Egypt. J. Chem. **Vol. 65**, No. 6 pp. 283 - 291 (2022)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Impact of Nano-Stabilizers on the Technological , Texture and Rheological Properties of Ice Cream

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Abstract

Nanotechnology has achieved widespread application in many fields including electronics, biomedical drug delivery, agriculture, and food technology. This is because nanomaterials add new properties and characteristics to the material that differfrom those of the original material. The aim of this research is to study the effect of adding nanomaterials (Nanostabilizers) on certain technological properties of ice cream, i.e., overrun, melting resistance, and water-syneresis and some rheological properties, i.e., viscosity and texture. Carboxymethyl cellulose (CMC), sodium alginate (SA), and kappa-carrageenan (K-C) were used in the following percentages: 0.15%, 0.18%, and 0.08 % respectively, in their original forms and 0.112%, 0.135%, and 0.06 % respectively, in their nanoforms. The effects of these treatments on ice cream pH, viscosity, Overrun, air cell size, melting resistance, syneresis, texture, color, and sensory acceptance were studied. It was found that the use of nanoform stabilizers increased viscosity, overrun, air cell size, and melting resistance; reduced syneresis; improved texture; and enhanced consumer acceptance. The obtained results indicated that the use of Nanostabilizers can improve the rheological and technological properties of ice cream.

Keywords: Nano stabilizer; Viscosity; Overrun; Melting resistance; Texture; Syneresis; Ice cream

1. Introduction

Nanotechnology has developed noticeably in recent years and its application continues to expand in several industrial sectors. Among the industries in which nanotechnology has been extensively used is the food industry. This has led to industrial advances, improvement of traditional technologies, and products with better features and functions. Continued use of nanotechnology in the food industry carries the possibility of increasing productivity, food security and economic growth of industries.

Nanotechnology involves controlling the shape and size of materials at the nanometer scale (10^{-9} of meter) to produce and design structures, devices, and systems with novel properties [1-2]. Nanomaterials are substances that possess at least one of its dimensions in the size range of 1-100 nm [3]. Nanosize materials differ from materials in their bulk form in their increasedsurface areas and new quantum effects. This

increase in surface area leads to a subsequent increase in chemical reactivity and changes to the material's electric and magnetic behaviors [4].

The applications of nanotechnology in food include the use of nanoparticles inside as food additives, or outside as food packaging [5]. The use of nanotechnology in food improves food quality, safety, nutritional value, texture, taste, color, strength, processability, water solubility, shelf life stability and oral bioavailability of functional compounds and reduces food production costs [6-7].

Nanomaterials are produced using two approaches "bottom up" or "top down”. The top down approach isperformed mainly through physical methods such as grinding and milling [8]. Ball milling treatment possesses advantages including its low cost, and its being environmental friendly, and increases solubility and digestibility [9]. For example, Zhang et al [10]

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EJCHEM use only: Receive Date: 25 October 2021, Revise Date: 21 November 2021, Accept Date: 28 November 2021
DOI: 10.21608/ejchem.2021.102692.4761

reported that the use of wet-media milling to produce chitosan nanoparticles showed an increase in the apparent viscosity and swelling of chitosan powder.

Ice cream is a highly complex food matrix and includes a mixture of many ingredients, i.e., water, milk fat, milk solids-not-fat (MSNF), sweeteners, stabilizers, emulsifiers and flavoring agents [11]. One of the most important factors affecting the quality of ice cream, especially its texture and consumer acceptanceis the stabilizer characteristics. Ice cream stabilizers are usually polysaccharides (such as guar gum, locust bean gum, carboxymethyl cellulose, alginate, carrageenan and xanthan) used in small amounts [11]. In ice cream formulation stabilizers increase mixture viscosity; preventthe wheying-off phenomenon; decrease rates of meltdown and ice and lactose crystal growth during storage; produce a smooth body, texture, and stable foam;and help the suspension of flavoring particles [11]. A major nanotechnology application in food processing is the development of certain nanostructured (or nanotextured) foodstuffs, such as spreads, mayonnaises, creams, yogurts and ice creams. An example is a low-fat nanotextured product that is as ″creamy‶ as the full-fat alternative, and it offers a ″healthy‶ option to consumers [12]. Therefore, the objective of the present study is to investigate the impact of certain nanoform stabilizers on select technological and the rheological ice cream properties.

