Evaluation of Functional and Sensory Properties of Ice-cream Incorporating Sea Buckthorn Seed Oil Microcapsules

Vishal Kumar[1], Durga Shankar Bunkar[1], Shiva[1], Prajasattak Kanetkar[1], Ayushi Jha[1], Vinod Kumar Paswan[1], S.K. Goyal[2]

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ABSTRACT

Background: The food industry continuously explores new formulations to resolve the growing consumer requirement for healthier, functional foods. Sea buckthorn seed oil (SBSO) is recognized for its recuperative and therapeutic advantages. The current research investigates the incorporation of microencapsulated SBSO in ice cream.

Methods: A base ice cream mixture was prepared using 10% milk fat, 14% sucrose, 0.5% emulsifier, along with 0.5% stabilizer. The SBSO was microencapsulated using an atomization drying method with maltodextrin and inulin as wall materials. Encapsulated and non-encapsulated SBSO both were added into the ice cream, followed by optimization of formulations based on parameters including antioxidant activity, total phenolic content (TPC), sensory properties, viscosity, overrun as well as hardness. The ice cream sample containing 2% SBSO exhibited the highest antioxidant activity, with a DPPH inhibition of 88.73% and TPC of 24.23 mg GA eq./g. Meanwhile, the ice cream with encapsulated SBSO powder (1%) demonstrated superior sensory attributes, viscosity, overrun and hardness compared to other formulations. Furthermore, the TPC increased proportionally with higher encapsulated and non-encapsulated SBSO levels.

Result: These results suggest that as a natural bioactive ingredient, sea buckthorn seed oil holds potential for creating innovative ice cream formulations with improved antioxidant properties.

Key words: Antioxidant, Functional food, Microencapsulated, Sea buckthorn seed oil, Therapeutic.

INTRODUCTION

India is increasingly recognized as a significant competitor in the global dairy industry due to its vast potential and growing influence in the sector (Shinde *et al.,* 2025). India is the largest producer of milk in the world and half of this milk is used by small, local businesses to make various traditional foods and treats (Rai *et al*., 2020). Ice cream is the most renowned treat globally, made from a mix of milk, dairy products and sweeteners. People of all ages enjoy it, which is a popular choice among different dairy-based treats (Legassa, 2020). As people learn more about the connection between food and health, new products have been developed with the need for ongoing technological advancements. Some of these products can potentially improve human health (Granato *et al*., 2018). In recent years, there has been a growing trend among consumers towards health consciousness and an increased focus on the nutritional benefits of food, prompting manufacturers to prioritize the development and promotion of functional foods (Rathod *et al.,* 2025). The chemical makeup of ice cream affects important qualities like its texture and taste, which in turn determine the overall quality of the final product (Syed *et al*., 2018). Traditional ice creams have quite high amounts of sugar and fat, which contribute to their calorie content. However, with increasing health concerns, low-calorie and reduced-fat ice creams are becoming more popular, as they help lower the risk of diseases like heart disease and cancer (Akalin *et al*., 2018). It is believed that about 25% of all current medicines come from plants, either directly or through modern technologies that build on traditional knowledge (Bouatrous, 2019). To satisfy these needs, the food sector has been exploring substitute ingredients that preserve the scent, consistency and taste of conventional foods.

The sea buckthorn (SBT) plant is well-known for its therapeutic and fragrant qualities, along with its many health benefits. Hippophae is the scientific name for sea buckthorns, which are deciduous shrubs in the Elaeagnaceae family (Letchamo *et al*., 2018). The residual oil cake obtained from the extraction of sea buckthorn oil from its seeds is a

[1]Department of Dairy Science and Food Technology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221 005, Uttar Pradesh, India.
[2]Department of Agricultural Engineering, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221 005, Uttar Pradesh, India.

