Sengupta *et al.*
Food Production, Processing and Nutrition (2023) 5:56
https://doi.org/10.1186/s43014-023-00171-y

Food Production, Processing and Nutrition

RESEARCH

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Biochemical characterization and hypocholesterolemic properties of sesame yogurt made from deoiled edible quality sesame flour (DEQSF) supplemented with rice bran oil

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Abstract

Despite having a high polyphenol content, deoiled edible quality sesame flour (DEQSF), a byproduct of the sesame oil extraction process, is frequently thrown away. DEQSF contains antioxidants, amino acids, minerals, protein, and many non-nutrient-based health advantages. It could serve as an excellent material for the formulation of a value-added functional food product. The current study developed fortified sesame yogurts using rice bran oil (RBO) and DEQSF at percentages of 6, 7, and 8 in order to compare them to control sesame yogurts manufactured from whole sesame seeds and kept at 4 °C for 28 days. The other goal was to examine the in vivo cholesterol-lowering potential of sesame yogurt prepared from DEQSF and RBO. Evaluations were done on the physicochemical, microbiological, sensory, anti-oxidative, proteolytic, morphological, and nutritional properties. The proximate composition of RBO-fortified sesame yogurts differed considerably when compared to control yogurt in terms of protein, fat, ash, total solids, and carbohydrate content. After 28 days of storage, the addition of 8% DEQSF not only decreased syneresis but also maintained proper viscosity and penetration properties. The right quantity of probiotic bacteria was present in the RBO-fortified sesame yogurts that contained 8% DEQSF, and RBO-fortified sesame yogurt treated with 8% DEQSF (w/v) had a general overall acceptability score. During storage at 4 °C, all RBO-fortified sesame yogurts had nearly identical antioxidant activity to the control sesame yogurt. The addition of 8% DEQSF increased the amount of proteolysis by *Lactobacillus spp.* and *Streptococcus spp.*, as evidenced by a significant increase in o-phthaldialdehyde levels. Microstructural studies confirmed the dense, compressed, homogeneous structure of the fortified sesame yogurt. To investigate the effects of RBO-supplemented, DEQSF-based yogurt on hypercholesterolemia, a hypercholesterolemic mice model was developed. Comparing animal groups that received fortified sesame yogurts to control groups, there was a significant effect on serum lipid profile as well as hepatoprotective potential. The implication was that RBO-fortified sesame yogurt could help cure hypercholesterolemia. In the end, it was discovered that 8% DEQSF (w/v) and RBO were the perfect combinations to produce sesame yogurt with an anti-obesity and hypocholesteremic impact.

Keywords Sesame flour, Yogurt, Sesame milk, Antioxidant, Rice bran oil, Hypercholesterolemia

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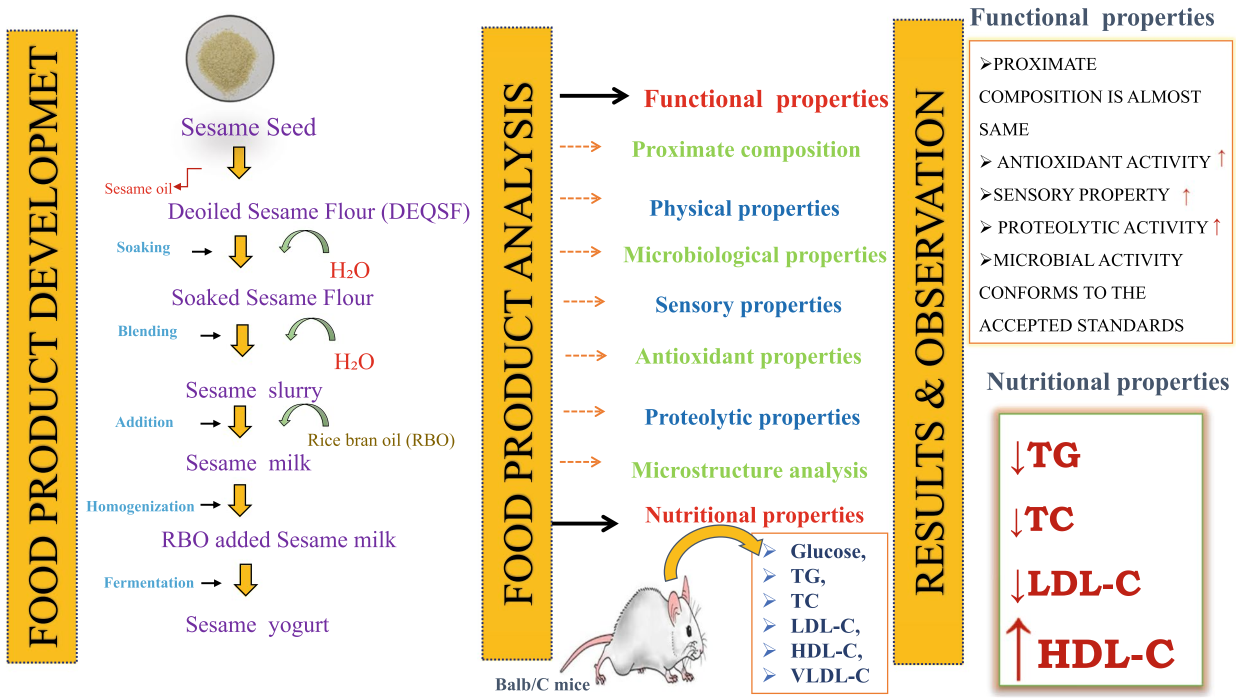
Graphical Abstract



Introduction

Milk and dairy products are considered vital food items because all the important nutrients are present in them in a proper proportion (Davoodi et al. 2013). However, research studies have shown that some compositions of milk are associated with adverse health effects like lactose intolerance, cow milk allergy, coronary heart diseases, type 2 diabetes, Alzheimer's disease, and anaemia (Kundu, Dhankhar and Sharma 2018). Plant-based milk substitutes may be an effective solution to these issues. Alternatives to plant-based milk are often free of certain constituents like lactose, cholesterol, saturated fatty acids, and antigens that are present in mammalian milk. It is well tolerated by people with lactose intolerance and cow's milk allergy due to the absence of non-allergic proteins and lactose. Plant-based milk alternatives are accepted as nutraceuticals and functional foods because various important phytonutrients, vitamins, minerals, and fibers are present in them. Plant-based milk substitutes, particularly those manufactured from vegetable oilseeds like soy, sesame, sunflower, flaxseed, etc., are the fastest-growing segment of the global functional and health food market's newer food product development category. In spite of its tremendous importance, however, very little work has been done on vegetable oilseed processing to develop non-dairy functional food products. In the Indian market, vegetable oil seeds, such as soy products, are available as fermented or nonfermented food products. Non-dairy food products, especially soy-based food products, are estimated to be the fastest-growing geography in the health food market, but there has been relatively less work in the area of research and development of other oilseed-based value-added products (Sengupta et al. 2019a, 2019b; Sengupta et al. 2018a, 2018b; Sengupta et al. 2019).

Among the oilseeds, functional food products made from sesame seed have been poorly studied to date. Various important phytonutrients are found in sesame seeds, such as calcium, manganese, copper, iron, vitamin B1, zinc, phosphorus, and dietary fibers (Dossou et al. 2022). Protein obtained from sesame seeds has high biological value. Sesame seeds contain approximately 21.9 percent protein (Wei et al. 2022). In addition, two unique substances, namely sesamin and sesamolin, are also found in sesame seeds. Various research studies have shown that these two unique substances play various vital roles in our bodies. Together, they can help to prevent high blood pressure, have a cholesterol-lowering effect, and also improve vitamin E supply in humans. Sesamin itself may protect our liver from oxidative damage (Kouighat et al. 2022; Rosalina & Weerapreeyakul 2021; Shi et al. 2022; Zheng et al. 2021). Since sesame seeds are of plant origin, various bitter-tasting polyphenol compounds (catechin, epicatechin, epigallocatechin gallate, etc.) are present and responsible for the unpleasant odour. As a result, sesame-based milk substitutes lag in sensory acceptance and have a short shelf life. To increase acceptance of sesame based non-dairy food products, different kinds of fortifying agents have been studied. Non-dairy yogurt is fortified with lactose, cheese-dried whey, non-fat dried milk, guar gum, and skim milk (Afaneh 2013). Fortifications with these fortifying agents not only help to reduce the unpleasant odour but also enhance the nutritional qualities of non-dairy yogurt (Afaneh et al. 2011).

Non-dairy yogurt frequently contains Rice Bran Oil (RBO) as a strengthening ingredient. The main bioactive compound present in RBO is gamma oryzanol, which acts as a potent antioxidant. RBO also contains some other important phytosterols such as campesterol, beta-sitosterol, stigmasterol, and squalene (Sengupta et al. 2016).

