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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS Pakistan Journal of Biological Sciences

ISSN 1028-8880
DOI: 10.3923/pjbs.2020.533.541

Research Article
Quality Characteristics of Processed Cheese Fortified with *Spirulina* Powder

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Abstract

Background and Objective: *Spirulina* is a rich source of nutrients viz., essential amino acids, essential fatty acids, carotenoids and vitamins. The study was carried out to evaluate of *Spirulina maxima* addition as source of nutrients, antioxidants and color on processed cheese properties. **Materials and Methods:** Processed cheese analogue treatments were supplemented with *Spirulina maxima* powder (1, 2 and 3%). The chemical, physical, color and sensorial properties of processed cheese analogue supplemented with *S. maxima* were evaluated through 3 months of cold storage (7°C). Also, the antioxidant capacity of *S. maxima* processed cheese analogue treatments was determined. **Results:** The spreadable processed cheese analogue with 3% *S. maxima* powder had higher chemical components except ash compared to control cheese. The results of physical properties showed that the penetrometer reading of the *S. maxima* processed cheese treatments was higher than those of control allover storage period, while oil separation and melt ability were lower. The *S. maxima* processed cheeses were more green (a-value) and lower whiter (L-value) than those of control. The highest free radical scavenging activity (57.24%) was recorded for *S. maxima* processed cheese analogue treatment (3%). From the sensorial results, the *S. maxima* processed cheese analogue (1 or 2%) treatments was higher acceptable compared to those of 3%. **Conclusion:** Hence, adding *S. maxima* powder (1 or 2%) during processed cheese analogue manufacture let the cheese to develop special color (green), high nutritional value, antioxidant activity and sensorial scores.

Key words: Processed cheese analogue, *Spirulina maxima*, physical properties, color properties, antioxidant capacity

Citation: Ashraf Gaber Mohamed, Baraka Abo El-Yazeed Abd El-Salam and Walid Abd El-Motaal Gafour, 2020. Quality characteristics of processed cheese fortified with *Spirulina* Powder. Pak. J. Biol. Sci., 23: 533-541.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Algae are a group of microorganisms capable of self-supporting photosynthesis. They get their energy from sunlight[1]. *Spirulina* is a primitive organism originating some 3.5 billion years ago[2]. *Spirulina* named as tecuitlatl by Aztecs (Mexicans) which means stone's excrement during 16th century[3]. *Spirulina* have classified as Cyanobacterium a Gram-negative bacterium that performs photosynthesis same as that occurs in plants. *Spirulina* is filamentous, photosynthetic, autotrophic, unbranched and multicellular blue-green algae with symbiotic bacteria that fix atmospheric nitrogen by the process of nitrogen fixation from the air[2]. *Spirulina* is mainly found in natural lakes having high pH value i.e. 8-10 all over the earth.

Because of its alimentary value, *Spirulina* has been consumed from a long past time in many parts of the world as a food supplement by humans as well as animals in various forms like a health drink, tablets and powder, etc. In Europe, Japan and North America cyanobacteria tablet have been sold. *Spirulina* known to be the richest source of protein and vitamin and can be used to treat children suffering from malnutrition. *Spirulina* is a rich source of nutrients viz., essential amino acids, essential fatty acids, carotenoids, minerals and vitamins, it has been considered as ''Food of the future'' and ideal food for astronauts by NASA[4,5].

The metabolism of carbohydrate, fats, protein and the reproduction of skin and muscle can be enhanced by the β-carotene, B-group vitamin, vitamin E, iron, potassium and chlorophyll available in the *Spirulina*. According to the findings of the National Cancer Institute, the United States of America, an intake of 6.0 mg β-carotene daily may be effective in minimizing the risk of cancer. Because *Spirulina* is well known to have very high iron content, it was tested against a typical iron supplement, iron sulfate. *Spirulina*-fed rats absorbed 60% more iron than rats fed the iron supplement[2].

Spirulina maxima, a filamentous alga, is a cyanobacterium belonging to the family Oscillatoriaceae, which blooms well in alkaline water and contains a unique blend of nutrients that no single source can provide. The alga is characterized by high protein content (60-70%) and a wide spectrum of nutrients that include B-complex vitamins, minerals, γ-linolenic acid and the super antioxidants, β-carotene, vitamin E, trace elements and other uncharacterized bioactive compounds. Because of its apparent ability to stimulate the immune system, *Spirulina* has several therapeutic functions such as antidiabetic, anti-inflammatory, antiviral and anticancer activities[6].

