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Artículo Original

Natural biopreservation of yogurt with cinnamon and chamomile essential oils: Microbial stability, physicochemical changes, and sensory acceptance

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Abstract: Introduction. Yogurt is a fermented dairy product with probiotic benefits, in addition to being nutritious; however, it is highly susceptible to microbial spoilage, particularly by molds and yeasts. In response to the growing demand for clean-label food alternatives, natural preservatives such as essential oils have emerged as promising options to enhance yogurt shelf life and safety. **Objective.** To evaluate the effects of natural biopreservation using cinnamon (*Cinnamomum verum*) and chamomile (*Matricaria chamomilla* L.) essential oils on quality and shelf-life of yogurt. **Materials and methods.** Different formulations were prepared with 0.05% and 0.10% of each essential oil, individually and in combination, and stored at 4 °C for 42 days. The physicochemical properties, sensory attributes and microbial counts (days 1, 21, and 42) were analyzed. **Results.** It was observed that both essential oils, particularly cinnamon alone and in combination with chamomile, at 0.05%, significantly inhibited the growth of molds and yeasts without negatively affecting pH, titratable acidity, or syneresis. The 0.05% concentration maintained better sensory acceptance, preserving desirable taste, aroma, texture, and overall quality; while formulations with 0.10% concentrations presented slightly altered flavor but remained within acceptable limits. The application of both essential oils combined provided synergistic antimicrobial effects and enhanced shelf life while preserving product quality. **Conclusions.** These findings support the use of cinnamon and chamomile essential oils as effective natural biopreservatives for yogurt, aligning with clean-label trends and improving both food safety and consumer satisfaction. **Arch Latinoam Nutr 2026; 76(3): 235-243.**

Keywords: Chamomile, cinnamon, essential oils, biopreservation, yogurt.

Resumen: Biopreservación natural del yogurt con aceites esenciales de canela y manzanilla: estabilidad microbiana, cambios fisicoquímicos y aceptación sensorial. Introducción. El yogurt es un producto lácteo fermentado nutritivo con beneficios probióticos, pero vulnerable al deterioro microbiano, principalmente por mohos y levaduras. Ante la creciente demanda de productos con etiqueta limpia, los conservadores naturales, como los aceites esenciales, han emergido como alternativas prometedoras para mejorar la vida útil y la inocuidad del yogurt. **Objetivo.** Evaluar el efecto de los aceites esenciales de canela (*Cinnamomum verum*) y manzanilla (*Matricaria chamomilla* L.) sobre la calidad y vida útil del yogurt. **Materiales y métodos.** Se elaboraron formulaciones con 0,05% y 0,10% de cada aceite esencial, individualmente y en combinación; y se almacenaron a 4 °C durante 42 días. Se analizaron las propiedades fisicoquímicas, los atributos sensoriales y recuentos microbianos (días 1, 21 y 42). **Resultados.** Se evidencia que ambos aceites esenciales, particularmente el de canela y la combinación al 0,05%, inhibieron significativamente el crecimiento de mohos y levaduras sin afectar negativamente el pH, la acidez titulable y la sinéresis. La concentración de 0,05% favoreció la aceptación sensorial, manteniendo sabor, aroma, textura y calidad general, mientras que la aplicación al 0,10% provocó ligeras alteraciones de sabor dentro de límites aceptables. La combinación de aceites esenciales generó un efecto antimicrobiano sinérgico que prolongó la vida útil del producto sin comprometer sus características. **Conclusiones.** Estos hallazgos respaldan el uso de aceites esenciales de canela y manzanilla como bioconservadores naturales eficaces para el yogurt, alineados con las tendencias de etiqueta limpia y con el potencial de mejorar la seguridad alimentaria y la satisfacción del consumidor. **Arch Latinoam Nutr 2026; 76(3): 235-243.**

Palabras clave: Manzanilla, canela, aceites esenciales, biopreservación, yogurt.

Introduction

Yogurt is a widely consumed fermented dairy product valued for its nutritional and health-promoting properties, largely attributed to its probiotic content (1–2). Probiotics —live microorganisms that confer health benefits when consumed in adequate amounts— contribute to the prevention of diarrhea, improvement of lactose digestion in individuals with lactose

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malabsorption, and to the modulation of the host immune response (3).

