



Organoleptic, Physicochemical and Microbiological Quality of Yoghurt Enriched with Indigenous Fruits of Botswana

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ABSTRACT

Background: Demand for healthy food products has increased research into yoghurt enriched with fruits and vegetables as sources of bioactive compounds. Indigenous fruits in Botswana are nutrient-rich and contain valuable bioactive compounds; however, they remain underutilized and receive limited attention for value addition. This study aimed to develop yoghurt enriched with indigenous fruits; Moretologa (*Ximenia americana* L.), Morula [*Sclerocarya birrea* (A. Rich) Hochst], Mowana (*Adansonia digitata* L.) and Mogose (*Bauhinia petersiana* Bolle) and evaluate their sensory, physico-chemical and microbial properties.

Methods: Yoghurt was developed using standard procedures and sensory analysis identified the best treatments. T1 (90% yoghurt: 10% indigenous fruit) was selected for Mogose and Moretologa, while T3 (80% yoghurt: 20% indigenous fruit) was chosen for Mowana and Morula, based on highest overall acceptability scores.

Result: Mogose yoghurt had higher protein (4.28%) than the control (3.27%). Addition of morula and mogose reduced syneresis (from 16.33% to 15.32% and 10.72%) and increased total soluble solids. Microbial analysis showed no coliforms and low yeast and mould counts, indicating safety. Overall, enriching yoghurt with indigenous fruits improved its nutritional and physico-chemical properties and promotes the use of underutilized plants.

Key words: Enrichment, Underutilized indigenous fruits, Yoghurt.

INTRODUCTION

Yoghurt is inversely associated with the incidence of type II diabetes, colorectal cancer and metabolic syndrome due to its nutritional composition (Mulet-Cabero *et al.*, 2024; Okur, 2022). Fruits are rich in antioxidants, dietary fibre and phenolic compounds and fruit-enriched yoghurt has been widely studied as a nutritious functional dairy product with improved sensory properties (Ahmad *et al.*, 2022). Mowana (*Adansonia digitata* L.) pulp is high in calcium and ascorbic acid, while its bark contains adansonin used to treat malaria and fever (Asogwa *et al.*, 2021). It is also rich in phenols and flavonoids and can reduce cholesterol, triglycerides and low density lipoproteins levels (Ahmed *et al.*, 2022). Morula [*Sclerocarya birrea* (A. Rich) Hochst] has anti-cancer and anti-inflammatory properties due to its bioactive compounds (Mashau *et al.*, 2022). Mogose (*Bauhinia petersiana* Bolle) seeds contain notable protein (18.19%), fat (18.35%) and ash (6.07%) (Kobue-Lekalake *et al.*, 2022). Moretologa (*X. americana* L.) fruit is rich in vitamin E, fibre and minerals and exhibits antioxidant, anti-inflammatory, antibacterial and antidiabetic activities (Kefelegn and Desta, 2021; Sharief *et al.*, 2022).

These indigenous fruits possess strong nutritional and phytochemical profiles and can enhance access to food and nutritious diets. However, in Sub-Saharan Africa, including Botswana, they remain underutilized in functional foods (Onomu *et al.*, 2023; Bille *et al.*, 2013). This study aimed to develop yoghurt enriched with Morula, Moretologa, Mowana and Mogose and evaluate its sensory, physico-chemical and microbial properties.

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MATERIALS AND METHODS

The study was conducted in Gaziantep University, Gaziantep, Türkiye from March 2023 to July 2023.

Materials

Moretologa, Mogose, Morula and Mowana were collected from Shakawe (18.3673°S, 21.8390°E), Malwelwe (23.9871°S, 25.2487°E), Kopong (24.4771°S, 25.8906°E) and Mosu (21.2177°S, 26.0196°E), respectively. Other materials (cow milk, packaging material, starter culture)

were purchased from the local market in Gaziantep, Türkiye. A probiotic starter culture containing *Streptococcus thermophilus*, *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Lactobacillus acidophilus* was used.

Sample preparation

Morula and Moretologa pulps were prepared by washing, peeling and pulping the fruits. Mogose seeds were milled into powder using an industrial blender, while Mowana powder was obtained by removing seeds and separating the pulp with a mortar and pestle. All samples were frozen at -21°C until use.