When the algal cells or filaments of *Spirulina* are transformed into a powder it can provide the basis for a variety of food products, such as soups, sauces, pasta, snack foods, instant drinks and other recipes[7]. The preparation of fermented foods such as cheese, yogurt and tofu, offered many new possibilities for the use of *Spirulina*. Diets in which *Spirulina* provides up to 100% of the protein produced growth rates comparable with those obtained with standard diets in several animal species. As little as 10 g a day of *Spirulina* brings rapid recovery from malnutrition, especially in infants[2].

Processed cheese enjoys great popularity all over the world, because it is favorable texture, taste and easy to handle and eat. Processed cheeses are produced by shredding or cutting natural cheeses with different degrees of ripening and mixing them with emulsifying agents under heated conditions, in a partial vacuum or at ambient pressure, until a homogenous mass is obtained[8]. Per local legislation, other ingredients can be added, such as powdered milk, stabilizers, preservatives, water, meat, fruit and spices, among others. The processed cheese supplemented with *Chlorella vulgaris* or *Spirulina platensis* as nutrient source were studied in many studies[9-11]. Little information is available to add *Spirulina maxima* as a source of color and antioxidant in the production of processed cheese.

In this study, processed cheese was produced by adding *S. maxima* powder to increase of the nutritional value and as source of antioxidants and color. Hence, the aim was to investigate the effects of *S. maxima* powder on the quality characteristics of processed cheese during the storage (3 months at 7°C).

MATERIALS AND METHODS

The study was performed at Department of Dairy Science, National Research Centre, Dokki, Giza, Egypt, from October, 2018 to June, 2019.

Materials:

- *Spirulina maxima* powder was obtained from Algal Biotechnology Unit, National Research Centre, Giza, Egypt
- Ras cheese (one month old) was purchased from Arabic Food Industrial Co. (Domety), 6th October City, Egypt
- Matured cheddar cheese (8 months old) and Kasomel emulsifying salts K-2394 were purchased from International Dairy and Food Co. (milky land), 10th October City, Egypt

Table 1: Chemical composition of ingredients (%)

Components	Ras cheese	Cheddar cheese	Skim milk powder	Butter	Acid curd	*Spirulina maxima* powder
Total solids	54.81	65.80	96.00	84.00	47.02	97.40
Fat	24.77	34.80	00.97	82.00	00.10	06.27
Protein	22.26	25.47	37.13	ND	43.01	70.00
Ash	05.76	05.42	07.84	ND	02.82	05.40
Carbohydrate	01.64	00.10	47.43	ND	ND	13.48
Fiber	ND	ND	ND	ND	ND	02.13

ND: Not detected

Table 2: Formulation of the various blends for spreadable processed cheese analogue with *Spirulina maxima* powder

Ingredients	Control	1	2	3
Ras cheese	47.58	-	-	-
Cheddar cheese	15.86	-	-	-
Butter	07.61	25.52	25.52	25.52
Acid curd (lactic casein)	-	32.89	32.89	32.89
Skim milk powder	-	05.75	05.75	05.75
Salt	-	02.00	02.00	02.00
Emulsifying salts	2.13	01.85	01.85	01.85
Spirulina maxima	-	01.00	02.00	03.00
Water	26.82	30.99	29.99	28.99
Total	100.00	100.00	100.00	100.00

- Low heat skim milk powder and butter were procured from Irish Dairy Board, Grattan House, Lower Mount St., Dublin, Ireland
- Acid curd (Lactic acid casein) was prepared by biological acidification. The skim milk (Dairy Technology Unit, Faculty of Agriculture, Cairo University, Egypt) at pH 6.6 is pasteurized at 72°C for 15 sec. Mesophile, non-gas starter bacteria (*Lactococcus lactis*, 0.5%) are inoculated at 25°C to pasteurized milk until coagulation. Then the lactic clot is washed and dried under vacuum at 40°C

Chemical composition of the ingredients used in processed cheese analogue treatments manufacture with *Spirulina maxima* powder is shown in Table 1.