Corresponding Author: Vishal Kumar, Department of Dairy Science and Food Technology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221 005, Uttar Pradesh, India. Email: vishalkumar@bhu.ac.in

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rich source of oil, protein and dietary fiber. It is free from toxic substances, making it a safe and suitable feed for animals capable of digesting fibrous materials. The oil content present in sea buckthorn seeds varies between 0.26 to 15 grams per 100 grams, depending on factors like the subspecies, where the plant comes from, how the berries are packaged, when they are harvested. The methods used to extract the oil (Bal *et al*., 2011).Sea buckthorn seed oil includes two important fatty acids: omega-3 andomega 6 fatty acid. These fatty acids comprise 20-35 grams and 30-40 grams per 100 grams of oil, respectively (Fan *et al*., 2007). In addition to triacylglycerols, natural fats and oils also contain lipophilic components. Among the most interesting of these are polar lipids, like glycolipids and phospholipids.

In the current millennium, the dairy sector is transitioning from a primary focus on bulk commodity production to a greater emphasis on the development of innovative, value-added products that offer enhanced flavor and distinct characteristics (Kumar *et al.,* 2024). The increasing desire for more nourished and advantageous foods has resulted in creating ice cream with functional properties, including antioxidants. Adding beneficial ingredients to ice cream boosts its value. It is an excellent medium for carrying the bioactive components of essential oils (Pandhi *et al.,* 2021). The current study focuses on enhancing ice cream's dietary and sensory characteristics by including microcapsules of spray-dried sea buckthorn seed oil.

MATERIALS AND METHODS

The milk used for the ice cream was sourced from the Dairy Farm at the Institute of Agricultural Sciences, BHU, Varanasi, U.P., India. The milk was adjusted to contain fat (6.00%) and solids-not-fat (SNF) (8.50%). Table cream with 25% fat and skimmed milk powder were also utilized in making the ice cream. Sea buckthorn seed oil was obtained from Deve herbs (Delhi, India). The material was then encapsulated using a ratio using a two-to-one ratio (core to wall material). All the reagents as well as chemicals utilized in the analysis were of high quality and analytical grade and they were purchased from Hi Media Laboratories Pvt. Ltd., based in Mumbai, India.The experiment was carried out at Department of Dairy Science and Food Technology, Institute of Agricultural Sciences, BHU, Varanasi in year 2024.

Manufacturing of microcapsules containing Sea Buckthorn seed oil

The sea buckthorn seed oil microcapsules (SBSOM) were made using a combination of maltodextrin (MD) and inulin in a 1:2 ratio as the wall material. The SBSOM was produced the spray drying process was employed using a mini spray dryer (JISL). The atomizer nozzle had an inner diameter of 0.7 mm, with the feed flow rate regulated by the pump rotation speed. The drying process was conducted under the following operational conditions: an inlet air temperature ranging from 160 to 180°C, an outlet air temperature between 80 and 85°C, a constant feed flow rate of 400 mL/h, an air pressure of 117.68 kPa and a vacuum pressure of 169.32 kPa. Prior to commencing the spray drying experiments, the system was operated for 30 minutes to achieve steady-state conditions. The spray-dried sea buckthorn seed oil powder was used to make the functional ice cream.

Manufacturing of the functional ice cream

The functional ice cream was produced at the ice cream facility in the Department of Dairy Science and Food Technology, Institute of Agricultural Science, BHU, Varanasi. The procedure for preparing the ice cream and the samples followed the method outlined by (Sacchi *et al.,* 2019), with a few minor modifications to suit the specific requirements of this study. The Pearson square method was applied to calibrate the fat and solids content in the ice cream mixture.