DEQSF has enormous potential for use in producing non-dairy products of similar kinds as those produced from deoiled soybean flour (Sengupta & Bhowal 2017a). Sesame-based non-dairy analogues such as sesame milk and sesame yogurts are available; however, few sesame-RBO-fortified food products might appeal to a more traditional dairy consumer. Recently, sesame milk from whole sesame seeds was developed. Unfortunately, the created sesame milk had a weak flavour that was barely tolerable, and it also had a short shelf life (Quasem et al. 2009). To overcome this problem, there is an urgent need for the fermentation of sesame milk (Ahmadian-Kouchaksaraei, Varidi, Varidi and Pourazarang 2014). Sesame yogurt from whole sesame seeds was successfully developed by Afaneh et al. (2011), but they came to the conclusion that the addition of dairy products was crucial to promoting the development of acid and flavour in sesame-based imitation dairy analogues.

Sesame flour, which is made by extracting the oil content of authentic sesame seeds with non-polar solvents (food grade n-hexane), has a lot of potential for converting to milk, such as sesame milk, and then into yogurts. Such yogurts have not been adequately investigated in respect of their physico-chemical and nutritional properties. The following nutrients are found in sesame meal: 7.92% moisture, 27.83% fat, 30.56% protein, 6.22% fibre, 5.27% ash, and 28.14% carbohydrate. Defatted sesame meal now has a higher protein level (41.15–49.58%) due to oil extraction (Melo et al. 2021). In the food sector, it is possible to use this meal as a source of protein. Methionine and cystine, two amino acids that have a high total sulphur concentration, are abundant in sesame flour. Since most plant proteins have low total sulfur-containing amino acid levels, sesame flour is unique in that it contains significant quantities of total sulfur-containing amino acids. As a result, yogurt can be made using sesame flour as the primary component due to its amino acid composition. An indicator of DEQSF's emulsifying activity was found to be superior to those of the whole sesame flour when functional properties such as solubility, water and oil holding capacity, foaming capacity and stability, gelation, bulk density, and viscosity of a sesame flour were compared with those of another oilseed flour (Fasuan, Gbadamosi and Omobuwajo 2018). Due to its distinctive nutritional qualities, sesame yogurt, which is made by the bacterial fermentation of sesame milk, has gained popularity in the market for plant-based yogurt substitutes. Yogurt is extremely popular among consumers, so producers and manufacturers are constantly developing new yogurt varieties with value-added ingredients. Sesame yogurt has been shown to have nutritional and health benefits (Namiki 2007). More recently, it has been discovered that sesame yogurt has significant antioxidant activity, which will help to avoid chronic inflammation. Yogurt-based products are continually being researched and released to the market in order to fulfil the needs of contemporary customers, which has resulted in a steady rise in sales and popularity of this non-dairy food.

There are few studies on sesame yogurt made with deoiled, edible-grade sesame flour and enriched with RBO, a potent antioxidant, and none of them mention sesame yogurt developed in an industrial setting. Sesame yogurt's nutritional value has also been somewhat overlooked. The use of deoiled sesame flour, a waste product of oil extraction, in the production of yogurt formulation is new to us. To establish dietary strategies for the prevention of chronic illness, RBO-supplemented, DEQSF-based yogurt has been recommended as a valid system in various formulations. Utilizing food industry waste to produce valuable dietary items is getting harder these days. Local markets provide a variety of traditional sesame-based food products manufactured from sesame oil or sesame seeds. Less research has been done on the use of in making yogurt. Additionally, the RBO inclusion increases the nutritional value of sesame yogurt. This study illustrates the viability of employing in the production of sesame yogurt enhanced with RBO as a viable non-dairy food item, particularly for those suffering from hypercholesterolemia. Additionally, the current approach also enhances the economy of the sesame-based sector. There is currently no literature encompassing the use of to develop yogurts in order to eliminate the problem associated with whole sesame seeds. Additionally, the consumption of sesame yogurt manufactured with DEQSF can overcome the drawbacks of soy yogurt consumption, such as the presence of elements that cause flatulence, the prevalence of soy protein allergies, and a beany or off flavour (Zahra et al. 2014). This study used an antioxidant-rich RBO along with DEQSF to produce non-dairy yogurt with the aim of examining its physicochemical, microbiological, sensory, antioxidative, proteolytic, morphological, and nutritional properties.

Materials and methods

Chemicals and reagents

Sesame seeds and decorticated sesame flour were bought from local shop of B.M. Agarwal, Paddapukur, Bhowanipore, Kolkata, West Bengal [Cultivation area: Nadia district, West Bengal, India (March to May); Temperature: 35 °C to 39 °C, Humidity: 44% to 59%]. RBO was provided by M/S Shethia Oil Mill (Burdwan, West Bengal, India). All of the regents used in our experiments were of analytical grade and were provided by Sigma Aldrich.

Preparation of sesame yogurt (control) from whole sesame seeds

The method established by Quasem et al. (2009) and Almnura and Arabia (2011) was used to describe how to make sesame milk from whole sesame seeds. The desired sesame seed percentage (12% w/w) was achieved by briefly combining sterilized water and decorticated sesame seeds. After that, the mixture was combined for 10 min at the highest speed in a blender (Kenstar MG-9603). The resulting sesame milk was homogenised in a lab homogenizer (Remi Motors-RQ-122) for five minutes at a speed of 500 RPM. Boiling and cheesecloth squeezing were used to remove the coarse particles from the homogenised sesame milk. The resulting milky solution was weighed, corrected to its initial weight (before filtering) by adding water, well blended, and heated (by pasteurization). The freshly made sesame milk was pasteurised for 15 min at 80 °C. A starter culture consisting of 2% of *Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophilus* was aseptically added after it had been chilled to 40 °C. Subsequently, 100-ml sterile, lidded, food-grade, transparent plastic cups containing inoculated sesame milk were filled. The cups were then incubated at 37 °C for 16 h.

Preparation of RBO-fortified sesame yogurtd from DEQSF and supplemented with RBO

The DEQSF was prepared using the procedures below: Full-fat sesame flour was extracted using a tenfold amount of hexane for four hours and centrifuged at 4000 RPM for ten minutes. The supernatant was then collected, the hexane was eliminated by steam distillation, and the was then kept in a refrigerator at four degrees Celsius. Sesame milk was made by soaking the DEQSF (6, 7, and 8% w/v) overnight instead of using commonly processed whole sesame. The soaked flour was combined for 15 min in a blender (Kenstar MG-9603) with six volumes of distilled water before being cooked and chilled. The resulting slurry was run through three layers of cheesecloth for filtration. The leftover liquid was squeezed from fine cheesecloth for one minute after filtering slowed, and the residue was then removed as normal. The resulting sesame milk was then homogenized and pasteurised at 80 °C for 15 min in a homogenizer (Remi Motors-RQ-122). The pasteurised milks were then cooled to 40 °C and given a single addition of (5%) RBO. Once the sesame milk-oil mixture was thoroughly incorporated throughout the sesame milk, it was homogenized once again in a homogenizer (Remi Motors-RQ-122). After preparing RBO incorporated sesame milk using the aforementioned method, 2% of starter (*Lactobacillus delbrueckii subsp. bulgaricus* and *Streptococcus thermophilus*, 2:1 v/v) was aseptically added to the mixture. After that, 100 ml sterile, transparent, food-grade plastic cups with lids were filled with the fortified sesame milk containing RBO and incubated at 37 °C for 24 h. The resulting sesame yogurts were kept in a refrigerator at 4 °C. Three different RBO-fortified sesame yogurts were developed and allocated as.

SESC: Sesame yogurt control from whole sesame seeds without incorporation of RBO.
SES I: RBO incorporated 6% DEQSF-based yogurt
SES II: RBO incorporated 7% DEQSF-based yogurt
SES III: RBO incorporated 8% DEQSF-based yogurt

Proximate composition of sesame yogurts

Using established procedures, triplicate analyses of the protein, moisture, total solids, and ash contents of the control and RBO supplemented sesame yogurts were performed (AOAC 2005). By modifying the procedure, fat was determined using the Bligh and Dyer (1959) approach. The amount of carbohydrates was determined by subtracting 100 from (moisture + crude protein + fat + ash). The Atwater formula was used to calculate energy values, with fat, protein, and carbohydrates contributing 9, 4, and 3.75 kcal g^{-1}, respectively.

Physical properties sesame yogurts

The pH of the yogurt samples was assessed using a pH meter (Hanna Instruments Microprocessor pH Meter pH 211, HANNA Instruments; pH range: -2.00 to 16.00pH). The acid content of yogurt samples was determined using AOAC guidelines (2005). The percentage of syneresis was calculated (Wu et al. 2000). The viscosity of yogurt was assessed by counting the number of rotations (Spindle No. 3 at 20 RPM) it could withstand for five minutes at a constant temperature of 25 °C in a Brookfield Model DV-E viscometer. Centipoise (cP) measurements of viscosity were made in triplicate. A penetrometer (Stanhope-Seta Surrey, England) was used to measure the penetration properties of a cone-form penetration body with an apical angle of 45° and a weight of 72.5 g. At a product temperature of 25 °C, the depth of penetration was measured in 5 s.