2. Materials and methods

2.1. Materials

Fresh cow's milk (4.5 % fat) and fresh milk cream (60% fat)were obtained from dairy plant in theFaculty of Agriculture, Cairo University. Skim milk powder (97 %MSNF), and sucrose were obtained from a local market. Carboxymethyl cellulose (CMC), Sodium alginate (SA), K-Carrageenan (K-C) were obtained from MIFAD, Egypt. Vanillin powderwas purchased from Cook's, Egypt.

2.2. Nanopowder production

The stabilizers were milledusing a ball mill (Model PH-BML 911, Photon, Al Qalyubia, Egypt) at 350 rpm for 34 hr.

2.3. Formulation of Ice cream mixes

Mixes were standardized to contain8% fat, 13% MSNF, 12% sugar, and 0.1 % vanilla. CMC, SA and K-C were used in the following percentages 0.15%, 0.18% and 0.08% respectively, in their original forms and 0.112%, 0.135% and 0.06% respectively, in theirnano forms. In total, the nanoform stabilizers comprise 75% of the percentages used by the original stabilizers.

2.4. Production of ice cream

Ice cream mixes were prepared according to El-Samhy et al [13] using a batch ice cream freezer (Model Starmatic V500, Promag, Bologna, Italy). The resulting ice cream was packed in plastic cups and placed in a freezing cabinet at –18°C for at least 24 hr before evaluation.

2.5. Particle size measurement

The particle size of stabilizer was measured before and after milling using a transmission electron microscope (TEM) (Model JEM-1400HC, JEOL, Tokyo, Japan) operating at an accelerating voltage of 80 kV. Sample preparation was performed as described by Akbari *et al*[14].

2.6. Viscosity determination

Mixes viscosity were determined after aging at 4°C using a Brookfield programmable viscometer (Model DV-II+Pro, Brookfield Engineering Laboratories, Middleborough, MA, USA) with a UL adaptor and ULA spindle as described by Elsayed Metwally[15]at 20 rpm

2.7. pH value estimation

The pH value of the mixes was measured using a digital pH-meter (Model 3505, Jenway, Hampshire, UK).

2.8. Overrun evaluation

The overrun of ice cream samples was calculated according to Arbuckle[16]with a standard 100 mLcup by using the following equation

$$\text{Overrun (\%)} = \frac{Weight\ of\ unit\ mix - weight\ of\ equal\ volume\ of\ ice\ cream}{Weight\ of\ equal\ volume\ of\ ice\ cream} \times 100$$

2.9. Air cells size measurement

Air cell measurements were performed as described by Caillet et al [17] with the modification of Temiz and YeşilSu[18]. Ice cream cups were firstly stored at –25°C .The frozen ice cream cubic samples were immersed in liquid nitrogen to solidify completely the fat components. A thin slice of ice cream was cut with razor blade and the sample was placed carefully onto a microscope slide. As the temperature partially increased (approximately –6°C), the ice cream partially melted and became more fluid, which allowed the observation of the air bubbles formed within the frozen ice cream. The air cells were observed by using a light microscope (Model DM750, Leica, Germany) with a camera (Model ICC50, Leica, Germany). Air cell diameterswere calculated using the Leica Application Suite (LAS V4.2) Microscope Camera Software.

2.10. Melting resistance determination

Ice cream melting resistance was measured according to Cottrell et al [19] and Aloğlu et al [20] 100 g of ice cream was placed on a 1-mm stainless-steel screen with on mesh which fitted on a funnel stand on a beaker at 25°C. The amount of melting was determined by weighing the molten parts after 15, 30, 45, 60, and 75 min. The quantity of melting (%) = (weight of molten ice cream / initial weight of ice cream) x 100.

2.11. Color estimation

Ice cream color was measured according to Balthazar et al [21] and Güven et al [22] using a colorimeter (Model CR-410, Konica Minolta, JAPAN). The measurements were recorded as L* (Lightness), a* (Redness), and b* (Yellowness). The color observer was set at 10°C.