Yoghurt preparation

Developed yoghurts were formulated as per the treatments depicted in Table 1 and processed following the steps in Fig 1.

Sensory evaluation

Sensory evaluation of developed yoghurts was conducted according to Amerine *et al.* (1965), following a 9-point

hedonic scale method. The sensory evaluation was carried out in a sensory laboratory, Food engineering department in Gaziantep University. A semi-trained and consented panel (n=20) consisting of both staff and students evaluated the yoghurts in terms of their colour, taste, aroma, texture and overall acceptability.

Proximate analysis of yoghurt

Moisture, protein and ash were determined according to AOAC (2004). Moisture content was analysed by the oven drying method, protein by the Kjeldahl method and for ash a muffle furnace at 550°C was used to ash the samples. Fat was determined using the Gerber method, following the procedure described by Celik and Bakirci (2003) and Fahmid *et al.* (2016), with a slight modification. Sulphuric acid (10 mL) was poured into the butyrometer, followed by 10 mL of yoghurt and 1 mL of iso-amyl alcohol. Thereafter, the contents were mixed to obtain a homogenized solution and the mixture was centrifuged at 1100 rpm for 10 minutes. Then the butyrometer was placed in a water bath adjusted

Table 1: Formulation of indigenous fruits enriched yoghurts.

Material (%)	T ₀ (control)	T ₁	T ₂	T ₃	T ₄	T ₅
Yoghurt	100	90	85	80	75	70
Mogose	-	10	15	20	25	30
Mowana	-	10	15	20	25	30
Morula	-	10	15	20	25	30
Moretologa	-	10	15	20	25	30
Starter culture	4	4	4	4	4	4

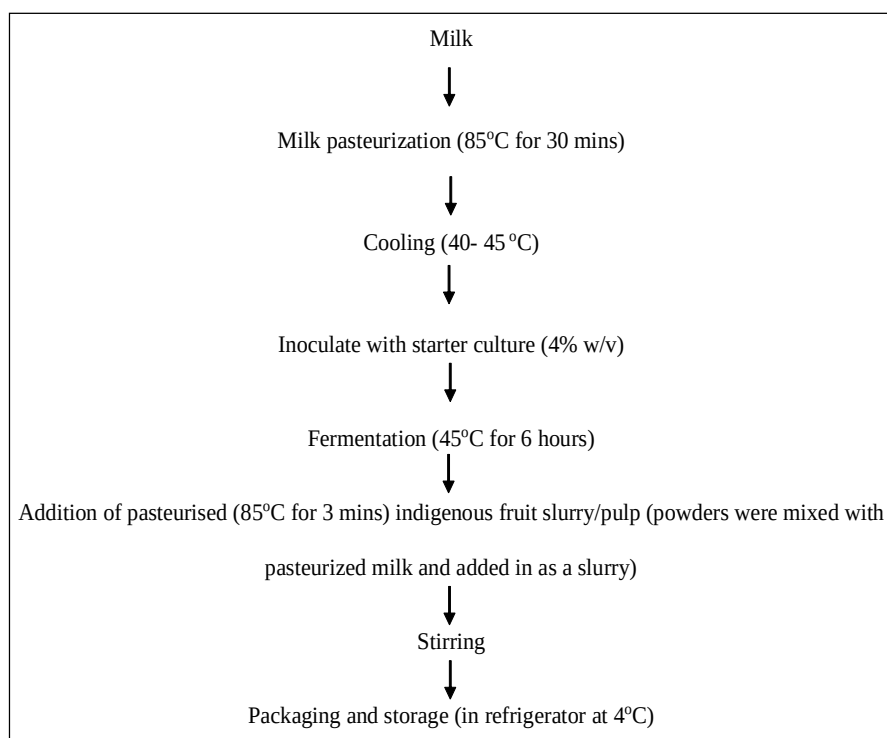


Fig 1: Process flow chart for developed yoghurts (Aluko, 2017; Gouda and Hamed, 2020).

at 65°C for 5 min and the separated fat in the butyrometer was recorded and expressed as percentage (%).

pH

pH of yoghurt samples was measured using a Hanna 211 Microprocessor pH meter (Hanna Instruments Inc., USA).

