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Comparative characterization of Hojari and Sha'bi frankincense (*Boswellia sacra*) with implications for food quality and safety

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Introduction: Frankincense (*Boswellia sacra*) is a traditional non-timber forest product increasingly incorporated into food and beverage formulations, yet information on the quality attributes and food safety implications of different commercial grades remains limited. This study comparatively characterized the physicochemical, mechanical, and color properties of two commercially important Omani grades of *B. sacra* frankincense (Hojari and Sha'bi) and evaluated the survival of *Escherichia coli* in bottled drinking water flavored with frankincense oil as a model food system.

Methods: Standard analytical methods were used to determine moisture content, solubility, ash, and protein levels, pH, mineral composition, and mechanical properties, while color attributes were assessed using the CIELAB system. *E. coli* survival was determined via viable count assays.

Results: Significant grade-dependent differences were observed, with Sha'bi frankincense exhibiting higher weight (3.83 g), moisture content (4.60%), solubility (24.57%), and lower stiffness (Young's Modulus = 2.47 MPa) compared with Hojari, which showed greater brightness (L^*= 56.98) and color saturation (chroma = 6.16). In contrast, length, hardness, ash, protein content, and mineral profiles, including trace and heavy metals, were comparable between grades. Microbiological assessment showed that *E. coli* survived in commercial water containing 0.05% frankincense oil, suggesting that this concentration does not exert a measurable inhibitory effect on bacterial viability.

Conclusion: These findings demonstrate that commercial frankincense grades differ in quality-related properties relevant to food formulation and handling, and they highlight the need for appropriate hygiene practices and monitoring of mineral contaminants when incorporating forest-derived resins into food and beverage systems. The study contributes to the sustainable utilization of traditional non-wood forest products by providing evidence-based data to support quality assessment and food safety considerations.

KEYWORDS

***Boswellia sacra*, drinking water, *E. coli* survival, frankincense, mineral content, texture analysis**

1 Introduction

Functional foods are food products that provide health benefits beyond their basic nutritional value, resulting in decreased morbidity and mortality rates in the community (Khairnar et al., 2024; Gibson et al., 2023). They include foods that are fortified with added ingredients or concentrated extracts to functional levels that can improve health or performance (Madhujith and Wedamulla, 2020; Chávez-Garay et al., 2025). Currently, there is an increasing demand from consumers for foods that offer health benefits beyond basic nutrition, driving research and development in the functional food sector (Londoño-Hernández et al., 2025). Wounding the bark of one of the oldest fragrant and medicinal plants, *Boswellia* trees, produces a natural oleo-gum resin known as frankincense or olibanum (Khalifa et al., 2023). The oleo-gum resin of frankincense has three main components: water-soluble gums (polysaccharides), essential oils (mono- and sesquiterpenes), and alcohol-soluble resins (diterpenes and triterpenes) (Tucker, 1986; Al-Kharousi et al., 2023). *Boswellia sacra* is native to Yemen, Somalia, and Oman. The trees are indigenous to the Dhofar region in Oman, where they grow in four main ecological zones: Hojar, Nejd, Shazr, and Sha'b. As a result, there are four main grades of Omani frankincense: Hojari, Nejdi, Shazri, and Sha'bi (Farah, 2008) (Figure 1).

Frankincense is a non-timber forest product (NTFP) with a substantial global market. The market for frankincense was valued at approximately USD 193.4 million in 2018 and is projected to reach USD 406.1 million by 2028 (Pullaiah, 2023). The anti-inflammatory potential of frankincense was reported by Indians as early as 5,000 years ago for the powder and extracts of *Boswellia serrata* (Mertens et al., 2009). Frankincense has also been used to treat back pain, chronic cough, leukemia, and liver and colon cancers (Farah, 2008). Frankincense has been described as having the shape of tears or lumps, with a size ranging from a pea to a walnut and with a pale amber or pale-yellow color (Tucker, 1986). The surface of the tears appears dusty with different colors such as yellow, bluish-white, and greenish-white. The fresh gum from *B. serrata* has been described as having a hot, bitter taste, with a good flavor (Shah et al., 2008).

Despite the increasing incorporation of frankincense into a wide range of food products including dairy products, sweets, coffee, tea, and bottled drinking water, scientific evidence supporting the selection of specific frankincense grades for food applications remains limited. Commercially, frankincense is marketed in different grades, such as Hojari (premium) and Sha'bi (lower grade), with substantial differences in price (Farah, 2008; Al-Kharousi et al., 2023). However, these classifications are largely based on traditional or visual criteria rather than systematic physicochemical characterization, creating a critical gap between market practices and scientific validation. It is important to standardize the quality of the traded oleo-gum resin and its products (Mertens et al., 2009).

Although some studies have explored the use of frankincense extracts in food systems such as improving sensory attributes in guava nectar (Riyad et al., 2020) or extending the shelf life of chicken using frankincense aqueous extract (1%) (Taha et al., 2024), these studies do not compare different commercial grades nor evaluate how their intrinsic physicochemical differences influence food quality, safety, and functionality. Moreover, while the antimicrobial properties of frankincense are recognized, there is a lack of data addressing a key contradiction in food applications, particularly the need to control harmful microorganisms without negatively affecting beneficial or functional microbiota (e.g., probiotics). *Escherichia coli* ATCC 25922 is a quality control strain and can be used as a model (Ezzaky et al., 2022) to study the inhibitory activity of the added frankincense in foods and beverages. Commercial bottled drinking water flavored with frankincense essential oil is available in the local market. A profound aroma and flavor of frankincense can be detected despite a low concentration of the essential oil added (0.05%, as indicated on the label). As it is a liquid that lacks many nutrients and interfering substances normally present in other foods and beverages, this water can be used as a reference sample to provide baseline data on the survival of the inoculated *E. coli*. In addition, no prior studies have systematically linked the physicochemical properties of Omani frankincense grades (Hojari vs. Sha'bi) with their practical implications for food formulation, safety, and microbial behavior in real or model food systems. This represents a significant knowledge gap, particularly given the growing commercialization of frankincense-flavored products.