Methods

Spreadable processed cheese analogue manufacture with *Spirulina maxima* powder: Spreadable processed cheese analogue treatments (45% total solids and 48% fat-in-dry matter) were manufactured according to the method of Meyer[12]. Spreadable processed cheese control was produced from Ras and matured cheddar cheeses as a base blend. Spreadable processed cheese analogue treatments were made by replacing of the base cheeses (Ras and cheddar) with acid curd and *Spirulina maxima* powder (1, 2 and 3%) as presented in Table 2. The control and treatments were manufactured by thoroughly mixing the ingredients in a laboratory style processing kettle of the 10 kg capacity, a pilot machine at National Research Centre. The cheese blends were heated using direct injection of steam at pressure of 1.5 bar to 66°C with controlled agitation for 4 min. The blends were further heated to 80°C in approximately 4 min. The *Spirulina maxima* powder (1, 2 and 3%) was added to the heated blends at 80°C. The resultant cheeses were filled into sterilized glass jar, covered with aluminum foil and their covers then cooled to 7°C. The resultant cheeses were analyzed when fresh and monthly up to 3 months of cold storage at 7°C.

Methods of analysis

Chemical analysis: The moisture, ash, protein, fat, fiber and total carbohydrate contents of *Spirulina maxima* powder were determined according to AOAC[13]. The high performance amino acid analyzer (biochrom 30, Germany) was used for essential amino acids determination of algae according to AOAC[13]. Total carotenoid content of *S. maxima* powder was determined. The pigments were extracted with acetone/methanol (4:6)[14] and transferred to light-petroleum (40-60°C) in separating funnel and washed thrice thoroughly with distilled water[15]. The absorbance of the light-petroleum phase was red at 474 nm and the concentration of the carotenoids was determined using the absorption coefficient[16] $A^{1\%}_{1\ cm}$ = 1600. Total carotenoid content was calculated by using the formula[17] give below and expressed as μg g^{-1} of *S. maxima* powder.

$$\text{Total carotenoids } (\mu g\ g^{-1}) = A \times V\ (mL) \times 10^4 - A^{1\%}_{1\ cm} \times w\ (g)$$

Where:

A = Absorbance
V = Total extract volume
W = Sample weight
$A^{1\%}_{1\ cm}$ = Absorption coefficient

For the spreadable processed cheese analogue treatments, total fat content was measured according to the method of AACC[18]. Total protein, total solids, fiber and ash contents were analyzed as described by AOAC[13]. Salt content was determined as mentioned by Bradley *et al.*[19]. Carbohydrate content was determined according to the method of Nielsen[20]. The pH was measured using digital pH meter (HANNA 8417) with combined glass electrode (Electric Instruments Limited).

Physical characterization of the cheese: The penetration of the spreadable processed cheese analogue treatments supplemented with *Spirulina maxima* powder and control was measured using a penetrometer (Koch Jer Instrument Co. Inc., USA) as described by Gupta and Reuter[21]. Melting quality was measured as described by Savello *et al.*[22]. Oil separation was determined according to the method of Thomas *et al.*[23].

The color of *S. maxima* processed cheese treatments and control was measured using Hunter colorimeter Model b25 A-2 (Hunter Assoc. Lab. Inc. Va, USA) following the instruction of the manufacturer[24]. The instrument was first standardized using a white tile (top of the scale) and a black tile (bottom of the scale). A specimen of the cheese (flat layer) was placed at the specimen port; the tri-stimulus values of the color namely, L, a and b were measured, where: L value represents darkness from black (0) to white (100), a value represents color ranging from red (+) to green (-) and b value represents yellow (+) to blue (-).

Antioxidant capacity of cheese samples: Free radical scavenging activity (RSA (%)) assay of *S. maxima* processed cheese treatments and control was measured using the method of Brand-Williams *et al.*[25] and expressed as percentage inhibition of the DPPH radical and was determined by the following:

$$\text{RSD}\ (\%) = \frac{\text{Abs}_{\text{control}} - \text{Abs}_{\text{sample}}}{\text{Abs}_{\text{control}}} \times 100$$

Sensorial characterization of the cheese: The sensorial characteristics of *S. maxima* processed cheese treatments and control were evaluated by the staff members at Department of Dairy Science, National Research Centre. Samples were evaluated according to Bandyopadhyay *et al.*[26].

Statistical analysis: Statistical analysis of the obtained data was performed using one-way analysis of variance (ANOVA) followed by Duncan's Multiple Range Test with $p \leq 0.05$ being considered statistically significant using SAS[27] program.