2.12. Texture profile analysis

Texture analysis was carried out using auniversal testing machine (TMS-Pro food technology corporation, Sterling ,Virginia ,USA) equipped with (250 lbf) load cell and connected to a computer programmed with TL-Pro food texture analysis software at room temperature (25±1°C). The Parameters evaluated in this test, according to Azari et al [23], were hardness, adhesiveness, gumminess and chewiness.

2.13. Syneresis calculation

Serum separation in ice cream samples was measured according to Farooq and Haque [24] by centrifugation occurred at 13,500 rpm for 25 min at 20ºC.

2.14. Sensory evaluation

Ice creams were tempered at room temperature (24±1°C) for 5-7 mins before evaluation, in order to rise the temperature to -14±1°C. A scale of 1 to 9 was used for hedonic sensory evaluation of the optimum formulation, with 1 being "dislike extremely" to 9 being "like extremely". The ice creams were evaluated for sensory characteristics including viscosity, sandiness, foaminess, degree of smoothness, liquefying rate, and mouth coating [25-27].

2.15. Statistical analysis

A randomized complete block design with one factor was used for the analysis of all data (except for texture parameters, syneresis and color parameters,with which two factors were used and melting, with which three factors were used) with three replications for each parameter. Treatment means were compared by least significant difference (L.S.D.) test as given by Snedecor and Cochran [28] using assistant program [29].

3. Results and discussion

3.1. Effect of ball milling treatment on the Particle size of different stabilizers

Three types of stabilizers Carboxymethyl cellulose (CMC), Sodium alginate (SA), and Carrageenan (K-C) were milled and compared with their original forms to study the effect of ball milling treatment on stabilizer particle diameter (nm). As shown in Table 1, the milling process led to a reduction in the particle size in all stabilizers. This is because the powders placed in the ball mill were subjected to high-energy collision from the balls. These results are in agreement with Wang et al [30], Palavecino et al [31]and Lu et al [32].

3.2. Viscosity of ice cream mixes

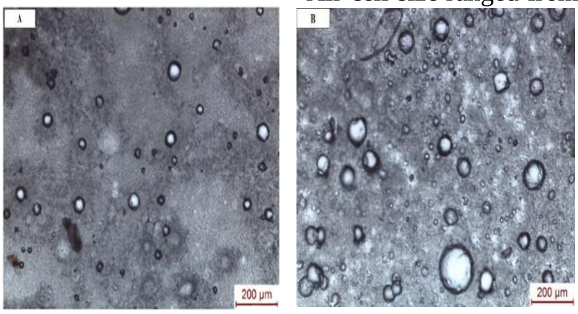
Table 1 showsthat the use of nano stabilizers increased the viscosity of ice cream mixes. The increased viscosity may have been a resulted of the increased surface area in case of smaller particles rather than bigger ones which consequently improved the particles water holding properties [10, 33].

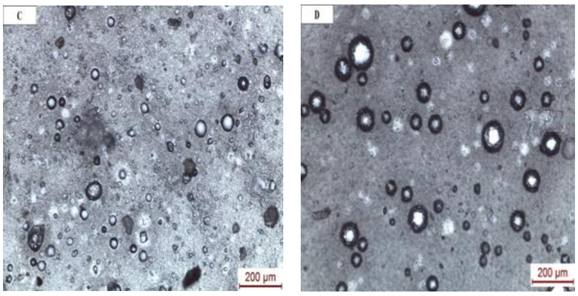
3.3. pH value of ice cream mixes

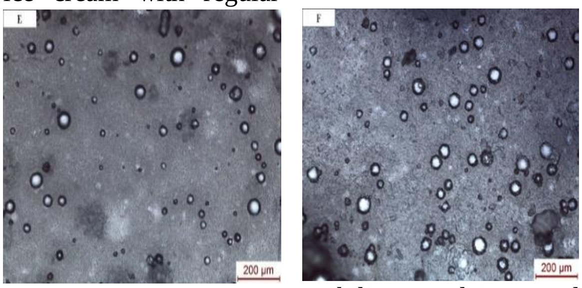
The pH-value of the ice cream mixes with regular stabilizers ranged from 6.50 to 6.57 andthepH-value of the ice cream mixes with nano stabilizers after aging ranged from 6.54 to 6.58 (Table 1). That was associated with a slight increase in the pH-value of the ice cream mixes with nanostabilizers. The pH-value increased when sodium alginate was used compared to carboxymethyl cellulose and carrageenan. Similar results were also reported by Taha et al [34].