Therefore, this study hypothesizes that the physicochemical characteristics of Omani frankincense vary between Hojari and Sha'bi grades and can be used as a scientific basis for grading and application-specific selection. It also hypothesizes that frankincense extracts can be used at concentrations that do not inhibit beneficial microorganisms in food systems. Accordingly, the objectives of this study were to determine and compare the physical and chemical properties (weight, size, texture, color, pH, solubility, moisture, protein, mineral, and ash content) of Hojari and Sha'bi frankincense. It also aimed to evaluate the survival of *E. coli* in a commercial frankincense-flavored drinking water model system. The results of this study guide frankincense researchers, consumers, and the industry in selecting appropriate grades among the various marketed types. It also sheds light on the potential of frankincense to deliver sensorial changes, such as smell and flavor to foods without changing their indigenous microbiota. By addressing the absence of grade-based scientific characterization and linking these properties to food-relevant microbial outcomes, this study provides novel insights that bridge traditional classification with modern food quality and safety requirements.

2 Materials and methods

2.1 Collection and storage of the oleo-gum resin of frankincense

Omani frankincense was selected due to its availability, unique properties, and cultural relevance. Two grades, Hojari and Sha'bi were acquired from a reputable frankincense trader in Dhofar. Hojari, representing the highest quality, and Sha'bi, the lowest, come from trees in distinct geographical regions (Ali et al., 2008). The trees producing the Sha'bi frankincense are more influenced by monsoon rains. Four Hojari samples were obtained, with three sub-graded as Hojari White (HW1, HW2, and HW3) and one as Hojari Green (HG). Five Sha'bi samples were collected (S1, S2, S3, S4, and S5). The trader sorted the samples, noting that the HG



FIGURE 1
The four main grades of Omani frankincense: Hojari, Nejdi, Shazri, and Sah'bi (left to right).

sample came from trees in Wadi Habjar (Wadi Hojar); HW1, HW2, and HW3 from Wadi Andor, and the Sha'bi samples from Wadi Aful and Al-Mughsail. Upon acquisition, all samples were handled in a controlled environment to avoid contamination or changes in their characteristics. All samples were kept in their original bags in the dark at room temperature until analyzed to preserve their physical and chemical integrity, as previous studies reported minimal degradation of the oleo-gum resin under these conditions (Al-Kharousi et al., 2023; Thomas et al., 2023).

2.2 Determination of weight, length, pH, and solubility

Fifty frankincense lumps from each sample were randomly selected after thorough mixing and individually weighed using an analytical balance (Precisa XT 120A, Switzerland). Their lengths were measured using an electronic digital caliper (Fisher Scientific FB70252, UK). For pH determination, 4–5 randomly selected lumps were ground using a pestle and mortar. A 10% (w/w) suspension was prepared in distilled water and stirred for 10 min using a magnetic stirrer (SMI, Stuart Scientific, UK). After settling of undissolved particles, the pH of the supernatant was measured at 21 ± 2 °C using a calibrated pH meter (Metrohm 744, Switzerland). Measurements were performed in triplicate (Yebeyen et al., 2009). For solubility (Harle et al., 2003), the same suspension was filtered through Whatman No. 41 filter paper. The residue was dried at 105 °C for 1 h in a mechanical convection oven (Gallenkamp 300 Plus, UK), cooled in a desiccator at room temperature, and weighed using the same analytical balance. The % solubility of the oleo-gum resin was calculated using Equation 1:

$$\% \text{ Solubility} = \frac{W_F - W_{ND}}{W_F} \times 100 \quad (1)$$

Where, W_F = original weight of frankincense, W_{ND} = weight of non-dissolved frankincense.

2.3 Determination of moisture and protein contents

Moisture content was determined by drying 2 g of frankincense in a mechanical convection oven (Gallenkamp 300 Plus, UK) at 105 °C for 5 h, followed by cooling in a desiccator and reweighing using an analytical balance (Precisa XT120A, Switzerland). Moisture content was calculated as the percentage weight loss relative to the initial mass (Yebeyen et al., 2009). Protein content was measured using an automated analyzer (FlashSmart N/Protein Analyzer, Thermo Scientific, Italy). Approximately 50 mg of ground sample was weighed into tin capsules, sealed, and analyzed after preheating the instrument for 1 h. The sample was combusted in oxygen, converting organic nitrogen into measurable nitrogen gas. Protein content was calculated using a nitrogen-to-protein conversion factor of 6.25 (Yebeyen et al., 2009).

2.4 Determination of ash and mineral content

Two grams of frankincense resin were ground in a porcelain crucible and ashed overnight in a muffle furnace (CWF 1200, Carbolite, England) at 550 °C. Ash content was calculated as the percentage of residue relative to the original sample mass (Thiex et al., 2012), and the ash was used for mineral analysis. For mineral determination, 10 mL of 6 N HCl was added to the ash and evaporated on a hot plate (Bibby, UK) at 150 °C. Then, 2 mL of concentrated HCl was added, and the sample was heated at 200 °C for 5 min. The solution was transferred to a 50 mL volumetric flask, diluted to volume with deionized water, mixed, and filtered through Whatman No. 541 filter paper. Filtrates were stored in plastic bottles until analysis. Mineral content was determined using an atomic absorption spectrometer (AA-6800, SHIMADZU, Japan) equipped with a graphite furnace (GFA-EX7) and autosampler (ASC-6100, Japan). Mineral content was determined using an atomic absorption spectrometer (AA-6800, SHIMADZU, Japan) equipped with a graphite furnace (GFA-EX7) and autosampler (ASC-6100, Japan).

2.5 Texture analysis

Frankincense lumps have irregular and rough surfaces; therefore, before the analysis, all surfaces of the test lumps were smoothed by filing with a conventional drill (Black and Decker, UK) fitted with a rotating filing tool. Three measurements were taken for each filed lump: height, length, and width. The multiplication of length and width gave the cross-sectional area of each lump.

A texture profile analyzer (Stable MicroSystems, Surrey, UK) with a 75 mm compression platen was used to measure the hardness and to calculate the Young's Modulus of the frankincense oleo-gum resin (Figure 2). The 10% compression test was used. The test conditions were as follows: pre-test speed: 2 mm/sec, test and post-test speeds: 5.0 mm/sec. The peak force of the compression as displayed in the force-time curve, was considered the hardness (N) (Rahman and Al-Mahrouqi, 2009).

Young's Modulus (Pa) was estimated from the slope (N/mm) of the linear portion of the force-displacement curve (Rahman and Al-Mahrouqi, 2009) and was calculated using Equations 2–5:

$$\text{Young's Modulus (E)} = \text{slope} \times \frac{\mathbf{h_o}}{\mathbf{A}} \times (1000)^2 \text{ (Pa)} \quad (2)$$

Where, h_o = the original height of the frankincense lump (mm); A = cross-sectional area of the frankincense lump (mm^2).

