represent standard deviation. Different letters indicate statistically significant differences between the groups ($p < 0.05$)

significantly higher values than the control group ($p < 0.05$). Cheese yield is influenced by multiple factors, including milk origin, composition, processing technology, and equipment used (12, 53). Among these, the quality and composition of raw milk play a particularly important role. Higher cheese yield is generally associated with higher water-holding capacity of the curd and enhanced retention of whey proteins within the gel network (52). The observed improvement may be explained by the combined effect of two main mechanisms. First, the high dry matter content of microalgal powder (96.13%) directly contributes to the total solids of the milk, thereby increasing the amount of material retained in the curd during whey separation. Second, *S. platensis* particles are likely entrapped within the acid-induced casein network, while interactions between microalgal surface proteins and milk proteins may further strengthen the gel structure, reducing the loss of soluble components into the whey. Consistent with this proposed mechanism, Kuhn et al. (38) reported that increased protein concentration in whey protein gels reduced gel porosity and enhanced water retention within the protein matrix. Overall, the approximately 2% improvement in yield observed in the 0.75% SP group compared to the control group supports the potential contribution of microalgal addition to cheese-making efficiency, although the magnitude of this effect may vary depending on cheese type and processing conditions.

The proximate composition of kesik samples is presented in Table 2. Dry matter content ranged from 38.30% (control) to 40.40% (0.75% SP), showing an increasing trend with increasing *S. platensis* addition, but the difference was not statistically significant ($p = 0.063$). This limited effect was likely related to the relatively low inclusion level of *S. platensis*, which may not have been sufficient to induce a measurable change in total solids. Suna (48) reported dry matter values of 30.50-30.85% in *S. platensis*-fortified white cheese, whereas Terpou et al. (51) observed an increase from 35.55% (control) to 37.39% in Feta-type sheep cheese with 0.25% SP. Lajnaf et al. (39) demonstrated dose-dependent increases in dry matter content (from 29.56% to 34.42% in bovine milk cheeses and from 18.99% to 22.50% in camel milk cheeses) with SP inclusion ranging from 0.1% to 1.0%. The general dry matter increase associated with SP addition has been attributed to the high dry matter and low moisture con-

tent of *S. platensis* (3, 37), as well as its contribution of protein, mineral, and fiber components to the food matrix (8). The absence of statistical significance in the present study is likely due to the low inclusion levels used relative to the concentrations at which significant effects have been reported in the literature.

Protein content ranged from $15.32 \pm 1.59\%$ in the control group to $18.22 \pm 0.40\%$ in the 0.75% SP group, and this difference was statistically significant ($p = 0.007$). In particular, the 0.50% and 0.75% SP groups exhibited significantly higher protein contents than the control group ($p < 0.05$). This increase can be directly associated with the high protein content of *S. platensis* (55.92% of dry matter). The addition of microalgal biomass contributes additional nitrogen to the cheese matrix, thereby increasing overall protein levels. However, the magnitude may also reflect the enhanced retention of both microalgal and milk proteins within the curd matrix and reduced protein loss to the whey during draining. Compared with milk proteins, microalgal proteins may exhibit different retention behavior during curd formation and whey separation, potentially contributing to a higher recovery of nitrogen in the cheese phase. Similar findings were reported by Barkallah et al. (8), who observed increased protein content in yogurt supplemented with microalgae. Mazinani et al. (42) reported an increase from 13.89% to 15.04% in Feta cheese supplemented with 0.8% spirulina, while Al-Soudy et al. (2) observed a moderate increase in Karish cheese at higher inclusion levels (16.33% control group vs. 16.90% at 1.5% SP). Bosnea et al. (11) similarly reported an increase from 11.02% to 12.10% in traditional Greek soft cheese supplemented with 1% SP, while Atallah et al. (6) observed increases in yogurt protein from 3.96% in the control group to 4.21-5.49% in groups supplemented with 0.5-2% SP. These comparisons indicate that the approximately 2.9 percentage point increase obtained in the present study falls within the expected range.