3.4. Overrun and air cell size of ice cream

Ice cream overrun ranged from 22.9% to 26.1% in treatments with regular stabilizers and reached to 30.03-37.07 % in the treatments with nano stabilizers (Table 1). Ice cream overrun increased using nano-stabilizers. This result is mostlydue to the increased viscosity in the nanostabilizer- treated ice cream mixes as high-viscosity mixes can hold air cells better than low-viscosity mixes [35]. Ice cream with nano-CMC showed the highest overrun. The addition of CMC may enhance the overrun of different ice cream mixes in comparison with alginate [34].







Air cell size ranged from 41.01 µm to 52.27 µm in ice cream with regular stabilizers and increased from 55.32µmto 114.34 µm in ice cream with nano-stabilizers (Table 1 and Fig. 1). This increase in air cell size could be a consequence of the increase in the overrun of nanostabilizer-treated ice cream.

Fig.1. Shape of air cell size of fresh ice creamsamples:(A): Carboxymethyl cellulose; (B): Carboxymethyl cellulose Nano;(C): Sodium alginate; (D): Sodium alginate Nano ;(E) Carrageenan; (F): Carrageenan Nano

3.5. Melting resistance of ice cream during storage

Fig.2 shows the melting percentage after 75 min at intervals of 15 min. Ice cream with nano stabilizers showed a higher melting resistance (lower % melting) when compared with ice cream with regular stabilizers. This result is probably due to the increase overrun in the ice cream samples treated with nano stabilizers. This result agrees with that in the study by Sakurai et al [36] and Hartel et al [37] as they found that ice creams with higher overrun melted more slowly than ice creams with lower overrun. They attributed this behaviour to the presence of air cells, which reduced the transfer of heat. The melting resistance of all types of ice cream increased with increasingstorage time, whichmay have been caused by the increase in ice crystal size during storage, a result consistent with in the study by Park et al [38].

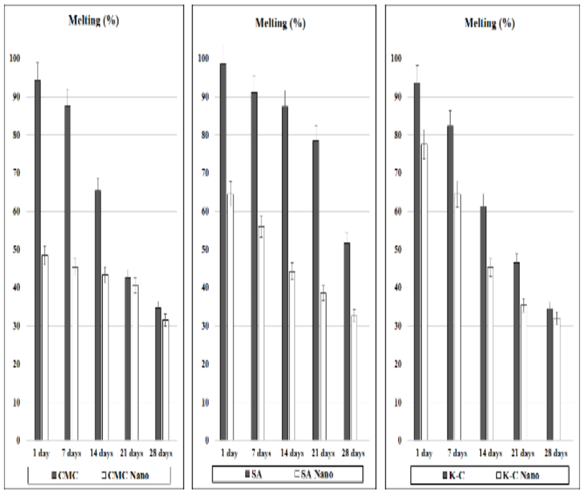


Fig.2. Effect of using nano stabilizers on % melting after 75 min during storage

3.6. Texture of ice cream during storage

a. Hardness

Ice cream with regular stabilizers was harder than ice cream treated with nanostabilizers (Table 2). Such a reduction in the hardness values for the samples treated with the nano stabilizers is most likely caused by the smaller ice crystals that obtained as a result of the high overrun values. These high overrun values reflect the increase in the number of the air cells in the ice cream matrix, which eventually cause easier penetration of the probe into the matrix[11, 39-41]. However, the hardness of all ice cream samples increased during the storage period. Such an increase in hardness may be due to an increase in the size of the ice crystals during storage [39].

b. Adhesiveness

The data in Table 2 show that the use of nano-stabilizers in ice cream led to low adhesiveness. However, adhesiveness in all treatments increased after 28 days of storage.