Young's Modulus equation was derived from the following equations:

$$E = \frac{\text{stress } (\sigma)}{\text{strain } (\varepsilon)} \text{(Pa)}, \quad (3)$$

$$\sigma = \frac{\text{force } (\mathbf{F})}{\text{area } (\mathbf{A})} \text{(Pa)} \quad (4)$$

$$\varepsilon = \frac{\mathbf{h_o} - h}{\mathbf{h_o}} \quad (5)$$

Where, h = height of a frankincense lump after compression (displacement) (mm); E = Young's Modulus (Pa); σ = stress (Pa); ε = strain (dimensionless).

2.6 Color analysis

The content of each sample was mixed, and then the color measurements were performed using a calibrated chromameter (Konica CR400, Ramsey, NJ, USA) for 50 frankincense lumps randomly selected. Three parameters were recorded: L^*, a^*, and b^*, and the color index and chroma were calculated using Equations 6, 7 (López Camelo and Gómez, 2004; Pandiselvam et al., 2023):

$$\text{Chroma} = \sqrt{a^{*2} + b^{*2}} \quad (6)$$

$$\text{Color index} = \frac{2000 \times a^*}{L^* \times \sqrt{a^{*2} + b^{*2}}} \quad (7)$$

All measurements were performed in replicate, and instruments were calibrated using appropriate standards. Quality control procedures included the analysis of blanks and replicate samples to ensure accuracy and precision.

2.7 Determination of the survival of *E. coli* in commercial bottled drinking water flavored with frankincense

Commercial bottled drinking water flavored with 0.05% essential oil of frankincense, as presented on the label, was purchased from a supermarket in Dhofar and was tested for its ability to inhibit *E. coli* ATCC 25922. This experiment was conducted to test one of the emerging commercial products for its effectiveness in modulating the growth of *E. coli*, which is commonly present in the gut and used as an indicator for food and water sanitary conditions. The count of *E. coli* (Al-Mazrouei et al., 2024) was done by growing it on Tryptone Soy Agar (TSA) for 24 h at 35 °C. A bacterial suspension with 0.3 McFarland (McF) standard density (VITEK 2 DensiCheck, bioMérieux, Marcy-l'Étoile, France) was prepared in Maximum Recovery Diluent (MRD). The DensiCheck device was validated using standard control materials with known values (0, 0.5, 2, and 3 McF) to assess its accuracy, precision, and reproducibility prior to sample analysis. After that, 9.9 mL of bottled water obtained from three different bottles was transferred to sterile tubes and inoculated with 100 µL of the prepared *E. coli* suspension and mixed using a vortex mixer (Fisherbrand, Whrilmixer, UK). The inoculated water samples were kept at room temperature (21 ± 2 °C), mimicking their storage temperature. Counts of *E. coli* in inoculated samples were tested at 0, 1, 6, and 24 h by preparing further 1 in 10 dilutions in MRD. After mixing, 100 µL was transferred onto triplicate plates of Standard Plate Count Agar (SPCA) as a non-selective medium and Tryptone Bile X-glucuronide (TBX) as a selective medium and spread evenly using sterile spreaders. The plates were incubated at 35 °C for 24 h, after which the colonies were counted with the aid of a colony counter (Gallenkamp, UK). For the controls, the experiment was repeated with three commercial bottled plain drinking water samples. The sterility of all water samples was checked by inoculating 100 µL of the water sample onto SPCA and TBX medium and incubating at 35 °C for 24 h. The microbiological media were from Oxoid, Basingstoke, UK.

2.8 Statistical methods

The statistical tests were conducted utilizing XLSTAT 2024 software (Version 2024.2.1, Adinosoft 1995–2024, Paris, France), in which the differences were considered significant if $P < 0.05$. The physical properties of the two grades of Omani frankincense were compared using unpaired t-tests. For *E. coli* counts analysis, the null hypothesis of "the counts were normally distributed" was tested using Shapiro-Wilk test. It showed that the $\log_{10}$ transformed *E. coli* counts were not normally distributed for control samples (plain water) on SPCA ($P = 0.001$, $\alpha = 0.05$) and TBX ($P = 0.003$, $\alpha = 0.05$) and test samples (water flavored with frankincense) on SPCA ($P = 0.001$, $\alpha = 0.05$) and TBX ($P = 0.002$, $\alpha = 0.05$); therefore, the non-parametric Kruskal-Wallis test was used to test significant differences in *E. coli* counts in different water samples over time.

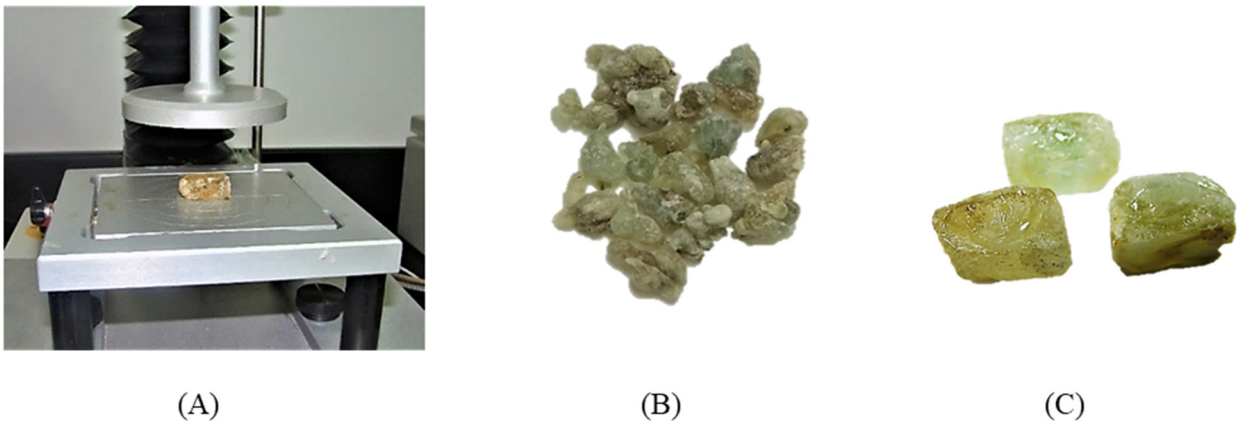
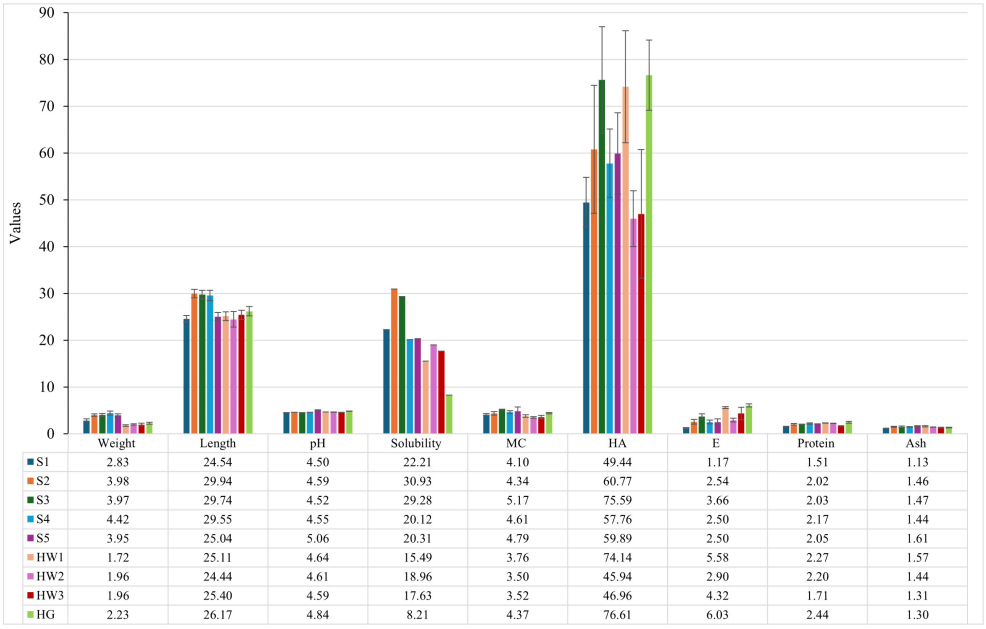