Despite these benefits, yogurt is highly susceptible to microbial spoilage, mainly caused by yeasts (e.g., *Candida, Kluyveromyces*, and *Saccharomyces*) and molds (e.g., *Penicillium* and *Rhizopus*), which can grow even under refrigeration, resulting in off-flavors, gas production, textural defects, and visible deterioration (4–6). Spoilage-related losses in dairy products are estimated to reach up to 20% globally, with increases of 11–25% linked to fungal contamination (7).

In response to the growing demand for clean-label foods and reduced use of synthetic preservatives (8), essential oils (EOs) have emerged as promising natural alternatives due to their antimicrobial, antifungal, and antioxidant activities (9–11). These effects are mainly attributed to bioactive compounds such as cinnamaldehyde and eugenol, which disrupt microbial membranes and inhibit metabolic functions (12). Cinnamon (*Cinnamomum verum*) EO shows strong antifungal and antibacterial activity and is classified as GRAS by the FDA (13), while chamomile (*Matricaria chamomilla* L.) EO has demonstrated antimicrobial and antifungal properties against a wide range of microorganisms. This effect may be attributed to the ability of essential oil compounds to disrupt mitochondrial dehydrogenase activity and the electron transport chain, thereby inhibiting spore germination and mycelial growth. Similarly, Shahin et al. (14) found that yogurt supplemented with oregano (*Origanum vulgare*) and thyme (*Thymus vulgaris*) essential oils remained microbiologically stable for up to 150 days under refrigeration, whereas untreated yogurt exceeded acceptable limits after 30 days (14-15). However, their strong aroma may affect sensory acceptance, making it necessary to identify effective yet acceptable concentrations. Therefore, this study aimed to evaluate the effect of cinnamon and chamomile essential oils, individually and in combination, on the physicochemical parameters, microbiological quality, sensory properties, and shelf life of yogurt, contributing to the development of safer, clean-label dairy products.

Materials and methods

The present study was developed from January to November 2024, including the stages of formulation, fermentation, sensory evaluation and storage.

Materials

The yogurt starter culture used in this study was a direct-to-vat blend of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* (Chr. Hansen–Peyma, Istanbul, Turkey). Fresh cow's milk was obtained from a dairy farm in Lagos de Moreno, Jalisco, Mexico. Essential oils of *Matricaria chamomilla* L. and *Cinnamomum verum* were used as functional additives.

Yogurt manufacturing process

Yogurt samples were prepared using 21 L of standardized cow's milk (3% fat, 14% total solids). The milk was filtered, pasteurized at 85 °C for 30 min (16), and cooled to 43 ± 2 °C before inoculation with 0.15 DCU/L of the starter culture. The inoculated milk was divided into seven 3-L batches: two cinnamon EO treatments (CEO 0.05% and 0.10%), two chamomile EO treatments (ChEO 0.05% and 0.10%), two cinnamon–chamomile blends (CChEO 0.05% and 0.10%), and a control without EO. All samples were fermented until coagulation and stored at 4 °C until analysis.

Physicochemical analyses

Physicochemical analyses were performed according to AOAC methods (17). Moisture and total solids were determined gravimetrically by drying samples at 105 ± 2 °C to constant weight (18). Crude protein was quantified using the Kjeldahl method with a nitrogen-to-protein factor of 6.38. Fat content was measured using the Gerber method. Ash content was determined by incineration of pre-dried samples at 550 ± 25 °C for 5 h (19). pH was measured at room temperature using a calibrated digital pH-meter. Titratable acidity, expressed as lactic acid percentage, was determined by titrating 20 mL of yogurt with 0.1 M NaOH using 0.1% phenolphthalein as indicator (20).

Microbiological analyses

Microbiological analyses included the enumeration of total aerobic mesophilic bacteria, total coliforms, and total molds and yeasts on days 1, 21, and 42 of refrigerated storage. For each sampling time, 10-fold serial dilutions were prepared in isotonic saline solution and plated in duplicate on selective media. Total aerobic mesophilic bacteria were counted on Plate Count Agar (BD Bioxon, Mexico) after incubation at 35 °C for 48 h. Total coliforms were determined on Violet Red Bile Agar (BD Bioxon, Mexico) under the same conditions. Molds and yeasts were enumerated on Potato Dextrose Agar (BD Bioxon, Mexico) after incubation at 20–25 °C for 5 days (3, 21, 22). Results were expressed as colony-forming units per gram (CFU/g).