c. Gumminess

Gumminess in nano Carboxymethyl cellulose and nano carrageenan treated ice cream was higher than gumminess in ice cream with regular stabilizer (Table 2). On the other hand, ice cream treatments with nano sodium alginate showed lower gumminess compared with ice cream with regular sodium alginate. During storage, the gumminess of ice cream treatments with carboxymethyl cellulose regular and nano decreased while ice cream treatments with carrageenan and sodium alginate regular and nano increased.

d. Chewiness

The chewiness of ice cream treatments with nano Carboxymethyl cellulose and nano carrageenan were higher than the chewiness of ice cream with regular stabilizers, while ice cream treatments with nano sodium alginate showed lower chewiness compared with ice cream with regular sodium alginate(Table 2). At the end of the storage period, the chewiness of ice cream treatments with Carboxymethyl cellulose and Carrageenan nano and regular decreased, while ice cream treatments with sodium alginate regular and nano increased

3.7. Syneresis of ice cream during storage

Ice cream with nano stabilizers showed lower syneresis compared with ice cream with regular stabilizers (Table 3). These results could beattributed to the improvement of water holding capacity and viscosity in the ice cream mixes. Syneresis increased during storage of ice cream.

3.8. Color of ice cream during storage

a. Lightness (L*)

The lightness of nano Carboxymethyl cellulosetreated ice cream was higher than L* of ice cream with regular stabilizer, and the L*of ice cream with nano sodium alginate was lower than the L* of ice cream with regular stabilizer (Table 4). During storage period, the L* of all ice cream treatments decreased, this trend is in accordance with that in the study by Kaur et al [42] and Singh et al [43].

b. Redness (a*)

As shown in Table (4), ice cream treated with Carboxymethyl cellulose nano was less redness when compared with ice cream with regular stabilizer. On the other hand, redness of ice cream treatments with sodium alginate nano and Carrageenan nano were more redness than ice cream with regular Stabilizers. The redness of all ice creamtreatments increased during storage, this trend is in accordance with Singh et al. [43]

c. Yellowness (b*)

The data in Table (4) show that ice cream treatments with nano stabilizers were less yellowness compared with ice cream treatments with regular stabilizers. During storage period, the yellowness for all ice cream treatments increased.

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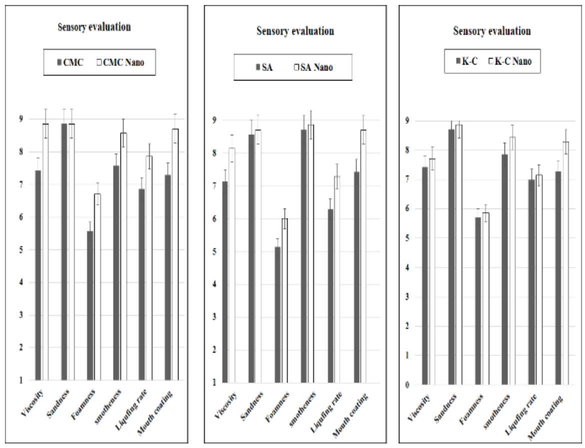

Fig.3. Effect of using nano stabilizers on sensory evaluation of ice cream

3.9. Sensory evaluation of ice cream

As Fig.3 illustrates, ice cream treatments with nano stabilizers were better than ice cream with regular stabilizers in viscosity, foaminess, smoothness, and mouth coating. However, there was no sandiness in any of the ice cream treatments

Table 1. Effect of milling treatment on particle diameter (nm) of stabilizers, viscosity (cp), pH, overrun (%) and air bubbles size (µm) of fresh ice cream sample

Measurements	T1	T2	T3	T4	T5	T6
Particle diameter (nm)	171.3 ± 14.15^{b}	10.25 ± 1.04^{c}	259.66 ± 27.68^{a}	19.4 ± 2.62^{c}	170.00 ± 40.95^{b}	18.1 ± 1.89^{c}
Viscosity (cp)	73.58±2.06^{f}	194.2±3.10^{b}	127.60±7.69 ^{d}	217.2±2.76^{a}	108.22±2.30^{e}	147.9±6.28^{c}
pH	6.50±0.023^{c}	6.55±0.025^{ab}	6.57±0.015^{ab}	6.58±0.006^{a}	6.50±0.010^{c}	6.5±0.036^{bc}
Overrun (%)	25.33±1.04^{d}	37.07±1.19^{a}	22.97±0.89^{e}	32.13±0.55^{b}	26.13±1.9^{d}	30.03±0.25^{c}
Air bubbles size (µm)	51.50±1.8^{bc}	114.3±38.25^{a}	41.01±8.1^{c}	71.38±6.44^{b}	52.27±3.06^{bc}	55.3±3.18^{bc}