FIGURE 2
Measuring the hardness of frankincense lumps using a texture profile analyzer. The equipment **(A)**, frankincense lumps of Hojari green sub-grade before filing **(B)**, and after filing **(C)**.



	Weight	Length	pH	Solubility	MC	HA	E	Protein	Ash
S1	2.83	24.54	4.50	22.21	4.10	49.44	1.17	1.51	1.13
S2	3.98	29.94	4.59	30.93	4.34	60.77	2.54	2.02	1.46
S3	3.97	29.74	4.52	29.28	5.17	75.59	3.66	2.03	1.47
S4	4.42	29.55	4.55	20.12	4.61	57.76	2.50	2.17	1.44
S5	3.95	25.04	5.06	20.31	4.79	59.89	2.50	2.05	1.61
HW1	1.72	25.11	4.64	15.49	3.76	74.14	5.58	2.27	1.57
HW2	1.96	24.44	4.61	18.96	3.50	45.94	2.90	2.20	1.44
HW3	1.96	25.40	4.59	17.63	3.52	46.96	4.32	1.71	1.31
HG	2.23	26.17	4.84	8.21	4.37	76.61	6.03	2.44	1.30

FIGURE 3
Physicochemical properties of the oleo-gum resin of Sha'bi and Hojari grades of Omani frankincense. HW, Hojari white; HG, Hojari green; MC, Moisture content (wet basis); HA, Hardness, E, Young's Modulus. Values represent mean ± standard error (SE), $n = 50$ for weight and length, and 3 for other parameters; bars represent SE.

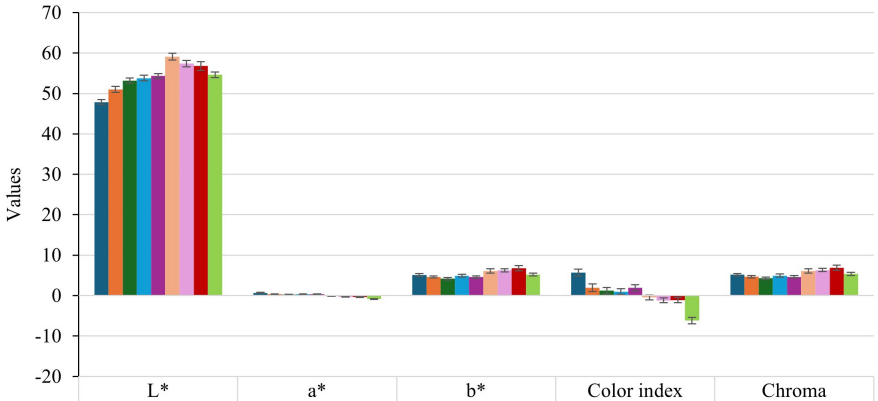
3 Results

Various physicochemical parameters of the oleo-gum resin of frankincense are presented in Figure 3.

3.1 Weight, length, pH, solubility, and moisture content

The mean weight of the Sha'bi oleo-gum resin lumps (3.83 ± 0.59 g) was significantly larger than the Hojari grade (1.97 ± 0.21 g) (t-test, $P = 0.0006$, $\alpha = 0.05$) (Figure 3, Supplementary Table 1). However, no significant difference was detected between the length of the Sha'bi and the Hojari frankincense (t-test, $P = 0.1116$, $\alpha = 0.05$). The mean length of the Sha'bi oleo-gum resin was approximately 28 mm whilst that of the Hojari was about 25 mm. No significant difference was detected in the pH of the solubilized oleo-gum resin of Sha'bi and Hojari frankincense (t-test, $P = 0.8419$, $\alpha = 0.05$). The mean pH was approximately 4.6 for both grades. However, the Sha'bi oleo-gum resin was significantly more soluble in water than the Hojari grade (t-test, $P = 0.0127$, $\alpha = 0.05$) (Figure 3, Supplementary Table 1). The mean solubility of the Sha'bi oleo-gum resin was 24.57 ±

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	L*	a*	b*	Color index	Chroma
S1	47.87	0.67	5.11	5.71	5.20
S2	50.98	0.32	4.59	1.96	4.66
S3	53.19	0.24	4.21	1.23	4.27
S4	53.78	0.31	4.88	0.99	4.94
S5	54.35	0.33	4.58	1.91	4.63
HW1	59.09	-0.09	6.08	-0.47	6.12
HW2	57.39	-0.29	6.26	-1.19	6.31
HW3	56.79	-0.33	6.81	-1.12	6.87
HG	54.62	-0.87	5.23	-6.20	5.35

FIGURE 4
Color parameters of the oleo-gum resin of Sha'bi and Hojari grades of Omani frankincense. Values represent mean ± standard error (SE), $n = 50$; bars represent SE.