Microbiological properties of sesame yogurts

The total number of live organisms present throughout storage allowed for an evaluation of the microbiological qualities of control and RBO-fortified sesame yogurts. Total viable counts were counted using Plate Count Agar (PCA), which was incubated at 37 °C for 24 to 48 h. The spread plate technique was used to count yeast and molds on Potato Dextrose Agar (PDA) using chloramphenicol. The plates were cultured aerobically at 25 °C for 28 days. Utilizing the pour plate technique, *Lactobacillus delbrueckii subsp. bulgaricus* was counted on acidified MRS agar. For 72 h, plates were incubated at 37 °C in a microaerophilic environment. The enumeration of *Streptococcus thermophilus* is done using M17 agar. For 48 h, plates were incubated aerobically at 37 °C. The presence of coliform bacteria was determined using MacConkey agar media. For the enumeration of *E. coli*, yogurt samples were serially diluted, plated on Eosin Methylene Blue (EMB) agar, and incubated at 44.5 °C for 24 h. The selective culture medium Bismuth Sulfite Agar is used to isolate Salmonella spp.

Sensory properties of sesame yogurts on 9-point hedonic scale

Twenty trained panellists from the School of Community Science and Technology, IIEST, Shibpur, were asked to evaluate the control and RBO-fortified sesame yogurts. Basic details about the test's goal and purpose were provided to the panelists. Before each serving, the panellists were instructed to rinse their mouths out with water. A 9-point hedonic scale (where 1 = dislike extremely and 9 = like extremely) was used to ask the panellists to score the yogurt samples for color, flavor, taste, and overall acceptability. On the same scale, the samples' overall acceptability was also graded, with 9 = extremely acceptable and 1 = extremely unacceptable (Ponka et al. 2022).

Antioxidant properties of sesame yogurts

Using 1, 1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity, the antioxidant capability of extracts from control and RBO-supplemented sesame yogurts was examined (Shetty et al. 1995). The ferric reducing antioxidant power (FRAP) assay was used to determine the reducing power of yogurts (Barahona et al. 2011). The ABTS radical scavenging activities of yogurt samples were evaluated using the Re et al. (1999) approach. The oxygen radical absorbance capacity (ORAC) assay had been completed in accordance with the previously mentioned method of Ou et al. (2002). Individual extracts' flavonoid concentrations were calculated using the Dowd method (Formagio et al. 2014).

Proteolytic activity of sesame yogurts

The conventional o-phthaldialdehyde (OPA) method was used to measure the released amino acids and peptides in yogurt samples to gauge the degree of proteolysis (Leclerc et al. 2002).

Microstructure analysis of sesame yogurts

By using a scanning electron microscope (SEM), freeze-dried items were analysed at the microscopic level for the desired structural characteristics. To entirely eliminate moisture, the freeze-dried sample was put in airtight desiccators filled with silica gel. By periodically testing the sample weight until they reached a constant weight, the removal of moisture was verified. The dried yogurt was first secured to an iron stub, and after being coated with a thin layer of gold for 40 s in a vacuum chamber, it was made electrically conductive. The images were captured at various magnifications at 800 × at an excitation voltage of 15 kv.

Nutrition intervention studies

The animal tests were conducted using the recently created control and fortified sesame yogurt with RBO. The diets were made in accordance with Reeves et al. (1993) of the American Institute of Nutrition (AIN); however, some adjustments were made in relation to the source and content of lipids and carbohydrates in accordance with the norm AIN-93G. The diets consisted of different ingredients were given in the Table 1.

Animals and feeding

Male Balb/c mice (Mus musculus) aged six weeks and weighing 20–25 g were used in the feeding experiment to assess the nutritional value of the control sesame yogurt and enriched varieties. Individual mice were housed in cages with a 12:12 h light–dark cycle at 21.2 °C and a humidity level of 65–75%. Prior to the feeding studies, all the mice were metabolically stabilised after a week of acclimatisation to the AIN93-G diet. The mice were separated into six groups of six, with no discernible differences between any of the groups in terms of starting body weight or serum total cholesterol levels. Throughout the entire feeding period,

Table 1 Composition of six tested experimental diets received by Balb/c mice groups in this study, according to the standard AIN-93G diet

Ingredients (g/100 g)	Group I	Group II	Group III	Group IV/V/VI
Casein	20.0	20.0	13.0	13.0
Corn starch	39.8	38.8	37.3	37.3
Dextrinized corn starch	13.2	12.9	12.9	12.9
L–cystine	0.3	0.3	0.3	0.3
Sucrose	9.5	9.5	9.5	9.5
Soy bean oil	7.0	7.0	7.0	7.0
Cellulose	5.0	5.0	5.0	5.0
Vitamin mix	1.0	1.0	1.0	1.0
Minerals mix	3.5	3.5	3.5	3.5
Cholesterol	0.00	1.25	1.25	1.25
Choline bi tartarate	0.25	0.25	0.25	0.25
Cholic acid	0.00	0.5	0.5	0.5
Sesame yogurt	0.00	0.00	8.5 (SES C)	8.5 (SES I/SES II/SES III)
Total	100	100	100	100
Energy (Kcal/ 100 g)	372.2	368.5	371.15	371.63

only the AIN93-G diet was given to the placebo group (Group I). The oral administration of 1.25% cholesterol and 0.5% cholic acid in the AIN93-G diet for four weeks caused hypercholesterolemia in the remaining mice. Based on blood cholesterol levels of 200 mg/dl at the end of the first four weeks, all hypercholesterolemic mice were randomly assigned to five dietary regimens for five weeks. Mice in Group II (the negative control group) were given the AIN93-G diet containing 1.25% cholesterol and 0.5% cholic acid, while mice in Group III were given control sesame yogurt (SESC) in addition to the AIN93-G diet, 1.25% cholesterol, and 0.5% cholic acid (positive control group). In addition to the fortified sesame yogurt with RBO integrated in the amounts of 6%, 7%, and 8%-DEQSF based yogurt, the mice in Groups IV, V, and VI were also given the AIN93-G diet, 1.25% cholesterol, and 0.5% cholic acid. 8.5% sesame yogurt was added as a supplement to a high-cholesterol diet (control and fortified). The details of the groups and the composition of the experimental diets are provided in Table 1. Throughout the experiment, all mice with the exception of Group I were fed cholesterol. These diets provided a similar amount of dietary fibre, protein, fat, and carbohydrates. The diets were therefore designed to be isocaloric. Mice in different groups were designated as follows:

Group I: Normal regular diet (placebo group)
Group II: Hypercholesterolemic mice fed high cholesterol diet (Negative Control)
Group III: Hypercholesterolemic mice fed high cholesterol diet and SESC (Positive Control)
Group IV: Hypercholesterolemic mice fed high cholesterol diet and SES I
Group V: Hypercholesterolemic mice fed high cholesterol diet and SES II
Group VI: Hypercholesterolemic mice fed high cholesterol diet and SES III

During the 5-week experimental feeding period, mice had free access to the diet and water. The amount of food consumed by each mouse was determined by deducting the wasted and spilled food from the total amount of food offered each day. Spilled food was collected during the experiment, and each mouse's daily caloric intake was evaluated to ascertain the effects of the specific experimental diet. Deionized water was administered using graduated water bottles. All of the research was given the go-ahead by the Institutional Animal Ethics Committee (IAEC-1394/2019–2020/SS/01; dated 20.12.2019) of the West Bengal State University, Barasat.

Body weight and food intake of mice fed different experimental diets

Following the feeding procedure, all of the mice seemed to be in good health, and there was no sign of toxicity. According to Chapman et al. (1950), feeding and growth performance were tracked by noting initial body weight, end body weight, feed consumption, and body weight gain.

Sampling procedure

Blood samples were taken from the mice's tail veins at the end of the five-week experiment. After allowing the blood to stand for at least 30 min at room temperature, the serum was separated by centrifugation at 3500 g for 15 min and then kept at 80 °C until analysis.

Biochemical analyses of serum of mice fed different experimental diets

Using reagent kits acquired from Mediclone Biotech Pvt., Ltd., serum glucose (measured during fasting) was calculated in accordance with Trinder's (1969) technique. Serum triglycerides (TG), serum high-density lipoprotein cholesterol (HDL-C), and serum total cholesterol (TC) were measured using the methods described by Allian et al. (1974), Fossati and Prencipe (1982), and Burstein et al. (1970), respectively. Friedewald's equation (Friedewald et al. 1972) was used to compute serum low-density lipoprotein cholesterol (LDL-C), while the Norbert formula was used to calculate serum very low density lipoprotein (VLDL) (Norbert 1995).