With regard to fat content, no significant differences were observed between the groups ($p > 0.05$). This is likely attributable to the relatively low fat content of *S. platensis* (6.04% on a dry matter basis) and the limited inclusion levels tested. Refaey et al. (46) reported that fat percentages increased with SP addition increasing from 0.25% to 0.50% in reduced-fat buffalo labneh, but decreased at higher SP levels (1%). In contrast, Bosnea et al. (11) reported a slight increase in fat content in a Greek soft cheese

parallel to SP concentration, while Suna and Yılmaz-Ersan (49) reported reduced fat content in labneh containing 1% SP compared with the control group. For ash content, no significant differences were observed either ($p > 0.05$). Although *S. platensis* is regarded as a rich source of

Tab. 2. Proximate composition of kesik cheese samples (% , mean $\pm$ SD)

Parameter	Control	0.25% SP	0.50% SP	0.75% SP	p value
Dry matter	38.30 $\pm$ 2.15	39.79 $\pm$ 1.18	40.12 $\pm$ 2.20	40.40 $\pm$ 2.27	0.063
Protein	15.32 $\pm$ 1.59 ^a	16.92 $\pm$ 0.98 ^{ab}	17.82 $\pm$ 1.90 ^a	18.22 $\pm$ 0.40 ^a	0.007
Fat	17.13 $\pm$ 2.06	17.75 $\pm$ 0.94	17.28 $\pm$ 0.61	16.25 $\pm$ 1.07	0.267
Ash	0.74 $\pm$ 0.18	0.69 $\pm$ 0.05	0.76 $\pm$ 0.28	0.86 $\pm$ 0.16	0.318

Explanation: Different lowercase letters within the same row indicate significant differences between the groups ($p < 0.05$).

minerals (16), its contribution at low inclusion levels appears limited. In contrast, Ismail et al. (27) reported significantly higher ash content in Ricotta cheese supplemented with 1% SP, and Al-Soudy et al. (2) observed increasing ash values with increasing SP concentration in Karish cheese. Thus, the concentrations tested in the present study were likely below the threshold required for a measurable increase in fat and ash contents.

pH values ranged from 5.02 to 5.26, with the SP-treated groups consistently showing higher pH values than the control group across all storage days ($p < 0.05$). The highest pH value was observed in the 0.75% SP group on day 21 (5.26 ± 0.05), while the lowest value was recorded in the control group on day 7 (5.02 ± 0.09). Both the group effect ($p < 0.001$) and the storage time effect ($p = 0.043$) were statistically significant, whereas the group $\times$ day interaction was not significant ($p = 0.500$). Titratable acidity values ranged from 0.25% to 0.36% lactic acid and generally showed a decreasing trend during storage. The highest acidity was detected in the 0.50% SP group on day 7 (0.36 ± 0.04), while the lowest value was observed in the 0.75% SP group on day 21 (0.25 ± 0.04). Additionally, significant changes in titratable acidity over storage time were observed in the 0.50% and 0.75% SP groups ($P < 0.05$). Both the group ($p = 0.013$) and storage time ($p < 0.001$) effects were statistically significant, whereas the group $\times$ day interaction was not significant ($p = 0.537$). The changes in pH and titratable acidity of kesik samples during storage are presented in Table 3.

The higher pH values observed in the SP-treated groups may be related to the alkaline nature of *S. platensis* biomass and the buffering capacity of its nitrogenous components. The incorporation of microalgal biomass introduces additional free amino acids and peptides into the system, which may act as buffering agents partially neutralizing hydrogen ions. Consistent with this, the pH in the 0.75% SP group remained at 5.26 on day 21, compared with 5.03 in the control group. Similar buffering effects of microalgal proteins and peptides were reported by Fadaei et al. (18). Ismail et al. (27) observed increased pH values and reduced

titratable acidity in Ricotta cheese supplemented with 0.25-1.0% *S. platensis* during 21 days of storage, which is in agreement with the present findings. In contrast, Al-Soudy et al. (2) reported a decrease in pH and an increase in acidity with increasing *S. platensis* concentration in Karish cheese; Shin et al. (47) reported a similar decreasing pH trend in experimental yogurts. Such contrasting acidification patterns have been attributed to the supportive effect of *S. platensis* on acid-producing microbial populations under certain matrix and processing conditions (54, 55), which suggests that the effect of spirulina on pH is highly dependent on the initial microbial composition and technological conditions.