Syneresis

Syneresis was conducted following the method by Celik and Bakirci (2003). Yoghurt (5 g) in a centrifuge tube, was centrifuged at 5000 rpm for 20 mins at 4°C. The volume of separated whey was determined after 1 minute. Syneresis (%) was expressed as the volume of separated whey per 100 ml of yoghurt sample.

Total soluble solids (TSS)

Total soluble solids of samples were assessed using a PTR 46X digital refractometer (Index Instruments Ltd, UK).

Titrateable acidity

Titrateable acidity was determined according to AOAC (2004) method. 10 mL of yoghurt was titrated against 0.1 N sodium hydroxide solution using phenolphthalein indicator and titrateable acidity expressed as % lactic acid.

Microbiological analysis

Yoghurt samples were prepared by mixing 10 ml of yoghurt with 90 ml peptone water and the mixture homogenized with Vortex mixer. Serial dilutions were prepared starting with 1: 10 homogenised yoghurt sample in peptone water. Total plate count and yeast and mould count were analyzed according to Dike-Ndudim *et al.* (2022) and Hetinkaya, (2020), respectively. Plate count Agar (PCA) was used for total plate count and 0.1 ml of diluted sample was inoculated on the plates using spread plate technique and incubated at 37°C for 24 hours. Yeast and mould counts were determined using Potato Dextrose Agar (PDA). Using spread plating technique 0.1 ml of diluted sample was spread over sterile plates which were incubated at 25°C for 5 days. Coliform counts were determined as described by Saleena *et al.* (2022). Pour plate method was used and 1ml of diluted sample was plated with 20 ml of Violet Red Bile Agar (RVBA) and plates were incubated at 37°C for 24 h.

Statistical analysis

Analyses were conducted in triplicate and results are presented as mean ± standard deviation, except for sensory analysis. Statistical analysis was performed using IBM SPSS 2022, applying ANOVA at a 95% confidence level ($p < 0.05$). Sensory data were analyzed using two-way ANOVA, with Duncan's multiple range test for mean separation, while LSD was used as a post hoc test for all other determinations.

RESULTS AND DISCUSSION

Sensory analysis

Yoghurt organoleptic attributes play a critical role in consumer acceptance and marketability of the product (Kumthekar *et al.*, 2021). A significant difference was observed in colour

between control yoghurt and the Morula enriched yoghurt treatments (Table 2). Control yoghurt was significantly different from Mogose (T_1 , T_3 and T_4), Mowana (T_1 , T_2) and Moretologa (T_5) enriched yoghurts. Moretologa has a bright orange colour which may have influenced the yoghurt colour. A study by Narayanan (2020) showed that panelists preferred the orange colour of probiotic yoghurt enriched with carrot juice (9.0) compared to control yoghurt (7.67). Control yoghurt had the highest texture score (7.9) while panelists neither liked nor disliked (5) some of the treatments in Moretologa and Mogose enriched yoghurt.

An increase in Morula pulp addition caused no significant changes in aroma scores across all yoghurt treatments, unlike findings by Jovanović *et al.* (2020), who reported significant differences with 1, 3 and 5% apple pomace. Morula pulp has a sweet-sour taste (Kugedera, 2019) and Mowana pulp shows a similar profile due to sugars (fructose, sucrose, glucose) and organic acids that contribute to tartness (Monteiro *et al.*, 2022). Enriching yoghurt with both pulps at 20% likely improved taste, resulting in higher taste scores. Overall acceptability, which reflects consumers' overall liking based on colour, texture, aroma and taste (Pereira *et al.*, 2021), was used to identify the best treatments for further analysis. Results showed that T1 (90:10) had the highest acceptability for Mogose and Moretologa yoghurts, while T3 (80:20) scored highest for Mowana and Morula yoghurts; these four yoghurts were selected for further analysis.

Proximate composition

Moisture content of developed yoghurts ranged from 83.62% to 89.42% (Table 3). Addition of indigenous fruits resulted in a significant increase in the ash content of yoghurt. The highest ash content (0.90%) was observed in the Mowana yoghurt with the Morula having the lowest (0.72%), but all these were higher than that of the control (0.04%). Similar findings were reported by Darwish *et al.* (2025) where enrichment with mango peel powder increased the yoghurt ash content. According to Kobue-Lekalake *et al.* (2022), Mogose seeds contain 18.39% protein, thus addition of Mogose powder increased yoghurt protein by approximately 30% compared to the control yoghurt (3.27%). Enrichment with Morula and Moretologa however did not yield any significant difference in the yoghurt protein content. Khatoon *et al.* (2021) recorded similar findings with persimmon enriched yoghurt and attributed the decrease to the low protein content of fruits compared to that of milk.