Statistical analysis

GraphPad Prism 5.0 was used to conduct the statistical analysis of the data (GraphPad Software, Inc., San Diego, CA) gathered from the many tests conducted throughout this investigation. The data were presented in the form of replicate means and standard deviations (SD). Using one-way ANOVA, the statistical difference test (analysis of variance) was run. Differences were considered significant at $p \leq 0.05$.

Result and discussion

Proximate compositions of sesame yogurt

Table 2 displays the approximate composition of control (SESC) and RBO-fortified sesame yogurts (SES I, SES II, and SES III) prepared from DEQSF. The SESC, SES I, SES II, and SES III all had moisture contents that ranged from 86.04 ± 0.52 to 88.91 ± 0.26%. This was dependent on the proportion of DEQSF used. SESC had the highest moisture value (86.04 ± 0.52%) compared to the other yogurts. The sesame yogurt samples' moisture levels were within the typical range for commercial yogurts (80–89%). The highest level of protein content was noted in SES III (3.29 ± 0.49; $p \leq 0.05$) followed by SES II (2.88 ± 0.54; $p \leq 0.05$) and SES I (2.46 ± 0.29; $p \leq 0.05$) in comparison with SESC (3.01 ± 0.05). The fat content was highest in SESC (6.29 ± 0.08%) followed by SES III (5.07 ± 0.48 $p \leq 0.05$), SES II (5.06 ± 0.49 $p \leq 0.05$) and SES I (5.04 ± 0.48 $p \leq 0.05$). The SES I, SES II, and SES III had fat contents that were higher than the threshold for low-fat yogurts (3.5). Ash content was found to be greatest in SES III (0.69 ± 0.35) in comparison with SESC (0.57 ± 0.01). With the addition of DEQSF, the RBO-fortified sesame yogurts' carbohydrate content rose from 6% in SES I to 8% in SES III. This was derivable from DEQSF which is known to be rich in carbohydrates. The energy value of SES III was significantly higher (74.47 ± 0.62; $p \leq 0.05$) followed by SES II (70.78 ± 0.71; $p \leq 0.05$) and SES I (66.96 ± 0.29; $p \leq 0.05$) when compared to SESC (85.01 ± 0.04). Therefore, RBO-fortified sesame yogurts made from DEQSF were said to be low-calorie. Further, these low-fat contents may help to prepare low-fat food formulations. R and Mary (2022) and Afaneh et al. (2011) developed sesame yogurt. Our findings showed that RBO-fortified sesame yogurts are in close agreement with these values. Many researchers had successfully used to generate beneficial food products other than yogurt. Recently, Gojiya et al. (2022) demonstrated that might be used successfully in the development of protein-rich corn-based extrudates, which had a relatively greater protein content than the control. According to research by Prakash et al. (2018), adding DEQSF to biscuits enhanced their protein, fat, crude fibre, and mineral

Table 2 Proximate compositions of sesame yogurts

Proximate Constituent Compositions (%w/w)	SESC	SES I	SES II	SES III
Moisture	86.04 ± 0.52[c]	88.91 ± 0.26[a]	87.95 ± 0.24[a]	87.03 ± 0.18[a]
Protein	3.01 ± 0.05[c]	2.46 ± 0.29[a]	2.88 ± 0.54[a]	3.29 ± 0.49[a]
Fat	6.29 ± 0.08[c]	5.04 ± 0.48[a]	5.06 ± 0.49[a]	5.07 ± 0.48[b]
Ash	0.57 ± 0.01[c]	0.65 ± 0.65[a]	0.68 ± 0.59[a]	0.69 ± 0.35[b]
Total Solids	13.96 ± 0.02[c]	11.09 ± 0.29[a]	12.05 ± 0.29[b]	12.97 ± 0.19[a]
Carbohydrate	4.09 ± 0.01[b]	2.94 ± 0.67[a]	3.43 ± 0.47[a]	3.92 ± 0.37[a]
Gross Energy (Kcal.100 g^{-1})	85.01 ± 0.04[a]	66.96 ± 0.29[b]	70.78 ± 0.71[c]	74.47 ± 0.62[c]

Results are expressed as mean ± SD ($n = 3$)

SESC Sesame yogurt control, *SES I* RBO incorporated 6% DEQSF-based yogurt, *SES II* RBO incorporated 7% DEQSF-based yogurt, *SES III* RBO incorporated 8% DEQSF-based yogurt

[a,b,c] Mean Values having different superscript letter in rows are significantly different ($p \leq 0.05$)

content while lowering their carbohydrate content. In a similar manner, DEQSF increased the nutritional value of yogurt in our study. According to these findings, and RBO were intriguing additives to yogurt fortification from a nutritional standpoint because they raised the protein and carbohydrate content while lowering the fat content. According to the results of the proximate composition study, all of the RBO-fortified sesame yogurt displayed higher nutritional quality than the control sesame yogurt (Martinez et al. 2021).

Physical properties of sesame yogurts

The physical properties of control and RBO incorporated sesame yogurt made from DEQSF were shown in Table 3. All yogurts had initial pH readings ranging from 3.82 to 4.53, but significant differences were observed in pH of SES I (4.23 ± 0.05), SES II (4.16 ± 0.03) and SES III (3.82 ± 0.05) and TTA of SES I (1.14 ± 0.01), SES II (1.16 0.03), and SES III (1.24 ± 0.05) in comparison with SESC. Over the course of 28 days in storage, the pH of SESC dropped linearly. The TTA for the SES I, SES II, and SES III was higher than the SESC at all times during the storage condition. The highest rate of TTA production was seen in SES III (1.32 ± 0.10%; $p \leq 0.05$) followed by SES II (1.30 ± 0.05%; $p \leq 0.05$), SES I (1.19 ± 0.06) and SESC (1.05 ± 0.01) during 28 days of storage. Shaker et al. (2000) examined the rheological characteristics of yogurt at four levels of fat content during fermentation and came to the conclusion that increasing fat reduced the starter cultures' ability to produce acid. Accordingly, differences in microbial population during fermentation could be linked to variations in titratable acidity that occur in yogurts in the current investigation (Eissa et al. 2010). The percentage of syneresis in each yogurt increased as storage time progressed, more rapidly for the SESC (24.26 ± 0.25) followed by SES I (20.44 ± 0.21; $p \leq 0.05$), SES II (19.15 ± 0.26; $p \leq 0.05$) and SES III (18.49 ± 0.16; $p \leq 0.05$). It had been determined that the interaction between raffinose and stachyose, the two major carbohydrates in DEQSF, was what caused the increase in syneresis level during storage. These findings were crucial for the non-dairy sectors since they showed that the addition of raffinose, stachyose, planteose, and sesamose did not alter the textural properties of yogurts, as shown by the syneresis values (Lu et al. 2021). SES III had the highest viscosity (880.34 ± 15.56; $p \leq 0.05$) followed by SES II (875.95 ± 29.05; $p \leq 0.05$), SES I (871.47 ± 10.26; $p \leq 0.05$) whereas viscosity value of SESC

Table 3 Physical properties of sesame yogurts during storage for 28 days at 4 °C in a refrigerator