5.15% whilst that of the Hojari oleo-gum resin was 15.07 ± 4.80%. The HG oleo-gum resin was the least soluble (8.21%). Both the Sha'bi and the Hojari oleo-gum resin had low moisture contents (means; 4.60 ± 0.41 and 3.79 ± 0.40, respectively, on a wet basis). The moisture content of the Sha'bi grade was significantly higher than the Hojari grade (t-test, $P = 0.0175$, $\alpha = 0.05$).

3.2 Texture, protein, ash, and color

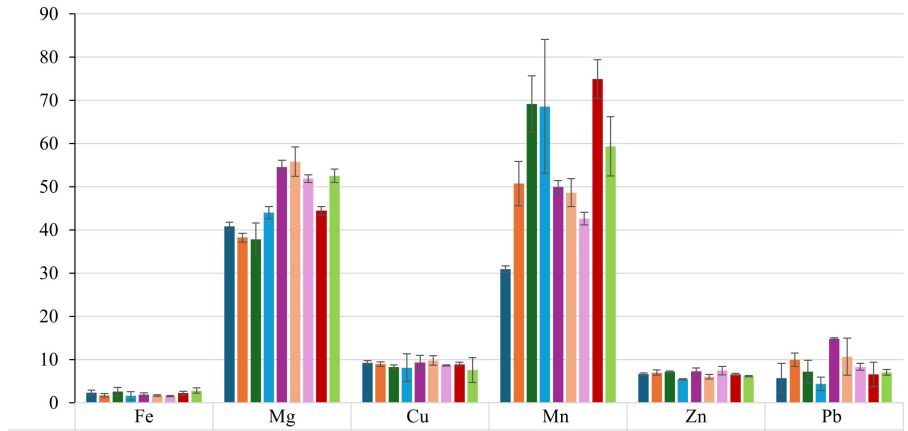
No significant difference was determined in the hardness of the Sha'bi and the Hojari grade oleo-gum resin (t-test, $P = 0.9882$, $\alpha = 0.05$). The mean hardness was approximately 61 N for both grades. However, the Young's modulus of the Sha'bi grade oleo-gum resin was significantly less than the Hojari grade (t-test, $P = 0.0205$, $\alpha = 0.05$) with a mean of 2.47 ± 0.88 and 4.71 ± 1.40 MPa, respectively. The protein content of the *B. sacra* resin was about 2%, slightly below 2% for Sha'bi and slightly above for Hojari. The ash content of the samples varied over a fairly narrow range with a mean for both grades of 1.41 ± 0.15%. As shown in Figure 4 and Supplementary Table 2, all color parameters of the Sha'bi oleo-gum resin were significantly different from the Hojari oleo-gum resin. L^*, b^*, and the chroma of the Hojari oleo-gum resin were significantly larger than for the Sha'bi grade (t-test, $P = 0.0068$; 0.0076; 0.0062, respectively, $\alpha = 0.05$) while a^* and the color index were significantly smaller (t-test, $P = 0.006$ and 0.0154, respectively, $\alpha = 0.05$). The HG oleo-gum resin varied most from HW in terms of a^* and color index values.

3.3 Mineral content

No major differences were observed in the mineral content of the samples (Figure 5, Supplementary Table 3). There were no significant differences between Sha'bi and Hojari grades in their content of iron, magnesium, copper, manganese, zinc, and lead (t-test, $P = 0.8966$, 0.08713, 0.8955, 0.8128, 0.7358, 0.9075, respectively, $\alpha = 0.05$). The mean contents of iron, copper, zinc, and lead were similar for both grades (2, 0.009, 7, and 0.008 mg/kg). The approximate amounts of magnesium and manganese were 43 and 0.054 mg/kg in Sha'bi and 51 and 0.056 mg/kg in Hagari grades, respectively.

3.4 Survival of *E. coli* in bottled drinking water with frankincense flavor

All uninoculated samples showed no bacterial growth on SPCA and TBX. The count of *E. coli* in all control (plain water) and test (frankincense-flavored) samples is shown in Figure 6. *E. coli* survived well in test samples with frankincense as compared to the control plain water samples, with no significant differences in the counts at 0, 1, 6, and 24 h between the test and control samples. Statistically, there was no significant difference in the count of *E. coli* between the plain and frankincense-flavored water samples on SPCA (Kruskal-Wallis test, $P = 0.088$, $\alpha = 0.05$) and TBX (Kruskal-Wallis test, $P = 0.0.070$, $\alpha = 0.05$). In fact, a similar trend in *E. coli* counts in plain and frankincense water samples was apparent, in which all counts started to increase in the period between 1 and 6 h and continued to rise sharply after 6 h and until 24 h of incubation.



	Fe	Mg	Cu	Mn	Zn	Pb
S1	2.35	40.81	9.26	30.92	6.63	5.69
S2	1.74	38.21	8.94	50.73	6.96	9.94
S3	2.57	37.79	8.26	69.13	7.15	7.14
S4	1.57	43.99	8.10	68.57	5.45	4.36
S5	1.85	54.50	9.34	49.97	7.30	14.84
HW1	1.69	55.82	9.78	48.59	6.01	10.64
HW2	1.56	51.85	8.60	42.62	7.44	8.28
HW3	2.20	44.41	8.91	74.93	6.55	6.56
HG	2.79	52.53	7.56	59.30	6.13	7.01

FIGURE 5
Mineral content [mg/kg for iron (Fe), magnesium (Mg), and zinc (Zn), and mg/kg $\times 10^{-3}$ for copper (Cu), manganese (Mn), and lead (Pb)] of the oleo-gum resin of Sha'bi and Hojari grades of Omani frankincense. Values represent mean ± standard error (SE), $n = 3$; bars represent SE.

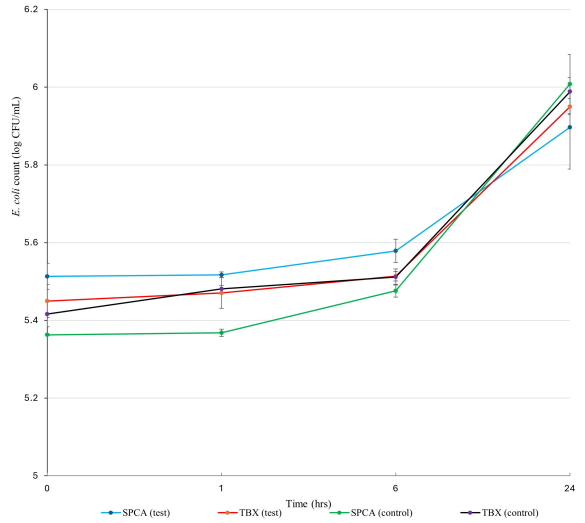


FIGURE 6
Survival of *E. coli* in commercial bottled drinking water with frankincense flavor. *E. coli* was recovered on selective medium (Tryptone X-glucuronide; TBX) and non-selective medium (Standard Plate Count Agar; SPCA) as compared to control commercial bottled plain water over 24 h. Values represent mean ± standard error (SE), $n = 3$, bars represent SE.