Fat contents of Morula, Mowana and Moretologa yoghurt were recorded to be 0.87, 1.00 and 0.80%, respectively and these were lower compared to the control yoghurt (1.27%). Similarly, Hyseni *et al.* (2025) also recorded lipid decrease in functional yoghurts enriched with strawberry and Aronia fruits. Enrichment of yoghurt with indigenous fruits resulted in an increase in carbohydrates content of all the yoghurt under study compared to the control yoghurt. In their study Othman *et al.* (2019) credited the increase of

carbohydrates in papaya enriched yoghurt to the high glucose and sucrose content of papaya pulp.

Syneresis, pH, total soluble solids and titratable acidity

Mowana yoghurt had the lowest pH (3.82) while Mogose yoghurt had the highest pH (4.75) (Fig 2). Wairimu *et al.* (2022) reported a slightly higher pH of 3.99 in goat milk yoghurt enriched with *A. digitata* pulp and reported that the pH reduction may be due to lactic acid production due to fermentation and organic acids (ascorbic, citric, succinic, tartaric and malic) present in baobab pulp. A pH of 3.92 was observed in Morula yoghurt, similarly Morula pulp is rich in ascorbic acid (62-400 mg 100 g), citric acid (8.5 g 100 g) and malic acid (1.2 g 100 g) which may have contributed to the lowered pH (Legodi *et al.*, 2022). Total

soluble solids of yoghurts under study ranged from 7.73 to 10.8°B.

Syneresis is the removal of interlocked whey from continuous yoghurt gel network and it is prominent in set style yoghurt and may also be observed in stirred yoghurt due to lack of gel rigidity (Arab *et al.*, 2023). Addition of Mowana and Moretologa increased syneresis while Morula and Mogose reduced it. The highest syneresis (19.75%) was noted in Mowana yoghurt and its acidity (3.82) may have contributed, when pH is too low syneresis increases due to diminished water retention capacity of the micelle casein molecule bonds resulting from reduction in electrostatic power of the cell molecules (Malaka *et al.*, 2021). Morula yoghurt had the lowest syneresis in the current study of 10.72%. Enriching yoghurt with fruits and vegetables

Table 2: Sensory parameters of control, mogose (*Bauhinia petersiana*), morula (*Sclerocarya birrea*), moretologa (*Ximenia americana*) and mowana (*Adansonia digitata*) enriched yoghurts.