The ice cream formulation consisted of 1000 mL of pasteurized milk, with the following concentrations: 14% sugar, 0.5% emulsifier (polysorbate 80) and 0.5% stabilizer (guar gum). The control sample exhibited a total solids content of 36%, with a protein concentration of 3.5% and milk fat content of 10%. This investigation employed five distinct treatment formulations, formulated as ice creams, based on the presence or absence of sea buckthorn seed oil powder: T1 (control ice cream); T2 (ice cream encompassed of 1% (w/v) sea buckthorn seed oil microcapsules (SBSOM); T3 (ice cream with 2% (w/v) sea buckthorn seed oil microcapsules (SBSOM), T4 (ice cream consisting 1% (w/w) sea buckthorn seed oil (SBSO); T5 (ice cream with 2% (w/w) sea buckthorn seed oil (SBSO). To prepare the functional ice cream, the milk was initially subjected to heating to 85°C. Then, every ingredient was included in the milk and stirred continuously for 1 minute. The mixture was subsequently cooled to a temperature of 4°C. During the aging phase, the blend was stirred slowly for about 8 hours. The ice cream mixture was subjected to cooling and freezing using a batch freezer at -18°C for 24 hours. Following this process, the product was stored at -18°C in a deep freezer, following the procedure given by (Paul *et al.,* 2020).

Ice cream characterization

Overrun

The overrun was analysed with the help of the method given by (Samakradhamrongthai *et al*., 2021), in accordance with the equation provided below

$$\text{Overrun} = \frac{Wt1 - Wt2}{Wt2} \times 100$$

Where,
Wt1 = Represents the weight of the ice cream mix.
Wt2 = Refers to the weight of the ice cream.

Mix viscosity

The ice cream mix's apparent viscosity was determined with the help of Brookfield viscometers with LV spindle 63

(BRK Instruments India LLP, Thane, India) at a shear rate of 100 rpm at 4 to 5°C, following the method outlined by (Muse and Hartel, 2004).

Hardness assessment

To assess the hardness of the ice cream, a TAXT plus texture analyzer equipped with a 2 mm diameter cylinder probe was employed. The evaluation was done at room temperature, maintained at 25±2°C. During the test, the probe was set to penetrate the ice cream at a speed of 1 mm/s, with a trigger force of 5 g and the probe penetrated a depth of 2 mm. The ice cream samples, which were kept in 100 ml plastic cups, were then evaluated for hardness in grams, following the methodology outlined by (Yan *et al.,* 2021).

Quantification of antioxidant and phenolic characteristics of ice cream

The DPPH scavenging activity was determined using the method outlined by (Sutaphanit and Chitprasert, 2014). A 1 mL aliquot of microcapsules dissolved in dichloromethane was combined with 1 mL of 0.2 mM DPPH solution. The resulting mixture was homogenized and incubated in the dark for 20 minutes. Absorbance was subsequently measured at 517 nm using methanol as a blank, employing a UV-VIS spectrophotometer (Shimadzu, Japan). The proportion of DPPH suppression in the prepared samples was subsequently determined using the given equation:

$$\text{DPPH Inhibition\%} = \frac{A1 - A0}{A1} \times 100$$

Where,

A1 = Absorption of the control.

A0 = Observed final absorption of the evacuated sample at the 517 nm wavelength. 95% methanol was utilized as the blank in the experiment.

The TPC of the samples was measured using the procedure outlined by (Krawitzky *et al*., 2014). 1 mL sample was combined with 5 mL of Folin-Ciocalteu reagent. After a 30-second interval and within 8 minutes, 4 mL of 7.5% sodium carbonate (Na_2CO_3) solution was added to the mixture in volumetric flasks. The flasks were then incubated in the dark at room temperature for 60 minutes. Absorbance was measured at 760 nm using a blank extraction solution (80% methanolic solution containing NaF) for reference, employing UV-VIS spectrophotometer (Shimadzu, Japan) at a wavelength of 760 nm. The overall phenolic concentration was then determined and presented as gallic acid equivalent (µg GAE/ml).