RESULTS AND DISCUSSION

Chemical composition of *Spirulina maxima* powder: The gross chemical composition of *S. maxima* powder is shown in Table 3. It could be seen that the protein is the major organic component (70%), followed by carbohydrate (13.48%)+fiber (2.13%). The other components (fat and ash) represent 6.27 and 5.40%, respectively. These results are in agreement with Matos *et al.*[28]. The growing world population and consequential efficiency in protein supply for human nutrition lead to increased studies exploring novel and alternative protein sources such as single cell proteins (SCP). Microorganisms such as algae, bacteria, fungi and yeast/filamentous can be used as a source of SCP, but due to their high level of essential amino acids coupled with low nucleic acid content, algae are preferred over fungi and bacteria as a source of SCP for human consumption[29]. Special carbohydrates produced by microalgae are important due to their potential therapeutic application. Here, β-1,3-glucan, a natural soluble fiber active as immune stimulator, antioxidant and reducer of blood cholesterol. In addition to the therapeutic use, β-1,3-glucan can be also used in food industry, mainly as fat substitute[30]. Lipids are constituents of all microalgae cells and the main biological functions include storing energy, signaling and acting as structural components of cell membranes. The lipid content of microalgae varies[31] between 1 and 40%. Also, it could be seen from the results that the total carotenoids content of *S. maxima* powder was 6.4 mg g^{-1}. Carotenoids are organic lipophilic compounds that are produced by plants and algae. They also act as antioxidants that inactivate reactive oxygen species (ROS) formed by exposure to excessive solarradiation[32].

Table 3: Gross chemical composition of *S. maxima* powder

Components	Percentage
Total solids	97.40
Fat	06.27
Protein*	70.00
Ash	05.40
Carbohydrate	13.48
Fiber	02.13
Total carotenoids (mg g^{-1})	6.40

*N×4.78

Table 4: Essential amino acids of *S. maxima* powder

Essential amino acids	Percentage
Isoleucine	3.91
Leucine	5.68
Lysine	3.48
Methionine	1.88
Phenylalanine	3.32
Threonine	3.68
Tryptophan	0.98
Valine	5.10

The essential amino acid composition of *Spirulina maxima* powder is shown in Table 4. Among the essential amino acids, leucine was as predominant (5.68%) followed by valline (5.10%). This result is agreement with Al-Dhabi and Arasu[33], who reported that the leucine was identified as predominant in all studied samples of *Spirulina* (0.53-7.59%). The lowest essential amino acid percent was recorded for tryptophan (0.98%) followed by methionine (1.88%). *Spirulina* is very rich in proteins (60-70%) of its dry weight of high biological value containing the essential amino acids needed by both adults and children.

Table 5: Comparison of changes in chemical composition between fresh control and *S. maxima* processed cheese analogue

		Treatments (*S. maxima* level (%))		
Components	Control	1	2	3
Total solids	45.00^{b}	44.99^{ab}	45.11^{ab}	45.26^{a}
Fat \ dry matter	50.00^{a}	50.01^{a}	49.88^{a}	49.71^{b}
Protein	13.66^{b}	14.38^{ab}	14.46^{ab}	14.67^{a}
Carbohydrates	2.90^{b}	3.90^{a}	3.95^{a}	4.75^{a}
Ash	4.96^{a}	3.65^{b}	3.80^{b}	3.83^{b}
Salt in moisture	3.75^{a}	2.20^{b}	2.24^{b}	2.32^{c}
Fiber	ND	0.11^{b}	0.20^{a}	0.27^{a}
pH	5.81^{a}	5.65^{b}	5.63^{b}	5.62^{b}

Means with the same letters in the same row are not significantly different, ND: Not detected

Chemical composition of fresh *Spirulina maxima* spreadable processed cheese analogue treatments: Table 5 show the changes in chemical composition of fresh *S. maxima* processed cheese analogue treatments compared to control. It could be observed that the total solids, protein and fat in dry matter values of processed cheese with 1 or 2% *S. maxima* powder were not different from those of control cheese. The spreadable processed cheese analogue with 3 % *S. maxima* powder had higher chemical components except ash compared to control cheese. Where, the protein, carbohydrates and fiber contents were increased by the high ratio of *S. maxima* powder (3%) and these may due to high levels of these components in *S. maxima* composition. These findings are in agreement with Jeon[34], who found that the *Chlorella* addition at levels (0.5 or 1%) did not exhibit any significant differences of chemical composition of processed cheese compared to control. Also, Mohamed *et al*.[9] found a significant differences between the control and only cheese analogue enhanced with 3% *Chlorella vulgaris* biomass in all the chemical components. Also, it could be noticed that the spreadable processed cheese analogue treatments with different levels of *S. maxima* powder contained the fiber, which can be attributed to the fiber content in the alga. This finding was in agreement with Tohamy *et al*.[10].