Treatment	Enrichment	Parameter				
		Colour	Texture	Taste	Aroma	Overall acceptability
T ₀	Control	8.4±0.52 ^d	7.9±1.29 ^f	7.4±1.07 ^f	7.5± 0.85 ^{bc}	7.7± 1.06 ^f
T ₁	Mogose	6.2±2.39 ^a	6.3±0.95 ^{abcde}	5.5±0.71 ^{abcd}	7.5±0.85 ^{bc}	7.1±1.03 ^e
	Mowana	6.8±1.48 ^{abc}	6.4±1.43 ^{abcde}	6.4±1.71 ^{bcdef}	8.0 ±0.01 ^c	6.5± 1.96 ^{bcd}
	Morula	6.8±1.14 ^{abc}	6.5±1.35 ^{bcde}	6.6± 1.84 ^{cdef}	7.0±1.05 ^{bc}	6.4± 1.37 ^{de}
	Moretologa	7.5±0.71 ^{abcd}	7.1±0.99 ^{def}	6.5±1.51 ^{bcdef}	7.2±0.79 ^{bc}	7.2±0.78 ^e
T ₂	Mogose	7.2±1.03 ^{abcd}	5.2±1.32 ^a	5.2±0.42 ^{abc}	5.4±1.07 ^a	5.0±0.67 ^a
	Mowana	6.71±1.25 ^{abc}	6.8±1.03 ^{cdef}	6.1±1.52 ^{bcdef}	6.9±1.10 ^{bc}	6.3±1.10 ^{bcd}
	Morula	6.71±1.06 ^{abc}	7.2±0.91 ^{def}	6.5±1.27 ^{bcdef}	7.8±0.79 ^c	6.3±1.08 ^{bcd}
	Moretologa	7.5±0.97 ^{abcd}	6.8±1.14 ^{cdef}	5.1±1.51 ^{abc}	7.3±0.95 ^{bc}	5.7±1.69 ^{abcd}
T ₃	Mogose	6.6±1.17 ^{ab}	5.7±1.42 ^{abc}	5.0±0.67 ^{ab}	5.7±1.42 ^a	5.3±1.16 ^{abc}
	Mowana	7.2±1.40 ^{abcd}	6.9±0.71 ^{cdef}	6.5±2.02 ^{bcdef}	7.0±0.77 ^{bc}	7.8±0.55 ^f
	Morula	6.6±1.65 ^{ab}	7.2±0.79 ^{def}	7.1±1.53 ^{ef}	7.3±1.06 ^{bc}	7.8±0.42 ^f
	Moretologa	7.1±1.17 ^{abcd}	6.0±1.12 ^{abcd}	5.7±1.22 ^{abcde}	7.1±1.15 ^{bc}	5.4±1.59 ^{abcd}
T ₄	Mogose	6.4±1.43 ^a	5.2±1.23 ^a	4.5±0.85 ^a	5.4±1.17 ^a	5.0±0.67 ^a
	Mowana	7.1±1.22 ^{abcd}	7.1±1.13 ^{def}	6.4±1.75 ^{bcdef}	7.0±1.01 ^{bc}	6.2±1.40 ^{abcde}
	Morula	6.4±1.67 ^{ab}	7.1±1.05 ^{def}	6.8±1.48 ^{def}	7.3±0.71 ^{bc}	6.4±1.45 ^{bcd}
	Moretologa	7.1±1.29 ^{abcd}	6.4±1.17 ^{abcde}	5.0±2.11 ^{ab}	6.4±1.17 ^{ab}	5.1±1.85 ^{ab}
T ₅	Mogose	7.2±1.03 ^{abcd}	5.2±1.32 ^a	5.2±0.42 ^{abc}	5.4±1.07 ^a	5.0±0.67 ^a
	Mowana	7.1±0.99 ^{abcd}	7.2±1.23 ^{def}	6.5±1.90 ^{bcdef}	7.0±1.05 ^{bc}	6.3±1.90 ^{bcd}
	Morula	6.5±1.65 ^{ab}	7.4±0.97 ^{ef}	6.4±2.07 ^{bcdef}	6.9±1.10 ^{bc}	6.2±1.62 ^{abcde}
	Moretologa	6.1±2.33 ^a	5.4±2.17 ^{ab}	5.1±1.28 ^{abc}	5.4±2.17 ^a	5.0±1.15 ^a

All values are mean±SD and means with different superscripts within a column are significantly different (p<0.05).

Table 3: Proximate composition of control, mogose (*Bauhinia petersiana*), morula (*Sclerocarya birrea*), moretologa (*Ximenia americana*) and mowana (*Adansonia digitata*) enriched yoghurts per 100 g.

Yoghurt	Moisture	Ash	Fat	Protein	Carbohydrates
Control	89.29±0.02 ^e	0.04±0.00 ^a	1.27±0.06 ^c	3.27±0.21 ^a	5.61±0.19 ^a
Mogose yoghurt	87.49±0.04 ^b	0.82±0.04 ^c	1.32±0.01 ^c	4.28±0.09 ^b	6.09±0.09 ^{bc}
Morula yoghurt	89.06±0.02 ^c	0.72±0.01 ^b	0.87±0.03 ^a	3.10±0.07 ^a	6.24±0.05 ^c
Mowana yoghurt	86.32±0.04 ^a	0.90±0.01 ^d	1.00±0.00 ^b	3.24±0.01 ^a	8.54±0.05 ^d
Moretologa yoghurt	89.42±0.02 ^d	0.75±0.02 ^b	0.80±0.01 ^a	3.30±0.04 ^a	5.91±0.02 ^b

All values are mean±SD and means with different superscripts within a column are significantly different (p<0.05).