Sensory evaluation

Sensory evaluation of the prepared ice creams was carried out at the Department of Dairy Science and Food Technology, BHU, Varanasi, using a method based on (Dertli *et al*., 2016) with some slight modifications. Ten evaluators (five men and five women) were indiscriminately chosen from the department's staff members, research fellows and graduate students. Before the test, the panellists were briefed on the sensory evaluation procedure. To assess the sensory qualities and attributes of the samples, each panellist used a 9-point hedonic scale to consider the developed ice cream. The assessments were performed at room temperature (25±2°C). The panelists evaluated the samples on a scale of 1 to 9, with 1 indicating 'extremely dislike' and 9 is for 'extremely like'.

Statistical analysis

To quantify the observational and physicochemical properties of the ice cream, the trial was recurring thrice. The significance of variations among samples was interpreted operating one-way ANOVA with SPSS version 25. A difference was deemed statistically meaningful if the p-value was below 0.05 ($p<0.05$).

RESULTS AND DISCUSSION

Impact of sea buckthorn seed oil microcapsules on the overrun, thickness and firmness of the ice cream

The specifications of the ice cream that we made are presented in Table 1. The overrun of the ice cream varied from 77%, with the SBSOM ice cream showing a slightly higher overrun (76.55±0.02%) compared to the control (69.06±0.02%) and SBSO ice cream (75.03±0.02%). The viscosity of the ice cream varied between 45% and 85%. SBSOM ice cream had a superior viscosity in comparison to the control, but the viscosity difference between SBSOM and SBSO ice creams was minimal (84.18±0.02 cP). The hardness of the ice cream samples varied from 41.70 to 52.63 grams. SBSOM ice cream was the softest (41.70±0.02 g), followed by SBSO ice cream (44.52±0.02 g), while the control ice cream had the highest hardness (52.63±0.02 g). Overrun indicates the volume of air assimilated into ice cream, which creates bubbles that need to be generated and stabilized. This factor is crucial in determining the texture and sensory qualities of the ice cream (Kurt and Atalar, 2018). When sea buckthorn seed oil (SBSO) and encapsulated sea buckthorn seed oil (SBSOM) were added, they both enhanced the overrun of the ice cream. The overrun of SBSOM ice cream (T2, T3) was slightly higher than that of SBSO ice cream (T4, T5), which aligns with findings by (Velotto *et al*., 2021). This increase in overrun suggests that the ice cream mixture became more stable. However, the overrun of all samples was still lower than the 129-144% range seen by (Borrin *et al*., 2018), who added curcumin-nano emulsion to their ice cream. The higher overrun in SBSO ice cream might be due to the larger amount of fat, which increases the apparent viscosity of the ice cream mix and allows for more air to be incorporated during freezing (Makouie *et al*., 2021). The viscosity of SBSOM ice cream (T2 and T3) was marginally elevated than SBSO ice cream (T4 and T5), as shown in Table 1. This difference is because carbohydrates (such as maltodextrin and sodium caseinate) were used to encapsulate the SBSO and carbohydrates are known to

increase viscosity in foods (Lima *et al*., 2016). Higher viscosity helps break down air cells more efficiently. Consequently, SBSOM ice cream exhibited enhanced thickness in comparison with the control sample. Hardness in ice cream is influenced by several factors, including viscosity, solid content and air (Yan *et al*., 2021). Overrun, defined as the capacity of the ice cream matrix to retain air bubbles, was evaluated by measuring the percentage increase in volume resulting from the incorporation of air during the whipping of the ice cream mix throughout the freezing process (Muse and Hartel, 2004). Air bubbles are formed during the production process as a result of stirring the ice cream mixture (Sung and Goff, 2010). The air bubbles in ice cream distribution result in smooth texture and affect the physical properties of melting and hardness of ice cream (Sofjan and Hartel, 2004). Overrun and hardness are inversely related; as overrun raises, the ice cream becomes softer. For example, Kulkarni *et al*. (2017) found that adding pumpkin powder to ice cream increased viscosity, which in turn reduced the ice cream's hardness.