Microbiological changes in kesik samples during storage are presented in Table 4. TVC ranged from 3.44 to 5.56 $\log_{10}$ cfu/g throughout storage. Initial counts did not differ significantly between groups ($p > 0.05$). During subsequent storage, TVC values increased in all groups. By day 21, TVC ranged from $4.61 \pm 0.43 \log_{10}$ cfu/g (0.50% SP) to $5.56 \pm 0.57 \log_{10}$ cfu/g (0.75% SP). Both group ($p = 0.001$) and storage time ($p < 0.001$) had significant effects on TVC, with a significant group $\times$ day interaction ($p = 0.008$). A notable finding was the „U-shaped” trend observed in the SP-treated groups, characterized by an initial decrease during the first 7 days followed by a subsequent increase. This biphasic behavior suggests a dual effect of *S. platensis* components. In the early stage, certain bioactive compounds present in the microalgal biomass may exert a mild antimicrobial effect, temporarily suppressing mesophilic populations. As storage progresses, however, the nutrient-rich composition of *S. platensis*, including proteins, peptides, and free amino acids, likely promotes microbial growth, enabling the recovery and proliferation of the initially suppressed population. This pattern does not support a purely antimicrobial or purely growth-promoting role of *S. platensis*, but rather indicates a dynamic, time-dependent interaction between these opposing effects. The higher TVC counts observed in the 0.75% SP group toward the end of storage are consistent with findings in white brined cheese (48) and labneh (49). In contrast, Voşgan et al.

Tab. 3. Changes in pH and titratable acidity of kesik cheese samples during storage (mean $\pm$ SD)

Day	pH				p	Titratable acidity (lactic acid%)				p
	Control	0.25% SP	0.50% SP	0.75% SP		Control	0.25% SP	0.50% SP	0.75% SP	
0	5.03 ± 0.09^c	5.10 ± 0.06^{bc}	5.15 ± 0.06^{ab}	5.23 ± 0.05^a	0.001	0.35 ± 0.05	0.32 ± 0.04	0.32 ± 0.02^{AB}	0.30 ± 0.03^A	0.189
7	5.02 ± 0.09^b	5.13 ± 0.04^a	5.15 ± 0.03^a	5.22 ± 0.04^a	<0.001	0.30 ± 0.04	0.30 ± 0.05	0.36 ± 0.04^A	0.31 ± 0.03^{AB}	0.100
14	5.12 ± 0.04^b	5.19 ± 0.05^a	5.20 ± 0.02^a	5.21 ± 0.03^a	0.001	0.31 ± 0.04	0.27 ± 0.04	0.30 ± 0.02^B	0.28 ± 0.04^{AB}	0.215
21	5.03 ± 0.14^b	5.11 ± 0.15^{ab}	5.12 ± 0.08^{ab}	5.26 ± 0.05^a	0.019	0.29 ± 0.04	0.26 ± 0.06	0.28 ± 0.04^B	0.25 ± 0.04^B	0.459
p	0.313	0.321	0.083	0.381		0.145	0.157	0.002	0.041	
Group P < 0.001, Day P = 0.043, Group $\times$ Day P = 0.500						Group P = 0.013, Day P < 0.001, Group $\times$ Day P = 0.537				

Explanations: TA = titratable acidity (% lactic acid). pH: Group $p < 0.001$, Day $p = 0.043$, Group $\times$ Day $p = 0.500$. TA: Group $p = 0.013$, Day $p < 0.001$, Group $\times$ Day $p = 0.537$. Lowercase letters indicate significant differences between the groups on the same day; uppercase letters indicate significant differences across storage days within the same group ($P < 0.05$).

Tab. 4. Microbiological changes in kesik cheese samples during storage ($\log_{10}$ cfu/g, mean $\pm$ SD)