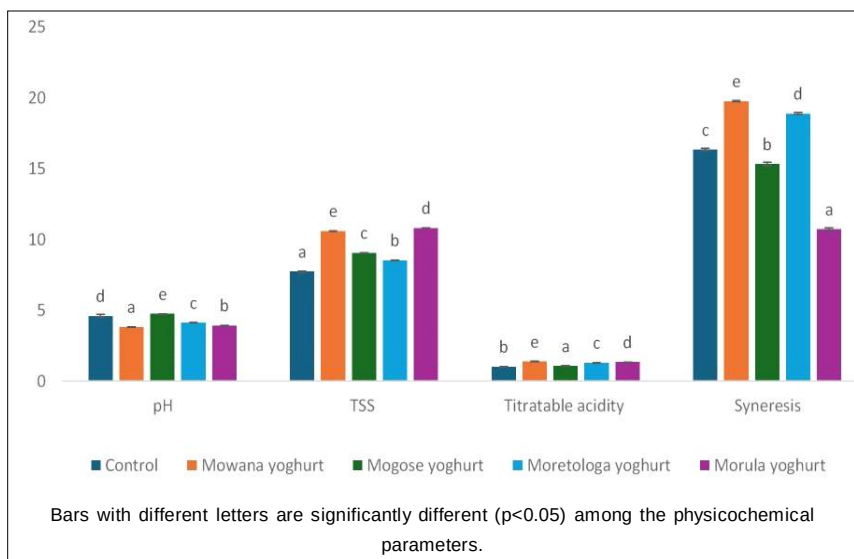


Fig 2: Physicochemical parameters of control, mogose (*Bauhinia petersiana*), Morula (*Sclerocarya birrea*), Moretologa (*Ximenia americana*) and Mowana (*Adansonia digitata*) enriched yoghurts.

Table 4: Microbial counts ($\log_{10}$ cfu/g) of control, mogose (*Bauhinia petersiana*), morula (*Sclerocarya birrea*), moretologa (*Ximenia americana*) and mowana (*Adansonia digitata*) enriched yoghurts.

Yoghurt	Total plate count	Yeast and Mould	Coliforms
Control	7.60±0.01 ^{cd}	3.70±0.01 ^a	ND*
Morula yoghurt	7.70±0.01 ^d	4.00±0.01 ^b	ND
Mowana yoghurt	5.74±0.01 ^a	3.70±0.01 ^a	ND
Mogose yoghurt	7.56± 0.02 ^c	3.69±0.01 ^a	ND
Moretologa yoghurt	7.45±0.09 ^b	4.70±0.02 ^c	ND

*Not detected. All values are mean±SD and means with different superscripts within a column are significantly different ($p<0.05$).

increases its dry matter and pectin, thus increasing yoghurt water absorption capacity, therefore reducing syneresis (Wajs *et al.*, 2023). Addition of indigenous fruits significantly increased titratable acidity of the products.

Microbial analysis

Heat treatment of milk and refrigeration render fermented dairy products microbiologically stable (Nielsen *et al.*, 2021). Fungal species however survive in dairy products as they are acidotolerant, psychrotolerant and xerotolerant (Garnier *et al.*, 2017). Mould spoilage in yoghurt is characterized by visible mould growth on product, colour and texture changes and off flavor and odour (Shi and Maktabdar, 2022). Results of the current study indicate that there were no significant differences in yeast and mould count in the control, Mogose and Mowana yoghurt products (Table 4). Morula and Moretologa yoghurts contained 4.0 and 4.70 $\log$ cfu/g yeast and mould counts, respectively. There was no detectable coliform contamination in any of the samples, suggesting yoghurt was processed in sanitary conditions. Coliform presence in dairy products may occasionally cause foodborne illnesses (Fathi *et al.*, 2019). Total plate count for yoghurts under the current study ranged from 5.74- 7.70 $\log$ cfu/g.

CONCLUSION

Enriching yoghurt with indigenous fruits improved its nutritional composition, organoleptic and physico-chemical properties. Although panelists generally preferred the control yoghurt due to familiarity, morula and mowana yoghurts scored high in overall acceptability and were not significantly different from the control. Enrichment significantly increased protein, ash and carbohydrate content, reduced syneresis and produced microbiologically safe yoghurt. Further studies are recommended to assess functional properties and shelf stability.

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Disclaimers

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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