Sample Code	Day	pH	TTA(%)	PS(%)	Brookfield Viscosity in Centipoises at 25 °C	Penetration at 25 °C (1/10th mm)
SESC	0	4.56 ± 0.02^a	0.98 ± 0.05^d	24.26 ± 0.25^a	860.36 ± 24.30^d	430.41 ± 12.26^d
	7	4.52 ± 0.03^a	0.99 ± 0.06^d	25.39 ± 0.29^a	858.26 ± 12.25^d	435.67 ± 16.58^d
	14	4.48 ± 0.05^a	1.02 ± 0.03^d	26.59 ± 0.56^a	857.14 ± 19.28^d	439.54 ± .16.36^d
	21	4.44 ± 0.09^a	1.03 ± 0.04^d	27.22 ± 0.59^a	850.36 ± 37.28^d	441.39 ± 15.74^d
	28	4.40 ± 0.07^a	1.05 ± 0.01^d	27.99 ± 0.58^a	848.96 ± 27.88^d	440.17 ± 18.49^d
SES I	0	4.23 ± 0.05^b	1.14 ± 0.01^d	20.44 ± 0.21^b	871.47 ± 10.26^c	450.39 ± 18.39^c
	7	4.13 ± 0.05^b	1.35 ± 0.02^c	20.59 ± 0.38^b	872.17 ± 22.58^c	455.32 ± 16.29^c
	14	4.12 ± 0.03^b	1.36 ± 0.05^c	20.66 ± 0.96^b	869.64 ± 23.11^c	457.26 ± 19.06^c
	21	4.09 ± 0.03^b	1.45 ± 0.05^c	21.48 ± 0.10^b	868.36 ± 18.57^c	458.69 ± 18.04^c
	28	4.05 ± 0.03^b	1.19 ± 0.06^c	22.58 ± 0.58^b	866.40 ± 22.87^c	462.78 ± 11.54^c
SES II	0	4.16 ± 0.03^c	1.16 ± 0.03^c	19.15 ± 0.26^c	875.95 ± 29.05^b	443.69 ± 13.45^b
	7	4.13 ± 0.03^c	1.19 ± 0.05^c	19.35 ± 0.29^c	876.74 ± 28.47^b	451.47 ± 11.06^b
	14	4.02 ± 0.09^c	1.22 ± 0.06^c	19.46 ± 0.49^c	871.65 ± 39.24^b	454.36 ± 12.25^b
	21	3.99 ± 0.05^c	1.29 ± 0.08^b	20.12 ± 0.59^c	870.25 ± 23.21^b	455.15 ± 16.05^b
	28	3.89 ± 0.06^c	1.30 ± 0.05^b	20.16 ± 0.36^c	868.14 ± 11.29^b	457.47 ± 18.00^b
SES III	0	3.82 ± 0.02^d	1.24 ± 0.05^a	18.49 ± 0.16^d	880.34 ± 15.56^a	442.25 ± 11.27^a
	7	3.82 ± 0.05^d	1.26 ± 0.03^a	18.89 ± 0.69^d	884.25 ± 25.64^a	443.47 ± 15.62^a
	14	3.81 ± 0.03^d	1.29 ± 0.06^a	19.21 ± 0.26^d	879.74 ± 29.26^a	444.36 ± 19.42^a
	21	3.75 ± 0.06^d	1.31 ± 0.05^a	19.45 ± 0.56^d	875.48 ± 25.25^a	447.14 ± 13.95^a
	28	3.70 ± 0.05^d	1.32 ± 0.10^a	19.85 ± 8.63^d	874.07 ± 27.19^a	450.11 ± 12.43^a

Results are expressed as mean ± SD ($n = 3$)

SESC Sesame yogurt control, *SES I* RBO incorporated 6% DEQSF-based yogurt, *SES II* RBO incorporated 7% DEQSF-based yogurt, *SES III* RBO incorporated 8% DEQSF-based yogurt

[a,b,c,d] Mean Values having different superscript letter in columns are significantly different ($p \leq 0.05$)

was 860.36 ± 24.30 on 0 day. According to Barrantes et al. (1996), the oil content of the yogurt bases was similar at 5%; hence the variations in viscosity were most likely caused by the quantity of DEQSF utilized. While the viscosity of the RBO-fortified sesame yogurt dropped after day 7, it increased up until that point in time for the control yogurt. Sahan et al. (2008) claimed that protein rearrangements and protein–protein interactions can cause viscosity to rise over time. Lee et al. (2007) and Supavititpatana et al. (2010) found that yogurt viscosity reduces throughout storage time. During storage, the penetration value of each yogurt increased. The penetration value of SES III had the lowest (442.25 ± 11.27; $p \leq 0.05$) followed by SES II (443.69 ± 13.45; $p \leq 0.05$), SES I (450.39 ± 18.39; $p \leq 0.05$) whereas the penetration value of SESC was 430.41 ± 12.26 (Table 3). Information about the sesame yogurts was further complemented by measurements of the penetration property and percentage of syneresis. Both measurements revealed sizable alterations that occurred during storage and distinguished the SES III from the others. The higher protein content in the DEQSF is most likely what caused the SES III to become harder. The yogurts made with vegetable oil, on the other hand, likewise had acceptable rheological characteristics. According to Tamime et al. (1991), the protein matrix structure of the gel and the association or embedding of the vegetable oils in the protein micelle chains and clusters could also be responsible for the differences in the penetration property and percentage of syneresis of these novel yogurts made from DEQSF.

Microbiological properties of sesame yogurts

Table 4 displays the microbiological composition of the analyzed RBO-fortified sesame yogurts and control yogurts. There was no distinct trend in the total microbiological counts (TPC) values with respect to the yogurts. With 8% enrichment, SES III had the highest total plate count (3.1×10^6log cfu.ml^{-1}) followed by SES II (2.5×10^6 log cfu.ml^{-1}), SES I (2.2×10^6 log cfu.ml^{-1}) whereas the total plate count of SESC was 2.8×10^6 log cfu.ml^{-1}. The yogurt's microbiological status met acceptable standards. Because of the hygienic practises used during production, the absence of coliform bacteria, yeast, and mould indicated that RBO-fortified sesame yogurt were free of faecal contamination. The *Lactobacilli spp.* and *Streptococcus spp.* bacteria were less prevalent in SESC (15.29×10^6 log cfu.ml^{-1} for *Lactobacilli spp. and* 7.01×10^6 log cfu.ml^{-1} for *Streptococcus spp.*) than in SES I, SES II, and SES III. The high *Lactobacilli spp.* count in the RBO-fortified sesame yogurts made from edible-quality DEQSF was suggestive of their viability with DEQSF. The result showed that the addition of RBO and sesame flour enhanced microbial growth. This is because sesame flour contains more protein than other flours. The *Lactobacillus spp.* and *Streptococcus spp.* utilise the protein for their growth, which increases their number. The behaviour of RBO-fortified sesame yogurts' lactic acid fermentation was noticed in this study, and it is compatible with other vegetable milks' behavior. According to Sengupta et al. (2018b), using DAG-enriched edible oils and edible deoiled soy flour made it simple to formulate a product with the same nutritional and organoleptic properties as real yogurt. They also discovered that soy yogurt's microbiological qualities were enhanced by the addition of RBO-DAG-enriched edible oil.

Sensory properties of sesame yogurts

Table 5 displays the average sensory ratings for the organoleptic evaluation and acceptance for the SESC, SES I, SES II, and SES III. The statistical analysis showed that there were notable changes in the sensory characteristics between the yogurt samples. SES III had the highest color score (8.12 ± 0.05; $p \leq 0.05$), while SES I had the lowest color score (7.56 ± 0.03; $p \leq 0.05$). Color appeal had an impact on appearance; the panellists preferred SES III's brighter shade with 8% DEQSF. Better flavour and aroma ratings came as a result of making yogurt using DEQSF. SES III had the highest scores of 8.19 ± 0.09; $p \leq 0.05$ and 8.52 ± 0.09; $p \leq 0.05$ for both taste and aroma, while SESC

Table 4 Microbiological properties of sesame yogurts on 0 day at 4 °C in a refrigerator

Sample Code	TPC (log cfu.ml^{-1})	Yeast & Mold (log cfu.ml^{-1})	Streptococcus spp. (log cfu.ml^{-1})	Lactobacillus spp. (log cfu.ml^{-1})
SESC	2.8×10^6	0.00	7.01×10^6	15.29×10^6
SES I	2.2×10^6	0.00	8.19×10^6	16.22×10^6
SES II	2.5×10^6	0.00	8.55×10^6	17.59×10^6
SES III	3.1×10^6	0.00	8.62×10^6	18.24×10^6

Results are expressed as mean ($n = 3$)

SESC Sesame yogurt control, *SES I* RBO incorporated 6% DEQSF-based yogurt, *SES II* RBO incorporated 7% DEQSF-based yogurt, *SES III* RBO incorporated 8% DEQSF-based yogurt

Table 5 Sensory evaluations of sesame yogurts on 0 days at 4 °C in a refrigerator

Sample Code	Colour	Taste	Aroma	Overall Acceptability
SESC	7.59 ± 0.05[d]	7.29 ± 0.12[d]	8.25 ± 0.04[d]	7.65 ± 0.06[d]
SES I	7.56 ± 0.03[c]	7.42 ± 0.05[c]	8.46 ± 0.09[c]	7.77 ± 0.06[c]
SES II	7.65 ± 0.06[b]	7.46 ± 0.06[b]	8.49 ± 0.06[b]	7.80 ± 0.05[b]
SES III	8.12 ± 0.05[a]	8.19 ± 0.09[a]	8.52 ± 0.09[a]	8.32 ± 0.07[a]

Results are expressed as mean ± SD ($n = 3$)

SESC Sesame yogurt control, *SES I* RBO incorporated 6% DEQSF-based yogurt, *SES II* RBO incorporated 7% DEQSF-based yogurt, *SES III* RBO incorporated 8% DEQSF-based yogurt

[a,b,c,d] Mean Values having different superscript letter in columns are significantly different ($p \leq 0.05$)

had the lowest scores of 7.29 ± 0.12 and 7.29 ± 0.12 for taste and aroma, respectively. Among all yogurts, SES III with 8% DEQSF had the highest overall acceptability rating of 8.32 0.07; p 0.05. According to studies by R and Mary (2022) and Afaneh et al. (2011), phase separation in sesame yogurt with additional dry cheese whey is caused by sesame solids. However, the overall acceptability of their sesame yogurt drink had not been reduced. No phase separation was detected in RBO-fortified sesame yogurt in this study, and the DEQSF with RBO used appeared to be sufficient to generate the desired texture of the RBO-fortified sesame yogurt with a higher overall acceptability than control yogurt. Researchers had developed non-dairy yogurt, which was primarily made from soy bean seeds (Sengupta & Bhowal 2017b, 2017c; Sengupta et al. 2017; Sengupta et al. 2013). The sensory scores of their non-dairy yogurt were almost identical to our results. Therefore, it could be said that this RBO incorporating sesame yogurt also has non-dairy yogurt like sensory properties.