Spreadable processed cheese analogue were made by replacing of the base cheeses (Ras and cheddar) with acid curd and the Cunha *et al*.[35] found the cheese analogue treatments made with acid casein were higher in total solids and protein contents than the control, while the ash content and pH values were lower. The obtained results confirmed this.

Physical characterization of *S. maxima* processed cheese: The data in Table 6 illustrate the physical properties of *S. maxima* processed cheese treatments compared to control during storage period. It could be seen that the penetrometer reading of the *S. maxima* processed cheese treatments was higher than those of control allover storage period and these may be due to the replacement of base cheeses (Ras and cheddar) with lactic casein which gives a softness for cheese. Also, it could be noticed that the penetrometer reading decreased with increasing *S. maxima* powder level and this is in agreement with Fradique *et al*.[36], who reported that the addition of microalgae resulted in an increase of firmness. The microalgae protein and carbohydrate molecules can also play an important role in the water absorption process, which promotes the increase of cheese firmness, as was reported by Raymundo *et al*.[37]. The penetrometer reading of all studied chesses decreased with progressing storage period. Mohamed *et al*.[9] found the penetrometer reading of processed cheese with *Chlorella vulgaris* biomass decreased with increasing storage period.

The oil separation depends on the state of the fat and protein in the processed cheese emulsion. Also, many factors can affect oil separation, such as type and amount of raw materials in the base formula, degree of creaming action, cooking time and temperature, the type of emulsifying salt and pH value in the final product[38]. From the results presented in Table 6, the oil separation of *S. maxima* processed cheese analogue was lower than those of control and this may be due to the replacement of base cheeses (Ras and cheddar) with lactic casein where its casein is intact, strong and able to hold the fat, hence, reduction of oil separation. While, the protein of control was degraded during the storage period resulting in weaker network and hence were less capable of fat hold. Also, the addition of *S. maxima* powder slightly increased the protein and carbohydrates contents and decreased the fat in dry matter, so the resultant cheeses were lower oil separation compared control.

As shown in Table 6, the meltability of *S. maxima* processed cheese analogue was lower than those of control and this may be due to the control network is weaker than those of treatments, hence faster melting. The meltability decreased with increasing *S. maxima* powder level. Cavalier-Salou and Cheftel[39] found that melting ability was correlated to soft texture, high degree of casein dissociation and low degree of fat emulsification. Shirashoji *et al*.[40] reported that the high firmness and low melting values in process cheese were correlated with small fat globule sizes. Moreover, Savello *et al*.[41] found that rennet casein cheese melted significantly more than the acid casein cheese.

Table 6: Physical characterization of processed cheese with *S. maxima* powder during storage

			Treatments (*S. maxima* level (%))		
Physical properties	Storage period (month)	Control	1	2	3
Penetrometer reading (mm)	Fresh	161.00^{d}	175.00^{a}	172.00^{b}	169.00^{c}
	1	160.00^{c}	168.00^{a}	168.00^{a}	167.00^{b}
	2	154.00^{d}	163.00^{a}	159.00^{b}	158.00^{c}
	3	144.00^{d}	160.00^{a}	156.00^{b}	154.00^{c}
Oil separation (%)	Fresh	28.50^{a}	18.00^{c}	19.11^{b}	20.00^{b}
	1	30.00^{a}	18.22^{b}	20.22^{b}	20.95^{b}
	2	32.55^{a}	20.50^{c}	22.50^{b}	21.50^{b}
	3	35.45^{a}	22.66^{b}	22.96^{b}	23.66^{b}
Melting index (mm)	Fresh	111.00^{a}	91.00^{b}	88.00^{c}	86.00^{d}
	1	99.00^{a}	88.00^{b}	83.00^{c}	75.00^{d}
	2	95.00^{a}	84.00^{b}	75.00^{c}	72.00^{d}
	3	90.00^{a}	81.0^{b}	79.00^{c}	77.00^{d}