Group	Day 0	Day 7	Day 14	Day 21	p
TVC (Group P = 0.001; Day P < 0.001; Group $\times$ Day P = 0.008)					
Control	4.35 $\pm$ 0.28	4.38 $\pm$ 0.72 ^a	4.90 $\pm$ 0.39 ^a	5.33 $\pm$ 1.03 ^{ab}	0.001
0.25% SP	4.36 $\pm$ 0.25 ^{AB}	3.85 $\pm$ 0.28 ^{ab,BC}	3.68 $\pm$ 0.50 ^{b,B}	4.74 $\pm$ 0.35 ^{ab, A}	<0.001
0.50% SP	4.83 $\pm$ 0.81 ^A	3.44 $\pm$ 0.56 ^{b, B}	4.08 $\pm$ 0.55 ^{ab, AB}	4.61 $\pm$ 0.43 ^{b, A}	0.003
0.75% SP	4.34 $\pm$ 0.70 ^{BC}	3.75 $\pm$ 0.23 ^{ab, C}	4.84 $\pm$ 0.83 ^{a, AB}	5.56 $\pm$ 0.57 ^{a, A}	0.001
p value	0.373	0.027	0.004	0.005	
TPC*					
Control	3.04 $\pm$ 0.12 (n = 2)	3.51 $\pm$ 0.33 (n = 4)	4.75 $\pm$ 0.68 (n = 6)	5.42 $\pm$ 0.68 (n = 4)	–
0.25% SP	< 2	< 2	4.56 $\pm$ 0.78 (n = 4)	4.04 $\pm$ 0.37 (n = 2)	–
0.50% SP	2.80 $\pm$ 0.28 (n = 2)	3.12 $\pm$ 0.16 (n = 2)	4.44 $\pm$ 0.76 (n = 6)	4.53 $\pm$ 0.44 (n = 2)	–
0.75% SP	< 2	< 2	4.05 $\pm$ 0.18 (n = 4)	4.90 $\pm$ 1.39 (n = 4)	–
LAB (Group P < 0.001; Day P < 0.001; Group $\times$ Day P < 0.001)					
Control	3.66 $\pm$ 0.08 ^{a, C}	4.08 $\pm$ 0.20 ^{a, B}	4.39 $\pm$ 0.50 ^{a, AB}	4.91 $\pm$ 0.19 ^{a, A}	<0.001
0.25% SP	3.60 $\pm$ 0.11 ^{a, B}	3.70 $\pm$ 0.09 ^{b, B}	4.00 $\pm$ 0.10 ^{ab, A}	4.56 $\pm$ 0.43 ^{ab, A}	<0.001
0.50% SP	3.58 $\pm$ 0.04 ^{a, C}	3.62 $\pm$ 0.04 ^{b, C}	3.73 $\pm$ 0.05 ^{b, B}	4.06 $\pm$ 0.04 ^{b, A}	<0.001
0.75% SP	3.26 $\pm$ 0.05 ^{b, C}	3.92 $\pm$ 0.13 ^{a, B}	4.11 $\pm$ 0.35 ^{a, AB}	5.05 $\pm$ 0.21 ^{a, A}	<0.001
p value	< 0.001	< 0.001	0.014	< 0.001	
YM*					
Control	3.02 $\pm$ 0.42 (n = 3)	3.83 $\pm$ 0.30 (n = 5)	6.01 $\pm$ 0.87 (n = 4)	5.66 $\pm$ 0.80 (n = 6)	–
0.25% SP	2.92 $\pm$ 0.08 (n = 3)	3.53 $\pm$ 0.09 (n = 4)	5.32 $\pm$ 1.20 (n = 6)	4.92 $\pm$ 1.01 (n = 4)	–
0.50% SP	< 1	2.96 $\pm$ 0.08 (n = 4)	5.03 $\pm$ 0.72 (n = 6)	4.85 $\pm$ 1.27 (n = 4)	–
0.75% SP	< 1	2.54 $\pm$ 0.43 (n = 4)	4.31 $\pm$ 1.20 (n = 4)	4.75 $\pm$ 1.08 (n = 5)	–

Explanations: TVC = total viable count; TPC = total psychrophilic count; LAB = lactic acid bacteria; YM = yeast and mold. Lowercase letters indicate significant differences between the groups on the same day ($p < 0.05$); uppercase letters indicate significant differences across storage days within the same group ($p < 0.05$). *For TPC and YM, values below the detection limit are indicated as < 2 or < 1 $\log_{10}$ cfu/g; n indicates the number of samples above the detection limit.

(56) reported lower TVC levels in mozzarella cheese containing 0.5% *S. platensis*. This discrepancy may be attributed to differences in processing conditions, particularly the high-temperature stretching step in mozzarella production.