This was shown statistically, in which the count of *E. coli* differed significantly at 24 h as compared to the counts at all other times (Kruskal-Wallis test, $P < 0.001$, $\alpha = 0.05$). Pairwise comparison showed that there was no significant difference between the counts at 0, 1, and 6 h; however, there were significant differences between the counts at 24 h and all other counts at 0, 1, and 6 h (Kruskal-Wallis test, P <0.001, <0.001, 0.03, $\alpha = 0.05$, respectively). The highest *E. coli* count for all samples was at 24 h (mean 6.0 ± 0.13 log CFU/mL) as compared to its count at 0 h (mean 5.5 ± 0.05 CFU/mL). Statistically, the count of *E. coli* on TBX was similar to its count on SPCA for both the plain water samples (Kruskal-Wallis test, $P = 0.531$, $\alpha = 0.05$) and the frankincense-flavored samples (Kruskal-Wallis test, $P = 0.149$, $\alpha = 0.05$), indicating that frankincense-flavored water (0.05% oil concentration) had no damaging effect on *E. coli* cells.

4 Discussion

Minimal information is available in the literature about the physicochemical characteristics of frankincense resin, despite its wide use in various applications, including its recent use to produce commercial functional foods and beverages (Al-Kharousi et al., 2023). Variations in the physicochemical properties of frankincense may vary depending on the grade and thus can influence the sensory, health benefits, safety, and consumer acceptability of the final food product. Previous investigations proved the antimicrobial activity of various extracts of frankincense (Al-Kharousi et al., 2023; Orfali et al., 2025). The antimicrobial activity property can be desirable if it is required to extend the shelf life of food or inhibit spoilage or pathogenic bacteria, but in some cases, this property is undesirable when the food contains live bacteria that are supposed to deliver health benefits to consumers. In this case, the concentration of frankincense extract should be carefully monitored. This

study investigated the physicochemical properties of the Hojari and Sha'bi grades of Omani frankincense to help elucidate any significant differences that might affect the selection of the grade required for particular food applications, aiding in its sustainable utilization. Furthermore, the survival of intentionally added *E. coli* in commercial bottled drinking water flavored with frankincense oil was used as a model to study the effect of low frankincense oil concentrations used commercially on microbial growth.

4.1 Weight, length, pH, texture, solubility, and moisture content of Hojari and Sha'bi frankincense

The weight, solubility, moisture content, and Young's Modulus of the Hojari and the Sha'bi grades differed significantly. The geographical location of the trees might have contributed to this variability because frankincense trees producing Sha'bi grade grow in coastal areas that are more affected by monsoon rains than the Hojari-producing areas (Farah, 2008; Al-Kharousi et al., 2023). The moisture content of the Sha'bi oleo-gum resin was significantly greater than that of the Hojari. This supports the finding of a lower Young's Modulus in the Sha'bi oleo-gum resin, indicating that the Sha'bi frankincense is easier to deform or softer than the Hojari frankincense. Different textures of frankincense oleo-gum resin or its extracts can affect how well frankincense can be incorporated into various food matrices. The low moisture content, consistently below 5.2% in all samples analyzed in this study, demonstrates the suitability of frankincense for various pharmaceutical and industrial preparations. Low moisture content of around 2.68% was reported for *Boswellia neglecta* resin (Hido et al., 2020).

The pH of frankincense can influence the stability of its bioactive compounds, such as boswellic acids. The pH can also affect the flavor profile of frankincense, which is important for its sensory attributes in food products. The acidic pH (about 4.6) determined in this study was less than that reported for *B. neglecta* (5.7) (Hido et al., 2020). No significant difference was found in the pH of the two grades, but the solubility of the Hojari grade was significantly less than that of the Sha'bi. Solubility studies aid in the development of functional foods by ensuring that the active ingredients are evenly distributed throughout the product, providing consistent health benefits with each serving. High solubility ensures that these compounds are readily absorbed in the body, enhancing their therapeutic benefits (Börner et al., 2021). The gum fraction influences the solubility of frankincense. It was reported as 45%−60% in *B. serrata* (Shah et al., 2008) and 5%−10% in another study (Ribechini et al., 2008) without referring to a particular species. The gum fraction has been studied for its solubility characteristics. Research indicates that only 27%−35% of frankincense gum is naturally water-soluble, but procedures including chemical modifications can increase its solubility to as high as 85.49% under optimized conditions (Daliri et al., 2023). Thus, the solubility of *B. sacra* that ranged from 8% (Hojari) to 31% (Sha'bi) in this study might indicate only solubility of a fraction of the gum.

A previous study (Tucker, 1986) reported that the size of frankincense lumps ranges from that of a pea to that of a walnut. The walnut size, shape, and color fit very well with those of the Sha'bi grade. Pea-size frankincense lumps are also marketed in Oman as "fumigation/smoking frankincense," and they are possibly separated from the large frankincense lumps during sorting. The length of frankincense lumps described as ranging from 5–25 mm (Afsharypuor and Rahmany, 2005) is consistent with the size description provided by Tucker (1986). In this study, the samples tended to be larger.

4.2 Hojari and Sha'bi frankincense color parameters

Although the values of the a^* component for both grades were around 0, they were positive with the Sha'bi grade indicating a red color and negative with the Hojari grade indicating a green color (López Camelo and Gómez, 2004). As expected, the HG sample had the lowest a^* value and thus the greenest color. The b^* component for the Sha'bi grade was significantly smaller than the Hojari grade, indicating a more yellowish tint in the Hojari grade (López Camelo and Gómez, 2004). The L^* component of the Sha'bi grade was significantly less than the Hojari grade, indicating a darker shade. It was noted that frankincense trees in the Sha'bi and Shazri zones produce brown or dark frankincense. Harvesting frankincense in the cold or during the rainy season can also give Hojari frankincense a darker tone (Farah, 2008). Multiple tapping might induce the frankincense trees to produce resin with different chemical compositions and thus different colors (Huang et al., 2017). The chroma parameter reflects the purity or the saturation of color (López Camelo and Gómez, 2004). The color of Hojari frankincense was significantly purer and more saturated than the Sha'bi grade. The color index of the Hojari grade was significantly less than the Sha'bi grade, and it was found to be the best color parameter to compare the colors of the two grades. This is because Hojari showed more lightness and less redness, which magnified the difference in the color index between the Hojari grade and Sha'bi grade (Equation 7).