Means with the same letters in the same row are not significantly different

Table 7: Color properties of *S. maxima* processed cheese during storage period at 7°C

			Treatments (*S. maxima* level (%))		
Color parameters	Storage period (month)	Control	1	2	3
L	Fresh	87.13^{a}	82.11^{b}	79.15^{c}	74.11^{d}
	1	86.00^{a}	81.33^{b}	78.85^{c}	72.89^{d}
	2	85.90^{a}	80.20^{b}	78.01^{c}	71.60^{d}
	3	85.34^{a}	79.60^{b}	77.30^{c}	70.05^{d}
a	Fresh	-1.30^{d}	-6.51^{c}	-7.95^{b}	-10.50^{a}
	1	-1.44^{d}	-7.31^{c}	-8.51^{b}	-11.25^{a}
	2	-1.50^{d}	-7.15^{c}	-9.82^{b}	-11.90^{a}
	3	-1.65^{d}	-8.61^{c}	-11.15^{b}	-12.80^{a}
b	Fresh	17.88^{d}	23.66^{c}	30.90^{b}	34.65^{a}
	1	18.30^{d}	24.30^{c}	31.25^{b}	35.90^{a}
	2	19.90^{d}	25.60^{c}	32.90^{b}	36.88^{a}
	3	20.22^{d}	26.15^{c}	34.90^{b}	37.11^{a}

L: Black (0) to white (100), a: Red (+) to green (-), b: Yellow (+) to blue (-), means with the same letters in the same row are not significantly different

Table 8: Antioxidant activity of *S. maxima* processed cheese analogue and control during the storage period at 7°C

			Treatments (*S. maxima* level (%))		
Antioxidant activity	Storage period (Month)	Control	1	2	3
RSA(%)	zero	5.52^{d}	33.68^{c}	42.54^{b}	57.24^{a}
	1	5.00^{d}	29.89^{c}	38.55^{b}	50.32^{a}
	2	4.49^{d}	27.78^{c}	37.23^{b}	47.32^{a}
	3	4.34^{d}	25.54^{c}	35.56^{b}	44.88^{a}

RSA: Free radical scavenging activity, means with the same letters in the same row are not significantly different

Color properties of *S. maxima* processed cheese: The color parameter changes of *S. maxima* processed cheese during storage period at 7°C are presented in Table 7. It could be noticed that the L value of control was whiter than those of treatments with *S. maxima.* The whiteness decreased with increasing storage period or *S. maxima* levels. The *S. maxima* processed cheeses were more green (a value) than those control and this may be due to algae chlorophyll content[36,42]. The green color increased with increasing the level of algae or storage period. Chlorophylls are greenish lipid-soluble pigments, which contain a porphyrin ring and found in all algae. Chlorophyll is registered and approved as a colorant additive and is mostly used in the food pigmentation and dietary supplement industries[31]. Also, the b value of control was lower than those of with *S. maxima* allover storage period and increased with increasing algae level.

Antioxidant capacity of *S. maxima* cheese: Antioxidants are compounds that help combat cell and DNA damage that leads to cancer, heart disease and other chronic diseases. The antioxidant activity of *S. maxima* processed cheese analogue treatments and control during the storage period (3 month) are shown in Table 8. It could be observed that, the free radical scavenging activity (RSA (%)) of *S. maxima* processed

Table 9: Sensorial properties of *S. maxima* processed cheese analogue and control during the storage period at 7°C

			Treatments (*S. maxima* level (%))		
Character assessed	Storage period (month)	Control	1	2	3
Spreadability	Fresh	6.32^{c}	6.85^{a}	6.60^{b}	6.57^{b}
1-7	1	6.00^{c}	6.62^{a}	6.48^{b}	6.45^{b}
	3	5.78^{c}	6.38^{a}	6.25^{b}	5.56^{d}
Softness	Fresh	6.88^{c}	6.96^{a}	6.90^{b}	6.85^{c}
1-7	1	6.87^{b}	6.94^{a}	6.90^{b}	6.84^{bc}
	3	6.86^{b}	6.95^{a}	6.87^{b}	6.82^{c}
Crumbliness	Fresh	6.96^{a}	6.98^{a}	6.96^{a}	6.92^{b}
1-7	1	6.94^{a}	6.97^{a}	6.94^{a}	6.90^{b}
	3	6.88^{b}	6.97^{a}	6.93^{a}	6.87^{b}
Stickiness	Fresh	6.58^{b}	6.57^{b}	6.60^{b}	6.65^{a}
1-7	1	6.46^{a}	6.45^{b}	6.48^{b}	6.55^{a}
	3	6.42^{b}	6.41^{b}	6.45^{b}	6.51^{a}
Acceptability	Fresh	7.00^{a}	6.97^{a}	6.95^{ab}	6.86^{c}
1-7	1	6.96^{a}	6.95^{a}	6.92^{a}	6.83^{b}
	3	6.90^{a}	6.93^{a}	6.90^{a}	6.80^{b}