TPC exhibited a consistent increasing trend during storage. At the initial stage, the values were below the detection limit (< 2 $\log_{10}$ cfu/g), particularly in the 0.25% and 0.75% SP groups, reflecting low psychrophilic populations at the early stage. From day 14 onwards, all groups showed detectable counts, followed by a marked increase by day 21, with the highest value observed in the control group (5.42 $\pm$ 0.68 $\log_{10}$ cfu/g). YM counts also showed a general increase during storage. On day 0, counts in some SP-treated groups were below the detection limit (< 1 $\log_{10}$ cfu/g), whereas all groups exhibited measurable levels from day 7 onwards. A sharp increase was observed up to day 14, particularly in the control group (6.01 $\pm$ 0.87 $\log_{10}$ cfu/g), followed by a slight decrease or stabilization by day 21. This pattern suggests a rapid growth phase during mid-storage. The numerically lower TPC and YM counts observed in the SP-treated groups compared to the control group suggest a possible inhibitory

effect of *S. platensis* on spoilage-related microorganisms, contrasting with the biphasic pattern observed for TVC. This difference may be associated with the sensitivity of psychrophilic and fungal populations to bioactive compounds present in *S. platensis*, including phenolic substances and membrane-active components, which have been reported to exhibit antimicrobial activity. This interpretation is supported by previous studies demonstrating the antimicrobial and antifungal activity of spirulina-derived compounds. El-Sayed et al. (17) and Alshuniaber et al. (4) reported inhibitory effects of spirulina phenolic compounds against food-related bacterial genera, while Abdel-Moneim et al. (1) demonstrated pronounced antifungal activity against *Candida*

and *Aspergillus* species, including *C. tropicalis*, *C. albicans*, *C. glabrata*, *A. niger*, *A. flavus*, and *A. fumigatus*. In the present study, the YM count reached 6.01 $\log_{10}$ cfu/g in the control group on day 14, but remained at 4.31 $\log_{10}$ cfu/g in the 0.75% SP group, corresponding to an approximately 2-log numerical reduction. A comparable trend was reported by Terpou et al. (51) in Feta-type cheese, where YM counts remained below the detection limit on day 0 in both the control and 0.25% SP groups, peaked around day 30, and subsequently decreased; at the end of storage no significant difference was detected between the control and SP-treated groups. In contrast, this difference persisted throughout storage, with the 0.75% SP group remaining approximately 1 $\log_{10}$ cfu/g below the control group on day 21. Similar reductions in YM populations have been reported in spirulina-supplemented cheeses previously (11).

LAB counts varied between 3.26 and 5.05 $\log_{10}$ cfu/g during storage. On day 0, the 0.75% SP group exhibited significantly lower LAB counts than the other groups ($p < 0.05$). During storage, LAB counts generally increased across all groups, although fluctuations were observed depending on the treatment.

Statistical analysis revealed significant effects of group ($p < 0.001$), storage time ($p < 0.001$), and their interaction ($p < 0.001$), indicating that both *S. platensis* concentration and storage duration influenced LAB dynamics. This effect may be related to the rich composition of *S. platensis*, which is known to support LAB growth and metabolic activity. It has been demonstrated in previous studies that *S. platensis* supplementation can enhance the viability of starter and probiotic cultures in fermented dairy products by providing additional nutrients (9). Similarly, Parada et al. (45) and de Caire et al. (14) reported that *S. platensis*-derived components can promote the growth of LAB, while Gldař and İrkin (24) and Shin et al. (47) observed increased LAB viability with SP addition in yogurt systems, particularly toward the end of storage. In line with these findings, Var et al. (54) recently reported that higher SP concentrations enhanced LAB growth in dairy fermentation systems, especially during extended storage. By day 21, the 0.75% SP group showed the numerically highest LAB count ($5.05 \pm 0.21 \log_{10}$ cfu/g), but this value did not differ significantly from the one in the control group ($p > 0.05$). Although this group had the lowest initial LAB count, its more pronounced increase during storage may have been supported by the nutrient-rich composition of *S. platensis*. However, this pattern was not consistently observed at lower SP concentrations, as LAB counts in the 0.50% SP group remained below those in the control group throughout most of the storage period. Thus, the present findings suggest a concentration- and storage-dependent effect rather than a uniform growth-promoting effect of SP on LAB. Further studies including additional concentration levels are needed to clarify this pattern.

Conclusion. The incorporation of *S. platensis* into traditional kesik significantly increased production yield ($p < 0.001$) and improved protein content ($p < 0.05$), and the 0.75% level was associated with the numerically highest LAB count at the end of storage. However, this concentration also exhibited the highest TVC counts, indicating that microbial responses were concentration- and storage-dependent rather than uniformly beneficial. Overall, these findings demonstrate the potential of *S. platensis* for improving selected nutritional and technological properties of kesik, while indicating that its microbiological implications require further investigation. Future studies should therefore include specific foodborne pathogens and sensory evaluation, together with techno-functional and bioactive properties.

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