Antioxidant properties of sesame yogurts

Figure 1 depicts the antioxidant properties of the analyzed RBO-fortified sesame yogurt and control yogurt. The highest total polyphenol content (16.28 ± 0.852; $p \leq 0.05$) was found in SES III, and the lowest polyphenol content (8.99 ± 0.21; $p \leq 0.05$) was found in SESC on day 0. The antioxidant activity values of all control and RBO-fortified sesame yogurts declined during the refrigerated period, but remained at their highest in SES III. A positive association between the concentrations of DEQSF and TPC was observed. The addition of edible quality DEQSF significantly increased the TPC of the yogurt because edible quality DEQSF contained abundant polyphenols (Mekky, Abdel-Sattar Segura-Carretero and Contreras 2019). Additionally, the starter culture's activities as well as the temperature and timing of the fermentation might have aggravated this issue.

DPPH radical scavenging activities of SES I (25.64 ± 1.45; $p \leq 0.05$), SES II (28.64 ± 1.65; $p \leq 0.05$) and SES III (30.64 ± 0.65; $p \leq 0.05$) were higher in comparison with SESC (18.54 ± 0.95; $p \leq 0.05$) on 0 day. After 28 days of refrigerated storage, DPPH radical scavenging activities decreased in RBO-fortified yogurt. This was in line with the findings of our earlier work, which revealed that non-dairy yogurt with RBO added has decreased DPPH radical scavenging activity after 28 days of storage (Sengupta et al. 2016).

The highest FRAP value was found in SES III (25.64 ± 1.45; $p \leq 0.05$) followed by SES II (22.64 ± 0.36; $p \leq 0.05$) and SES I (18.54 ± 0.98; $p \leq 0.05$), in comparison with SESC (12.69 ± 1.12; $p \leq 0.05$) at the 0 day. The higher antioxidant activity in RBO-fortified yogurt might result from the phytochemical content of the DEQSF, rice bran oil, and microbial metabolic activity.

The result of ABTS + radical scavenging activity in SES I (265.84 ± 11.25; $p \leq 0.05$), SES II (270.12 ± 23.65; $p \leq 0.05$) and SES III (289.67 ± 11.65; $p \leq 0.05$) was higher in comparison with SESC (255.64 ± 1.15; $p \leq 0.05$) on 0 day. According to a recent publication by Sengupta et al. (2019a, 2019b), the peptides in soy yogurt were likely what caused the increase in antioxidant activity. Both in the free and microencapsulated systems in the yogurt matrix, the peptides' activity was maintained. These results were consistent with those published by Alfaro et al. (2015), who discovered that adding purple rice bran oil to frozen yogurt increased its antioxidant activity. The scientists claim that this was caused by the addition of phytochemicals with antioxidant activity to the mix. Similar to the previous study, in terms of storage period, there were notable variations in antioxidant activity.

The results of total flavonoid in SES I (30.15 ± 1.64; $p \leq 0.05$), SES II (32.46 ± 0.94; $p \leq 0.05$) and SES III (38.45 ± 1.15; $p \leq 0.05$) were higher in comparison with SESC (22.19 ± 0.50; $p \leq 0.05$) on 0 day. In both the control and RBO-fortified sesame yogurts, the flavonoid content displayed a trend resembling that of the total phenolic content. This might be due to the higher total flavonoid content in the rice bran oil and the DEQSF used in the RBO-fortified sesame yogurt.

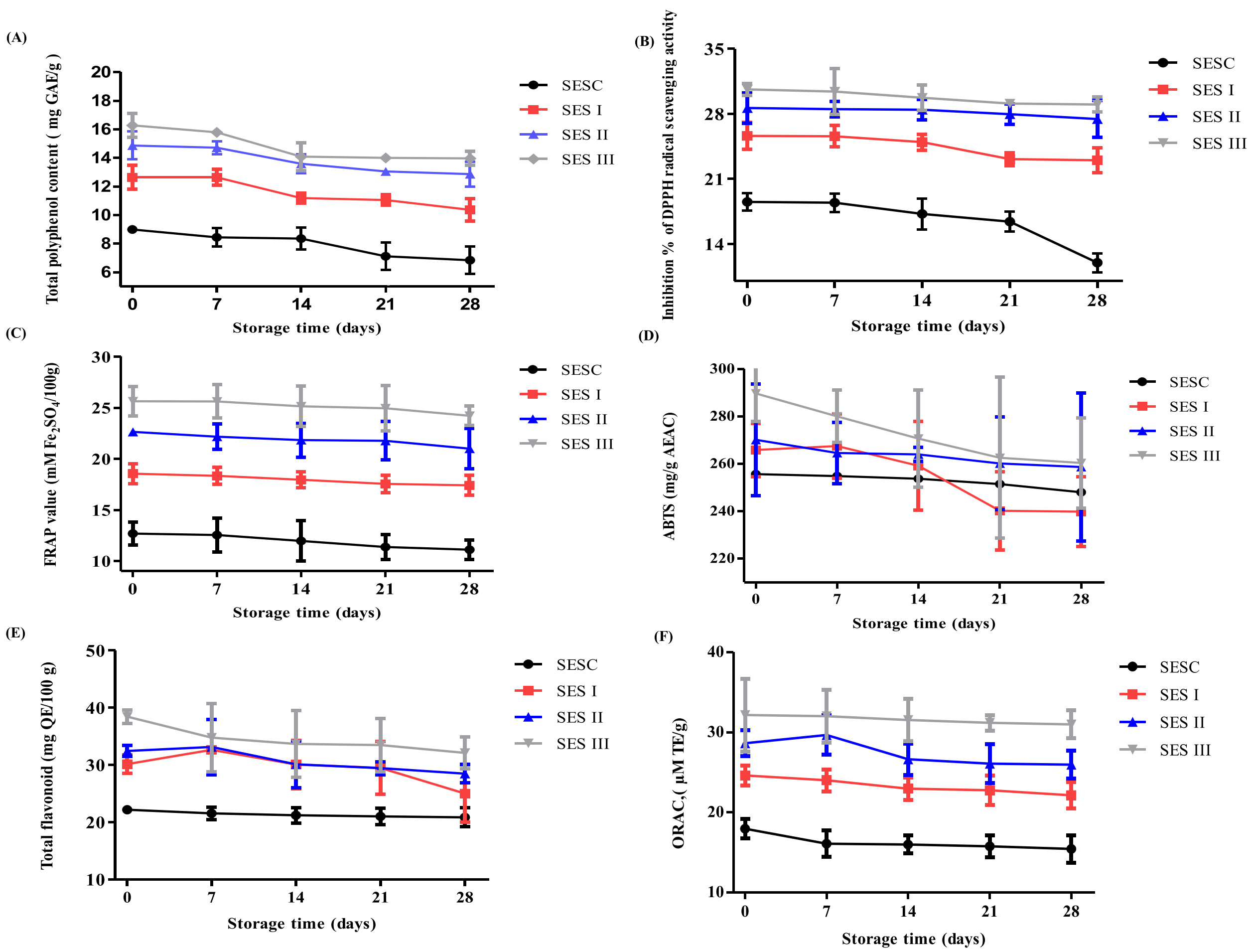


Fig. 1 Changes in antioxidant activity [TPC (**A**), Inhibition % of DPPH (**B**), FRAP (**C**), ABTS radical scavenging activities (**D**), ORAC (**E**) and Flavonoids (**F**)] of sesame yogurts at 4 °C during storage period of 28 days. SESC: sesame yogurt control; SES I: RBO incorporated 6% DEQSF-based yogurt, SES II: RBO incorporated 7% DEQSF-based yogurt, SES III: RBO incorporated 8% DEQSF-based yogurt; The data are presented as mean ± SD. and alphabets show the pairwise comparison of groups (bars with different letters statistically differ from one another, $p < 0.05$)

The highest ORAC value was found in SES III (32.15 ± 4.54; $p \leq 0.05$) followed by SES II (28.64 ± 1.64; $p \leq 0.05$) and SES I (24.61 ± 1.25; $p \leq 0.05$), in comparison with SESC (17.95 ± 1.210; $p \leq 0.05$) at the 0 day. The higher antioxidant activity in RBO-fortified yogurt might result from the phytochemical content of the DEQSF, rice bran oil, and microbial metabolic activity. Since RBO-fortified yogurt has a high antioxidant content, a high ORAC value indicated better activity against free radicals and a resultant decreased in reactive oxygen species (ROS). ORAC assays were helpful in finding phytochemicals with high antioxidant activity, such as phenolic acids, alkaloids, tannins, saponins, steroids, and sesame yogurt's terpenoids.