Enumeration of phenolic and antioxidant attributes of ice cream

Table 2 presents the total phenolic content and antioxidant properties of SBSOM and SBSO ice cream. The TPC for SBSOM ice cream was measured as (21.82±0.02 µg GAE/ml) for T2 and (23.11±0.02 µg GAE/ml) for T3, while SBSO ice cream had values of (22.52±0.01 µg GAE/ml) for T4 and (24.52±0.02 µg GAE/ml) for T5. In terms of antioxidant activity, the DPPH inhibition percentage for SBSOM ice cream was (86.24±0.02%) for T2 and (87.39±0.02%) for T3, while for SBSO ice cream, it was (87.25±0.02%) for T4 and (88.73±0.02%) for T5. The DPPH scavenging activity in the ice cream with SBSO was in line with the findings from (Mishra *et al*., 2020). SBSO ice cream showed enhanced antioxidant and phenolic levels in contrast to the ice cream made accompanied by encapsulated SBSO. This could be due to the elevated temperatures used in the spray drying process for making SBSO powder, as temperatures above 60°C can reduce the activity of bioactive compounds in the oil. These results are similar to those of (Nguyen and Hwang, 2016), who found that increasing the amount of Aronia juice led to higher polyphenol and flavonoid content compared to a control group. Antioxidants are molecules that prevent or slow the oxidation of other substances by inhibiting the initiation or propagation of oxidative chain reactions (Halliwell, and Gutteridge, 2015). The antioxidant effect encompasses the enhancement of antioxidant enzyme activity and the suppression of oxidase activity. Free radicals can be generated through redox reactions and the peroxidation of transition metal ions, such as iron and copper. Consequently, promoting the synthesis of antioxidant enzymes, alongside reducing the activity of oxidases and the formation of metal ions, can effectively exert a strong antioxidant effect (Ji *et al.,* 2020). In this study, the TPC of the ice cream increased with SBSOM (T2 and T3) contrasted with SBSO (T4 and T5). The less phenolic content found in SBSO ice cream could be due to the deprivation of volatile compounds during the production procedure. The results regarding the TPC of SBSOM ice cream are consistent with the findings by (Deme *et al*., 2021). The antioxidant potential of plant-based foods is primarily influenced by their polyphenolic content. Phenolic compounds are the predominant bioactive constituents responsible for the antioxidant activity observed in plants. This activity is largely attributed to their redox properties, which facilitate the scavenging of free radicals and the neutralization or decomposition of peroxides (Ursache *et al.,* 2017). Higher phenolic content in foods can help prevent diseases caused by oxidative stress (Durmaz *et al*., 2020).

Table 1: Effect of sea buckthorn seed oil microcapsules on overrun, viscosity and the hardness of the ice cream (n=3).

Treatment	Antioxidant	Total phenolic content
T1	65.10±0.02^{a}	0.00±0.00^{a}
T2	86.24±0.02^{b}	21.82±0.02^{b}
T3	87.39±0.02^{d}	23.11±0.02^{d}
T4	87.25±0.02^{c}	22.52±0.01^{c}
T5	88.73±0.02^{e}	24.25±0.02^{e}

Table 2: DPPH inhibition % and TPC assessments of different ice cream samples incorporated with encapsulated and non-encapsulated sea buckthorn seed oil (n=3).

Treatment	Viscosity	Overrun	Hardness
T1	45.33±0.02^{a}	69.06±0.02^{a}	52.63±0.02^{e}
T2	85.48±0.02^{e}	76.55±0.02^{d}	41.70±0.02^{b}
T3	84.18±0.02^{d}	77.03±0.02^{e}	40.32±0.02^{a}
T4	82.33±0.02^{c}	74.08±0.02^{b}	43.32±0.02^{c}
T5	80.25±0.02^{b}	75.03±0.02^{c}	44.52±0.02^{d}