Data are means of three replicates ± Standard Error (SE). Means in the same row with different superscripts letters are significantly different at (P≤0.05) .T1: Carboxymethyl cellulose; T2: Carboxymethyl cellulose Nano;

parameter	Storage period (Days)	T1	T2	T3	T4	T5	T6
Hardness (N)	1	6.7±0.10^{h}	5.8±0.10^{i}	0.4±0.10^{lm}	0.3±0.10^{m}	7.17±0.29^{g}	5.3±0.15^{j}
	14	8.6±0.10^{f}	8.5±0.15^{f}	1.9±0.20^{k}	0.6±0.10^{l}	16.13±0.15^{b}	11.9±0.35^{e}
	28	15.3±0.10^{c}	12.0±0.15^{e}	16.2±0.10^{b}	13.2±0.10^{d}	17.77±0.26^{a}	13.33±0.2^{d}
Adhesiveness (mj)	1	2.62±0.10^{f}	1.29±0.11^{h}	0.15±0.09^{k}	0.15±0.02^{k}	1.91±0.10^{g}	1.17±0.15^{h}
	14	0.64±0.10^{i}	0.49±0.10^{ij}	0.13±0.07^{k}	0.08±0.01^{k}	0.52±0.10^{ij}	0.45±0.12^{j}
	28	3.17±0.10^{d}	2.96±0.15^{e}	5.40±0.10^{a}	3.41±0.09^{c}	4.9±0.06^{b}	2.52±0.10^{f}
Gumminess (N)	1	1.60±0.10^{f}	2.50±0.10^{c}	0.20±0.10^{j}	0.20±0.01^{j}	1.13±0.15^{h}	1.37±0.06^{g}
	14	1.60±0.10^{f}	2.50±0.10^{c}	1.30±0.10^{g}	0.20±0.10^{j}	1.70±0.10^{f}	2.6±0.14^{b}
	28	0.70±0.10^{i}	2.20±0.10^{d}	2.00±0.20^{e}	1.30±0.10^{g}	1.90±0.10^{e}	3.2±0.25^{a}
Chewiness (mj)	1	19.74±0.14^{b}	29.42±0.09^{a}	0.51±0.10^{o}	0.54±0.11^{o}	12.94±0.06^{d}	17.2±0.20^{c}
	14	2.42±0.13^{l}	4.46±0.15^{g}	3.40±0.10^{j}	0.60±0.10^{o}	4.73±0.07^{f}	8.1±0.16^{e}
	28	1.04±0.13^{n}	3.75±0.10^{i}	4.25±0.15^{h}	1.70±0.10^{m}	2.84±0.13^{k}	3.6±0.11^{i}

T3: Sodium alginate; T4: Sodium alginate Nano; T5: Carragennan; T6: Carragennan Nano.

Table 2 Effect of using nano stabilizers on texture parameters of ice cream during storage

Data are means of three replicates ± Standard Error (SE). Means in the same row with different superscripts letters are significantly different at (P≤0.05) .T1: Carboxymethyl cellulose; T2: Carboxymethyl cellulose Nano; T3: Sodium alginate; T4: Sodium alginate Nano; T5: Carragennan; T6: Carragennan Nano.