Proteolytic properties of sesame yogurts

The o-phthaldialdehyde (OPA) reaction was used to measure the amino groups produced during milk fermentation to determine the proteolytic activity of control and RBO-fortified sesame yogurt. The results revealed that the RBO-fortified sesame yogurt significantly increased proteolysis compared to the control yogurt (Fig. 2). As expected from the peptidic percentage, this difference was mirrored in stronger antioxidant activity. During storage, proteolysis rose considerably ($P < 0.05$). However, there was no appreciable difference in the levels of proteolytic activity between the control and RBO-fortified sesame yogurts ($P > 0.05$). Similar observations were reported in previous studies that showed the inclusion of soybean, sunflower, rice bran, mustard, and sesame oils

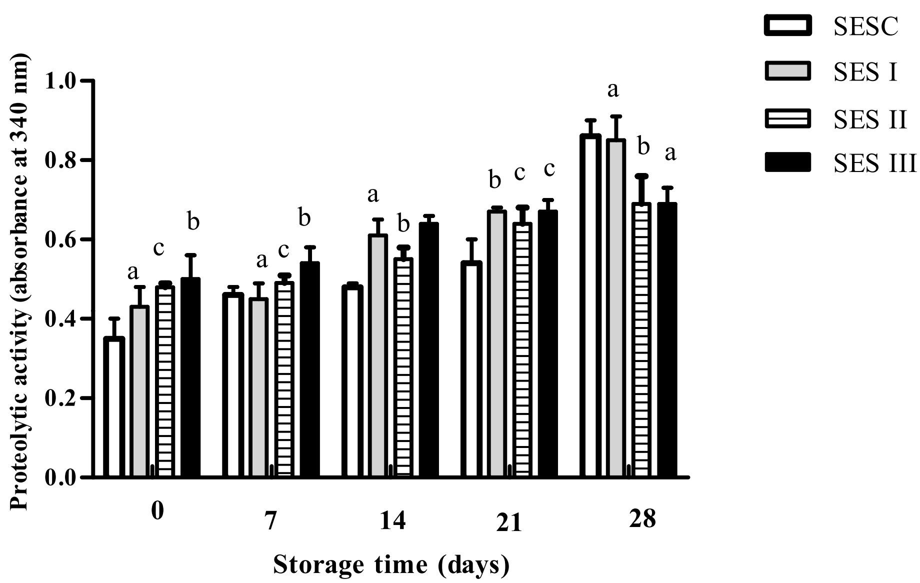


Fig. 2 Changes in OPA values (mg/g) of sesame yogurts at 4 °C during storage period of 28 days. SESC: sesame yogurt control; SES I: RBO incorporated 6% DEQSF-based yogurt, SES II: RBO incorporated 7% DEQSF-based yogurt, SES III: RBO incorporated 8% DEQSF-based yogurt; The data are presented as mean ± SD. and alphabets show the pairwise comparison of groups (bars with different letters statistically differ from one another, $p < 0.05$)

increased ($p < 0.05$) proteolytic activity of lactic acid bacteria in soy yogurt (Sengupta et al. 2018b).

Microstructure analysis of sesame yogurts

Figure 3 displays SEM micrographs of control and RBO-RBO-fortified sesame yogurts. The SEM demonstrated the adding effects of varying percentages of DEQSF and RBO on sesame yogurt microstructure. In SES I, SES III, and SES III, the gel was found to have very small pore diameters and to change its structure with a tiny filament. Furthermore, the gel in SES I, SES III, and SES III containing RBO appeared to be robust and bonded and to be composed of typical long protein filaments. The SESC samples, on the other hand, displayed an isolated, disorganized gel with plenty of big pores and gaps. The SESC gel appeared twisted in shape and included minute proteinaceous filaments. The size of the pores in the SESC microstructure varied. A fine filament and microstructure were given by the inclusion of RBO and DEQSF, which also contributed a number of extremely small pores. DEQSF increased the smoothness, creaminess, texture, and microstructure of the final product. Sengupta and Bhowal (2017a) and Sengupta et al. (2018b) discovered that combining soy yogurt with deoiled soy flour and rice bran oil caused the body to alter and produce a thin gel with extremely few holes. These findings supported the hypothesis that non-dairy yogurt produced by adding vegetable oil causes structural alterations, with a fine gel having relatively few pores in comparison to the control yogurt.

Body weight, food intake, blood serum lipid profile and liver weight of mice fed different experimental diets

The feeding of a high-cholesterol diet increased the total body weight of the mice in Group II to Group VI compared with Group I (39.15 ± 12.85; $p \le 0.05$) at week four of the intervention (Fig. 4). Mice in Group VI supplemented with 8% DEQSF-based yogurt made from RBO (SES III) had 27.38% less body weight than mice in Group II ($P < 0.05$). The current finding, which was in accordance with earlier studies, showed that RBO supplementation with 8% DEQSF-based yogurt in group VI protected against diet-induced obesity, with mice's total body weight being comparable to mice receiving a placebo. Moreover, the findings showed that hypercholesterolemic mice (Groups II, III, IV, V, and VI) consumed considerably less food per day than placebo animals (Group I).

In comparison to group II and group III, group IV, group V, and group VI experienced substantial ($p \le 0.05$) reductions in triglyceride (TG), total cholesterol (TC), and LDL-Cholesterol levels after receiving 6, 7, and 8% DEQSF-based yogurt prepared from RBO, respectively, for 4 weeks (Figs. 4). In comparison to groups II and III, high-density lipoprotein-cholesterol levels were considerably higher ($p \le 0.05$) in the IV, V,

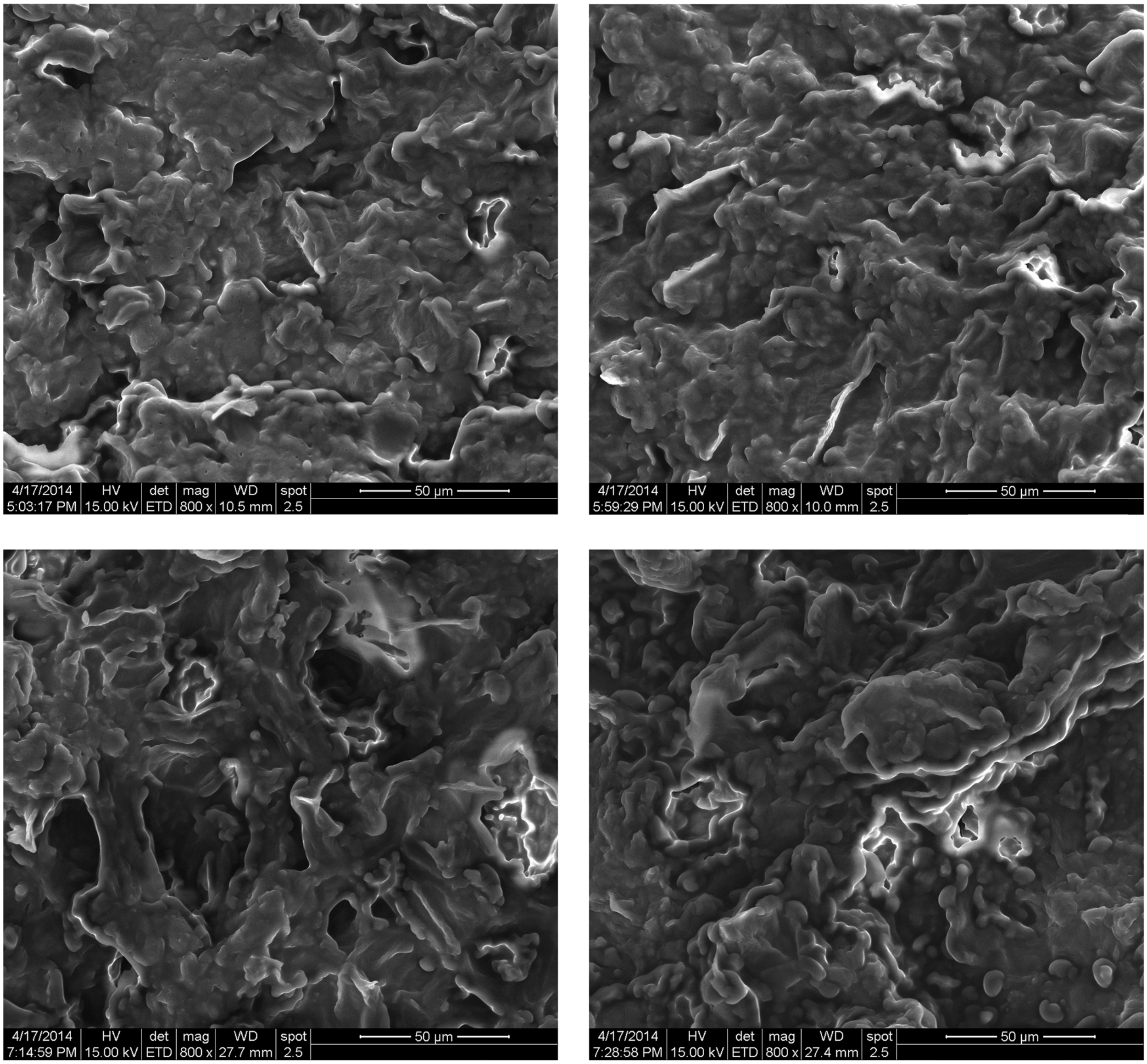


Fig. 3 Microstructure analysis of sesame yogurts. SESC: sesame yogurt control; SES I: RBO incorporated 6% DEQSF-based yogurt, SES II: RBO incorporated 7% DEQSF-based yogurt, SES III: RBO incorporated 8% DEQSF-based yogurt