Sensory evaluation

Table 3 presents the sensory evaluations for different characteristics, including body and texture, color and appearance, mouthfeel, flavor and overall preference, of the five ice cream samples. Small differences in sensory properties were observed between the control and SBSOM ice cream. For color and appearance, SBSOM ice cream scored (7.94±0.02) for T2 and (7.82±0.02) for T3, while SBSO ice cream scored (7.72±0.02) for T4 and (7.32±0.02) for T5. Treatments T1 and T3 exhibited superior body and texture in comparison to treatment T2, likely due to the added viscosity from the microcapsules. The flavor scores for the control and SBSOM ice creams (T2) were (8.12± 0.02) and (8.12±0.02), respectively, while SBSO ice cream (T5) had a lower flavor score of (5.12±0.02). The incorporation of microcapsules has led to a marked intensification in the flavor profile, particularly when compared to non-encapsulated counterparts. This enhancement is likely associated with the prominent aftertaste of sea buckthorn seed oil, which is characterized by a pronounced fresh note. For mouthfeel, both the control and SBSOM ice creams (T2) scored (7.52±0.02). In contrast, SBSO ice cream (T4 and T5) had a mildly sour aftertaste, with normal ratings of (5.72±0.02)

Table 3: Sensorial evaluations of different ice cream samples encapsulated and nonencapsulated sea buckthorn seed oil (n=3).

Treatment	Color and appearance	Body and texture	Flavor	Mouthfeel	Overall
T1	7.94±0.02^{d}	7.95±0.02^{d}	8.12±0.02^{d}	7.52±0.02^{d}	7.72±0.02^{d}
T2	7.94±0.02^{d}	7.72±0.02^{b}	8.12±0.02^{d}	7.52±0.02^{d}	7.72±0.02^{d}
T3	7.82±0.02^{c}	7.62±0.02^{a}	7.82±0.02^{c}	7.32±0.02^{c}	7.32±0.02^{c}
T4	7.72±0.02^{b}	7.92±0.02^{d}	5.82±0.02^{b}	5.72±0.02^{b}	5.82±0.02^{b}
T5	7.32±0.02^{a}	7.82±0.02^{c}	5.12±0.02^{a}	5.02±0.02^{a}	5.02±0.02^{a}

and (5.02±0.02), respectively. In terms of overall acceptability, treatments T1 and T2 received the highest scores of (7.72 ±0.02), which were higher than the other treatments. There was a small difference in color and appearance between SBSOM and SBSO ice creams. SBSO ice cream had a creamy-yellowish color and adding SBSOM didn't affect the ice cream's visual appearance. This finding is similar to the study by (Mishra *et al*., 2020), which noted that yogurt with encapsulated seed extract had a higher color score compared to yogurt with just seed extract.SBSO ice cream also had a flavor profile similar to that of oil-enriched ice cream described by (Ramadan, 2012), which had a flavor score of (6.56±0.88). The texture and body of SBSO ice cream (T4 and T5) were rated higher than SBSOM ice cream (T2 and T3), likely due to the increased viscosity from adding microcapsules. (Agrawal *et al*., 2016) observed only minor differences in texture and body when ginger juice was added to ice cream. In the case of basil oil ice cream, a bitter aftertaste was noted. The overall acceptance scores in this study align with the findings of (Zanjani *et al*., 2018), which showed no off-flavors after adding encapsulated probiotic strains.These findings indicate that encapsulation aids in minimizing the adverse effects (such as undesirable tastes, color and texture) of SBSO in food items.

CONCLUSION

This study assessed the nutritional and sensory features of ice cream prepared with SBSO microcapsules. The results are important for the functional dairy industry, as SBSOM could be added to a range of dairy items because of its excellent stability in terms of sensory qualities and biologically active compounds. Sensory assessments indicated that incorporating SBSOM did not notably affect the ice cream's body and texture, color, flavor, appearance, mouthfeel and overall preference. Considering these outcomes, it can be concluded that biologically active substances from essential oils can be used as pure ingredients in food items to enhance both their nutrient-rich and sensory qualities.

Conflict of interest

All authors declared that there is no conflict of interest.

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