Table 3 Effect of using nano stabilizers on Syneresis (ml/30g) of ice cream during storage

Storage period (Days)	T1	T2	T3	T4	T5	T6
1	10.16±0.28^{ijk}	9.16±0.28^{mn}	9.00±0.50^{n}	8.16±0.28^{o}	10.66±0.28^{ghi}	9.83±0.28^{jkl}
7	10.6±0.28^{ghi}	9.83±0.28^{jkl}	9.83±0.28^{jkl}	9.00±0.50^{n}	11.16±0.28^{efg}	10.66±0.28^{ghi}
14	11.16±0.28^{efg}	10.66±0.57^{ghi}	10.33±0.28^{hij}	9.33±0.28^{lmn}	11.66±0.28^{cde}	11.16±0.28^{efg}
21	11.50±0.50^{de}	11.17±0.28^{efg}	10.83±0.28^{fgh}	9.67±0.28^{klm}	12.17±0.28^{abc}	11.67±0.28^{cde}
28	12.33±0.28^{ab}	11.83±0.28^{bcd}	11.33±0.28^{def}	10.17±0.28^{ijk}	12.67±0.28^{a}	12.17±0.28^{abc}

Data are means of three replicates ± Standard Error (SE).Meansin the same row with different superscripts letters are significantly different at (P≤0.05) .T1: Carboxymethyl cellulose; T2: Carboxymethyl cellulose Nano; T3:

parameter	Storage period (Days)	T1	T2	T3	T4	T5	T6
Lightness (L*)	1	89.63±0.08^{g}	90.45±0.05^{cd}	91.15±0.06^{a}	91.03±0.03^{a}	90.14±0.07^{ef}	90.14±0.07^{ef}
	14	89.38±0.08^{h}	90.00±0.10^{f}	90.76±0.05^{b}	90.29±0.18^{de}	89.69±0.03^{g}	89.37±0.04^{h}
	28	88.89±0.06^{i}	89.33±0.06^{h}	90.50±0.26^{c}	87.74±0.03^{j}	89.40±0.17^{h}	88.94±0.20^{i}
Redness (a*)	1	-4.73±0.04^{h}	-4.90±0.02^{i}	-4.45±0.03^{f}	-3.92±0.04^{c}	-4.63±0.03^{g}	-4.35±0.05^{e}
	14	-4.45±0.04^{f}	-4.76±0.05^{h}	-4.16±0.06^{d}	-3.71±0.06^{b}	-4.20±0.09^{d}	-3.92±0.03^{c}
	28	-4.32±0.03^{e}	-4.61±0.05^{g}	-3.92±0.02^{c}	-3.43±0.01^{a}	-3.95±0.01^{c}	-3.64±0.09^{b}
Yellowness (b*)	1	20.75±0.07^{cd}	20.18±0.10^{e}	17.58±0.08^{l}	16.86±0.05^{n}	18.73±0.04^{h}	17.83±0.04^{k}
	14	20.93±0.07^{bc}	20.65±0.05^{d}	17.89±0.10^{k}	17.34±0.05^{m}	19.13±0.05^{g}	18.16±0.05^{j}
	28	21.04±0.09^{ab}	21.13±0.25^{a}	18.45±0.17^{i}	17.86±0.15^{k}	19.55±0.09^{f}	18.69±0.21^{h}

Sodium alginate; T4: Sodium alginate Nano; T5: Carragennan; T6: Carragennan Nano.

Table 4 Effect of using Nano stabilizers on color parameters of ice cream during storage

Data are means of three replicates ± Standard Error (SE). Means in the same row with different superscripts letters are significantly different at (P≤0.05) .T1: Carboxymethyl cellulose; T2: Carboxymethyl cellulose Nano; T3: Sodium alginate; T4: Sodium alginate Nano; T5: Carragennan; T6: Carragennan Nano

4. Conclusion

The nano stabilizers treatment was proven as an effective method for enhancing the rheological and technological properties of ice cream. It increased mixes viscosity, overrun, and melting resistance and improved the texture and syneresis of the treated ice cream. Further studies are needed to investigate the stability and safety of these nano stabilizers during storage and marketing. It is of utmost importance to point out that nano additives need further health-related studies to investigate any potential side effects for proper health official approval.

5. Conflicts of interest

There are no conflicts to declare

6. Acknowledgment

Authors would like to gratefully thank Dr. Mohammed Desoky (Soil Science Department, Faculty of Agriculture,Cairo University) and Dr. Tarek Nour (Dairy Science Department, National Research Center) for providing ball mill and some preliminary analyses, respectively.

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