and VI groups. Additionally, it was found that yogurt made from RBO DEQSF had a substantial potential ($p \leq 0.05$) to control the serum levels of VLDL-cholesterol in the V and VI groups. In the hypercholesterolemic group (II to VI group), the weight of the liver dramatically increased. Yogurt made with DEQSF and supplemented with RBO, however, prevented this increase in organ weight. The groups VI and IV of mice receiving fortified sesame yogurt were the most and least successful in lowering body fat levels and enhancing lipid profiles, respectively.

The effect of RBO-supplemented deoiled soy flour-based yogurt on lipid homeostasis was recently reported by Sengupta et al. (2016). They claimed that the enriched yogurt considerably improved the TC, LDL, VLDL, HDL, and triglyceride lipid profiles. According to the findings, RBO-fortified soy yogurt dramatically reduced TC, LDL, VLDL, and triglyceride levels while raising HDL. They stated that the antioxidant properties of RBO and deoiled soy flour contribute to its hepatoprotective action. Sengupta et al. (2019a, 2019b) reported on the hepatoprotective and hypolipidemic effects of soy yogurt

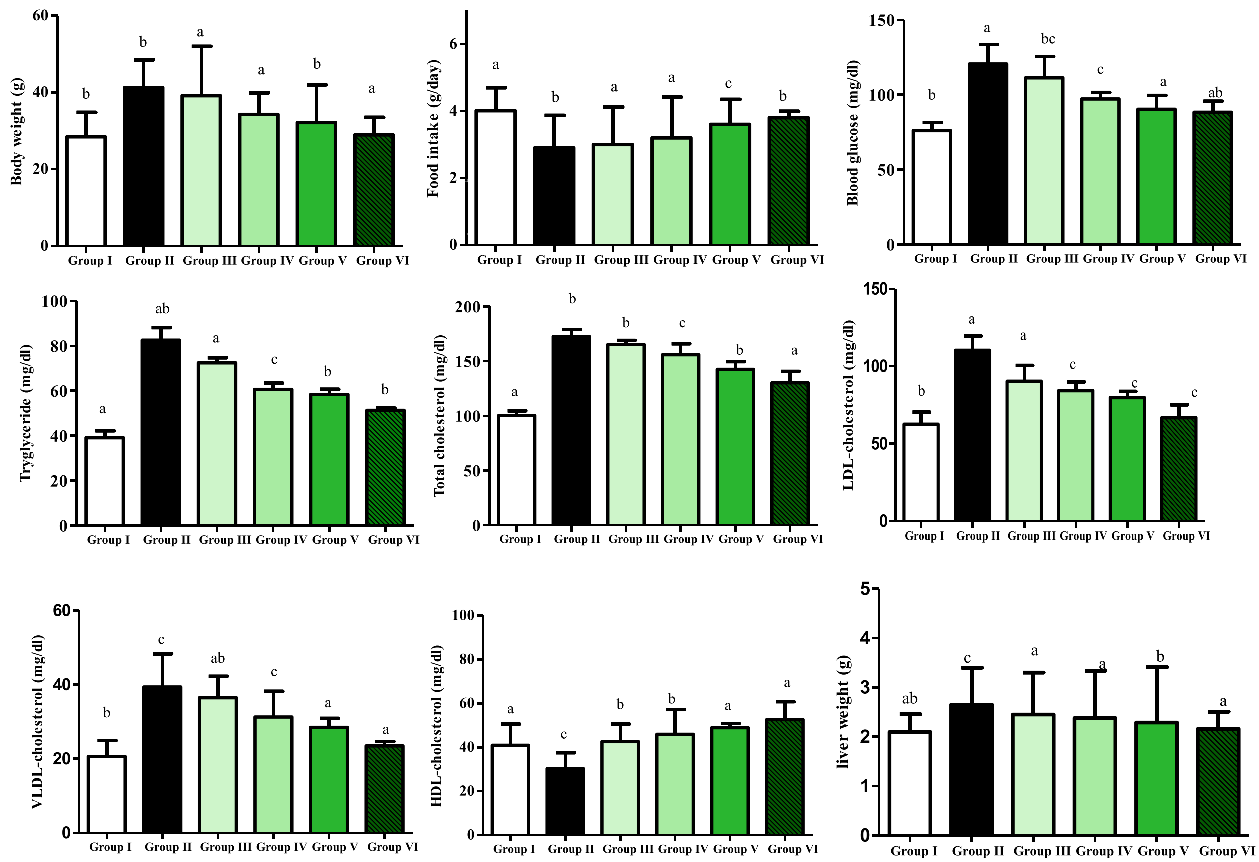


Fig. 4 Body weight, food intake, blood serum lipid profile and liver weight of mice fed different experimental diets. The data are presented as mean ± SD. and alphabets show the pairwise comparison of groups (bars with different letters statistically differ from one another, $p < 0.05$). Group I: AIN-93G diet (placebo group); Group II: AIN-93G diet + 1.25% cholesterol + 0.5% cholic acid (Negative Control); Group III: Hypercholesterolemic mice fed high cholesterol diet and SESC (Positive Control); Group IV: AIN-93G diet + 1.25% cholesterol + 0.5% cholic acid SES I; Group V: AIN-93G diet + 1.25% cholesterol + 0.5% cholic acid and SES II; Group VI: AIN-93G diet + 1.25% cholesterol + 0.5% cholic acid and SES III; SESC: sesame yogurt control; SESC: sesame yogurt control; SES I: RBO incorporated 6% DEQSF-based yogurt, SES II: RBO incorporated 7% DEQSF-based yogurt, SES III: RBO incorporated 8% DEQSF-based yogurt

enriched with polyunsaturated fatty acids in their study on hypercholesterolemic mice. In our investigation, the serum lipid profile data also demonstrated a substantial improvement between the fortified yogurt-treated group and the control group. The liver tissues experienced no injury, according to the current study. To support claims of a hypolipidemic impact, more study was needed to show how yogurt made with sesame flour supplemented with RBO affects liver, kidney, and heart tissue.

Conclusion

Sesame yogurt that had been fortified and supplemented with RBO can be made using DEQSF. This product had unique properties, including physico-chemical, microbiological, sensory, antioxidative, proteolytic, morphological, and hypocholesterolemic qualities, as well as a wealth of exceptionally high-quality nutrients. The items might be useful in functional foods that aim to reduce certain metabolic disorders. It was anticipated that the non-dairy industry would place a high value on the scientific data pertaining to this innovative fortified yogurt variety prepared from DEQSF and RBO.

Abbreviations

DEQSF	Deoiled edible quality sesame flour
RBO	Rice bran oil
TPC	Total polyphenol content
DPPH	2, 2–Diphenyl–1–picrylhydrazyl
FRAP	Ferric reducing antioxidant power
ABTS	2,2′-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid
ORAC	Oxygen Radical Absorbance Capacity
OPA	O–phthaldialdehyde
TG	Triglycerides
TC	Total cholesterol
LDL-C	Low density

Acknowledgements
For technical assistance during the investigation, the authors thank the School of Community Science and Technology, Indian Institute of Engineering Science and Technology, Shibpur, India.

Authors' contributions
Samadrita Sengupta is responsible for conceptualization, methodology, data collection, first draught writing, review, and editing; Srabanti Basu is in charge of review and editing; validation; and supervision; and Jayati Bhowal is given credit for conceptualization, methodology, proofing, review and editing, validation, and supervision.

Funding
No external funding is involved in this research.

Availability of data and materials
The corresponding author will provide the datasets used in and/or analysed during the current work upon reasonable request.

Declarations

Declarations
Ethics approval and consent to participate.
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Received: 24 November 2022 Accepted: 11 May 2023
Published online: 07 August 2023

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