4.3 Protein, ash, and mineral contents of Hojari and Sha'bi frankincense

The highest amount of protein found in this study was 2.44% in HG frankincense. Higher protein proportions of 22% in *B.* serrata and 6% in *B. carterii* have been reported. The main types of proteins found in frankincense are proteoglycans and glycoproteins. Arabinogalactan proteoglycans proteins are the main components (32%−56%) of the water-soluble polymeric compounds in *B. serrata* and *B. carterii* (Al-Yasiry and Kiczorowska, 2016). Ash content has been postulated as indicative of the resin's purity (Gundidza et al., 2011). A maximum amount of 3.16% ash has been stipulated for good quality gum Arabic for use in the food and pharmaceutical industries (Abdel-Rahman et al., 2018). The samples used in this study met this target, as the mean value for both grades was 1.4%. Likewise, the Ethiopian frankincense (*B. neglecta*) showed high purity, indicated by its low ash content (0.99%) (Hido et al., 2020).

Minerals are important for vital functions in the body. All of the minerals tested in this study are microminerals except magnesium, which is a macromineral. Macrominerals are needed in larger amounts than microminerals. Microminerals also include trace and ultra-trace minerals that, with excess bioavailability, have a toxic effect on living organisms. Iron, copper, zinc, manganese, and lead are considered trace elements (Sousa et al., 2019). All samples contained iron, magnesium, copper, manganese, zinc, and lead. The average amounts of iron were about 2 mg/kg in both grades of frankincense, and were less than that reported in mushrooms (568–3,904 mg/kg) (Turkekul et al., 2004) and lentils (73–90 mg/kg) (Thavarajah et al., 2009), more than the iron reported in *B. sacra* frankincense (0.135 mg/kg) analyzed in Saudi Arabia (without referring to the producer country and the grade of frankincense) (Alshwyeh et al., 2024), and chickpeas (0.46–0.67 mg/kg) (Thavarajah and Thavarajah, 2012). Both Sha'bi and Hojari contained more magnesium (43.06 and 51.15 mg/kg, respectively) than chickpeas, which have been reported to contain 12.51–15.87 mg/kg (Thavarajah and Thavarajah, 2012). However, the average amounts of copper in both grades (0.009 mg/kg) were less than that reported in *B. sacra* analyzed in Saudi Arabia (0.02 mg/kg) (Alshwyeh et al., 2024), mushrooms (18–54 mg/kg) (Turkekul et al., 2004), and in chickpeas (0.07–0.11 mg/kg) (Thavarajah and Thavarajah, 2012). Zinc is ubiquitous due to its biological significance. Its average content in this study was 6.6 mg/kg in both grades, which is less than what was reported in mushrooms (30 to 150 mg/kg) (Turkekul et al., 2004) and lentils (44–54 mg/kg) (Thavarajah et al., 2009), but more than that reported in *B. sacra* commercial frankincense (0.075 mg/kg) (Alshwyeh et al., 2024), and chickpeas (0.37–0.74 mg/kg) (Thavarajah and Thavarajah, 2012). Manganese content ranged from 0.031 mg/kg in Sha'bi to 0.075 mg/kg in Hojari frankincense, more than that in *B. sacra* commercial frankincense (0.01 mg/kg) (Alshwyeh et al., 2024) and less than that in mushrooms (64 mg/kg) (Turkekul et al., 2004).

The total amount of lead in the human body is about 10 μg/dL in adults and 1.4 μg/dL in children; however, lead is a toxic heavy metal that can find its way into animals and plants from soil, water, and air (Collin et al., 2022). The U.S. Food and Drug Administration (FDA) (2025) monitors and regulates lead levels in foods because there is no known safe threshold level of exposure to lead. The FDA specifies the dietary intake reference value for lead in young children as 0.26 μg/kg/day and 0.16 μg/kg/day in older children and adults. The main concern about lead is its cognitive effect on children; therefore, lead levels obtained from dietary consumption should be limited in babies and young children (Wong et al., 2022).

In Oman, homemade frankincense-flavored water is prepared by soaking frankincense in drinking water, and many people chew frankincense. In Iran, some researchers (Ghabel and Khadivzadeh, 2009) reported that 263 (29.2%) of the interviewed 900 pregnant women ate frankincense during pregnancy to enhance the intelligence of their babies. It would be crucial to determine the levels of lead that reach the fetus because lead has the potential to pass through the placenta into the fetus. Preventing direct exposure to lead and maintaining a sufficient diet can halt its accumulation in the body's organs and tissues (Collin et al., 2022). The highest lead concentration in the present study was 0.015 mg/kg, which is less than that reported in *B. sacra* commercial frankincense (Alshwyeh et al., 2024), and mushrooms (Turkekul et al., 2004). Lead levels in baby foods were found to be 0.01–0.1 μg/g (Iwegbue et al., 2010). The allowable level of lead in bottled water is 5 parts per billion (ppb), as set by the U.S. Food and Drug Administration (FDA) (2025); thus, it is less than that was found in this study (15 ppb), but 15 ppb is the level allowed by the U.S. Environmental Protection Agency for lead in public drinking water, as lead that can leach from pipes is taken into consideration for the tap water standard [U.S. Food and Drug Administration (FDA), 2025]. These findings suggest that continuous monitoring of minerals in frankincense is crucial to ensure they remain within recommended levels, especially for toxic elements like lead (Alyahya and Asad, 2020; Amer et al., 2023; Alshwyeh et al., 2024).