Spreadability: (1: Poor spreadability, 7: Good spreadability), Softness: (1: Very firm, 7: Very soft), Crumbliness: (1: Very crumbly, 7: Not crumbly), Stickiness: (1: Very sticky, 7: Not sticky), Acceptability: (1: Very poor acceptability, 7: Very good acceptability), means with the same letters in the same row are not significantly different

cheese analogue treatments was higher than those of control and this may be due to antioxidant compounds of *S. maxima*. *Spirulina* happens to contain several compounds shown to have antioxidant properties, including phenolic compounds, phycocyanins, tocopherols and beta-carotene[43]. Also, the RSA (%) increased with increasing *S. maxima* powder level and decreased with progressing of storage period. This result is in agreement with Mohamed and Shalaby[44], who reported that the percentage of RSA gradually decreased during cold storage (three months) for all cheese treatments. The highest RSA (57.24%) was recorded for *S. maxima* processed cheese analogue treatment (3%).

Sensorial characterization of the *S. maxima* processed cheese: Sensorial properties are important indicator for consumer preferences, so the sensorial properties of *S. maxima* processed cheese treatments compared to control is shown in Table 9. It could be noticed from the obtained results that the all studied treatments were acceptable all over storage period and gained high scores. The spreadability and softness scores of *S. maxima* processed cheese treatments were higher than those of control during storage period and these scores decreased with increasing *S. maxima* levels. This may be due to the replacement of base cheeses (Ras and cheddar) with lactic casein which gives softness for cheese. The spreadability and softness scores of processed cheese analogue with 3% *S. maxima* powder were lower than those with 1 or 2% *Spirulina maxima* and this result is in agreement with those obtained by Pereira *et al.*[45], who reported that, the cheeses with lower moisture and higher algae contents (Table 5) were firmer than cheeses with higher moisture content. Crumbliness is the strength of the internal bonds of product body. The crumbliness of processed cheese analogue with 1 or 2% *S. maxima* powder was higher than those with 3% *S. maxima* throughout the storage period and this could be due to pH of *S. maxima* processed cheese analogue (3%) was lower than other treatments. Also, the crumbliness slightly decreased with progressing the storage period. This is mainly due to the decrease in pH values that occurred throughout the storage period which makes the protein more crumbly[9]. Stickiness is the resist separation of cheese from a material it contacts[46]. No stickiness was detected for all studied treatments during storage period. The *S. maxima* processed cheese analogue (3%) had the highest stickiness score throughout the studied storage period. This result is in agreement with those observed by Mohamed *et al.*[9], who mentioned that the cheese analogues with 2 and 3% *Chlorella* biomass showed very slight stickiness and this may be due to effect of biomass on the cheese protein solubility. From the aforementioned sensorial results, the *S. maxima* processed cheese analogue (3%) treatment was lower acceptable compared to other treatments.

From the aforementioned results, the *Spirulina maxima* powder can be added at level 2% during production of spreadable processed cheese analogue because of its sensorial properties and showed acceptable green color and high free radical scavenging.

CONCLUSION

Microalgae are promising organisms for sustainable products for use as feed stocks for food, feed and biofuels. It could be concluded from the results that the addition of *S. maxima* powder during processed cheese analogue manufacture leads to cheese with high chemical components, free radical scavenging activity, good physical properties and special color (green) compared to control cheese. The processed cheese analogue with *S. maxima* (1 or 2%) was more acceptable than those of 3%.

SIGNIFICANCE STATEMENT

This study confirmed that the alga of *Spirulina maxima* can be used during processed cheese analogue production as a source of natural antioxidants, special color and nutrients. The study contributes to produce of *Spirulina maxima* processed cheese analogue with green color, high nutritional value, antioxidant activity and sensorial scores.

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