4.4 Impact of commercial bottled water with frankincense oil on *E. coli* survival and growth

In the present study, commercial bottled frankincense-flavored water did not exhibit any inhibitory effect on the growth of *E. coli*. This conclusion is supported by statistical analysis, which showed no significant differences ($P > 0.05$) in *E. coli* counts between plain and frankincense-flavored water samples on both SPCA and TBX media at all time points. Instead, a consistent growth pattern was observed across both treatments, where bacterial counts increased gradually between 1 and 6 h, followed by a more pronounced rise up to 24 h of incubation. The effect of incubation time was statistically significant, as *E. coli* counts at 24 h were significantly higher ($P < 0.05$) than those at earlier time points (0, 1, and 6 h), indicating time-dependent bacterial proliferation rather than treatment-related effects. In contrast, no significant differences ($P > 0.05$) were detected among counts at 0, 1, and 6 h, suggesting limited variability during the early stages of incubation. The highest bacterial load was recorded at 24 h (mean 6.0 ± 0.13 log CFU/mL), compared to the initial count at 0 h (mean 5.5 ± 0.05 log CFU/mL), with relatively low standard deviations indicating good reproducibility of the data. Furthermore, the absence of significant differences between counts obtained on TBX and SPCA over time suggests that frankincense-flavored water did not induce sublethal injury to *E. coli* cells. Typically, exposure to antimicrobial stress results in injured cells that require recovery before growth can resume, which would manifest as discrepancies between selective and non-selective media. The comparable counts observed in this study indicate that the cells remained physiologically intact, supporting the conclusion that frankincense, under the tested conditions, did not exert a measurable antimicrobial or damaging effect (Hoadley and Cheng, 1974; Bonnet et al., 2020).

Previous studies indicated that *E. coli* can survive for extended periods in bottled water, with survival influenced by temperature and water type. Higher survival rates were observed at 10 °C and 23 °C compared to 4 °C (Al-Qadiri et al., 2011; Schalli et al., 2023). Although water does not provide many nutrients for bacterial growth, the results demonstrated the ability of *E. coli* to multiply in bottled drinking water with or without frankincense essential

oil (0.05%). This indicates that the incorporation of frankincense essential oil at low concentration, as claimed commercially, is unlikely to change microbial integrity in foods and beverages, although more investigation is required to test its effects on different microbial types, especially live bacteria present as probiotics in functional foods. Previous research proved that the minimum inhibitory concentration (MIC) of different grades of frankincense essential oils is much higher than what is used commercially in the tested samples. For example, an MIC of 1.56% (*v*/*v*) was found with *E. coli* using Hajari and Sha'bi grades (Al-Kharousi et al., 2023). Frankincense has already been given general recognition as safe (GRAS) status (NO. 2765) as a flavor agent by the Flavor Extract Manufacturers' Association (FEMA). Investigating the potential of using frankincense extracts on the health of individuals and linking this to its safety on the body, and to its effects on the sensory attributes of foods and consumer preferences is a hot topic gaining the attention of researchers (Miran et al., 2022).

Frankincense remains a vital economic and cultural commodity globally and in Oman. Its diverse applications in traditional medicine, cosmetics, and aromatherapy drive a robust market (Pullaiah, 2023). However, addressing sustainability challenges is essential to maintain its production and trade for future generations (Brendler et al., 2018). Moreover, there are concerns about the quality and labeling of frankincense products in the market. A survey revealed that many products do not comply with label declarations, which can undermine consumer confidence (Meins et al., 2016). The use of frankincense in food products must comply with food safety regulations to ensure consumer safety. Issues such as the interaction of frankincense oil with packaging materials need to be addressed to prevent contamination (Al-Kharousi et al., 2014). The use of advanced encapsulation and extraction techniques can significantly enhance the functionality of frankincense in food. Utilizing microencapsulation and nanoencapsulation, frankincense formulations (enclosing frankincense compounds within micro or nano-sized particles) can improve their solubility, stability, and bioavailability, making them more suitable for functional food applications (Al-Balushi et al., 2024; Xu et al., 2024). Spray drying is another technique that involves converting frankincense extracts into a dry powder form, which can enhance their stability and ease of incorporation into various food products (Golchin et al., 2022). The electrospraying technique uses electrical forces to create fine particles for encapsulation. It is a promising method for encapsulating sensitive compounds without exposing them to high temperatures or toxic solvents, thus preserving their functionality (Tanhaei et al., 2021). Advanced extraction methods can also enhance the functionality of frankincense by increasing the yield and purity of its bioactive compounds. Frankincense extracts can be added to beverages and fermented products to enhance their nutritional and functional properties. Encapsulation can help in the controlled release of bioactive compounds, improving their effectiveness (Al-Kharousi, 2025).

This investigation focused on determining the physicochemical properties of the two most available grades of frankincense in Oman, Hojari and Sha'bi. It also provided, for the first time, a measurable evaluation of the survival of *E. coli* in commercial bottled drinking water flavored with frankincense. Beyond the descriptive findings, the observed differences in physicochemical properties between the two grades can be interpreted within the framework of food matrix-microbe interactions, where parameters such as solubility and resin composition influence the availability and diffusion of bioactive compounds, thereby affecting microbial survival. Moreover, our previous research of essential oils derived from the same frankincense Hojari and Sh'bi grades proved that they have similar antimicrobial activity (Al-Kharousi et al., 2023), indicating that the essential oil of either grade can be utilized for their antimicrobial potential.

The implication of the results suggests that differences in the physicochemical characteristics of the two grades can guide their selection for different food applications, influencing their texture, color, and potentially microbial stability depending on the food matrix. The study is limited to testing frankincense obtained only from *Boswellia sacra* and evaluating its activity in water rather than in more complex food systems, where interactions with fats, proteins, and carbohydrates may alter antimicrobial performance. Additionally, sensory evaluation was not conducted to correlate physicochemical differences with consumer preference. Future research should explore these properties across different *Boswellia* species and in diverse food matrices, as well as integrate sensory and functional analyses to better establish structure-function-perception relationships.

5 Conclusions

The results demonstrated significant differences in the physicochemical properties of Hojari and Sha'bi frankincense, supporting their selective use in industrial applications based on functional requirements. Despite these differences, both grades exhibited comparable mineral profiles, although attention to lead levels is necessary to ensure consumer safety. The lack of inhibitory activity of 0.05% frankincense in water against *E. coli* indicates that this concentration is not effective for microbial control in aqueous systems. Collectively, these findings emphasize the importance of grade-specific characterization for application-driven use and highlight the need for establishing safety standards for frankincense products intended for internal consumption. Future research should evaluate frankincense in more complex food matrices and at different concentrations or extraction forms to better assess its antimicrobial potential. Comparative studies across different *Boswellia* species and inclusion of sensory evaluation are also recommended. Additionally, safety assessments, particularly regarding heavy metals, and mechanistic studies on the release and activity of bioactive compounds are needed.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ZA-K: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. AM: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. MR: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. An AI tool was used to explore and collect references using Scopus AI (Elsevier), via https://www.scopus.com/search/form.uri?display=basic#scopus-ai (accessed on 8 January 2026).

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Supplementary material

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