Sensory evaluation of yogurt

A sensory analysis was conducted with 30 untrained volunteer panelists aged 19–49 years (median: 21), of whom 56.67% were men and 43.33% women; 80% of participants were between 19 and 24 years old. Participants were voluntarily recruited from the University of Guadalajara and were required to be regular consumers of yogurt or fermented dairy products. Individuals with lactose intolerance, milk allergy, or known hypersensitivity to any of the ingredients used in the formulations were excluded from the study. Prior to participation, all volunteers were informed about the nature of the study and the presence of milk as a declared allergen in the samples and provided their voluntary consent to participate. The sensory evaluation was performed to assess consumer acceptance of yogurt formulations during refrigerated storage. This sample size falls within the range recommended for preliminary consumer acceptance studies conducted under controlled laboratory conditions (24).

Each participant received 10 mL of yogurt in odor-neutral, transparent plastic containers coded with randomized numbers. Evaluations were performed under controlled ambient conditions with neutral lighting on day six of refrigerated storage. A nine-point hedonic scale was used to evaluate the acceptance of the sensory attributes of odor, color, flavor, texture, syneresis, and viscosity (3, 25). The scale ranged from 1 to 9, where 1 = Strongly dislike, 2 = Dislike very much, 3 = Dislike moderately, 4 = Dislike slightly, 5 = Neither like nor dislike, 6 = Like slightly, 7 = Like moderately, 8 = Like very much, and 9 = Strongly like (3, 23). Between samples, panelists cleansed their palates with water and unsalted crackers to prevent flavor carryover. Environmental conditions and sample presentation were strictly controlled to ensure the reproducibility and reliability of the sensory data.

Statistical analyses

All experiments were performed in triplicate. Results were expressed as mean values ± standard deviation. Statistical significance was evaluated using one-way analysis of variance (ANOVA), and differences among group means were determined by Tukey's test ($p < 0.05$). Pearson's correlation coefficients were calculated to determine the strength and direction of the relationships among sensory attributes of yogurt formulations. Statistical analyses and graphical representations were performed in R software (version 4.4.2).

Results

To evaluate the effect of essential oils on acidity and pH during fermentation, each treatment was monitored throughout the 6-h process. A consistent decrease in pH was observed in all samples, dropping from 6.50 to approximately 4.50 and following a similar trend among treatments (Figure 1a).

Concurrently, titratable acidity increased from 0.15% to values ranging between 0.62% and 0.85% (Figure 1b). The lowest acidity was observed in the ChEO 0.05% treatment, followed by the control, ChEO 0.10%, CChEO 0.10%, CChEO 0.05%, CEO 0.10%, and CEO 0.05%, in ascending order.

On the other hand, the addition of cinnamon and chamomile essential oils, either individually or in combination, influenced yogurt pH and titratable acidity during storage (Table 1). All treatments, including the control, showed a gradual decrease in pH and a corresponding increase in acidity, indicating continued lactic acid production by yogurt starter cultures. By day 42, the CEO 0.10% treatment exhibited the lowest acidity. In contrast, CEO 0.05% showed the lowest pH and the highest acidity, even exceeding the control. The CChEO 0.05% treatment slightly enhanced acidification, whereas CChEO 0.10% presented intermediate values and did not differ significantly from the control at the end of storage. These findings indicate a different effect on acidification depending on the type of EO, where lower doses

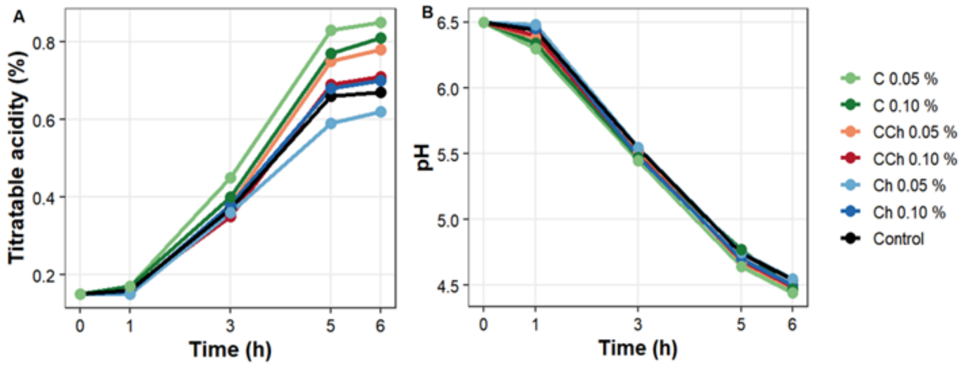

Figure 1. Titratable acidity (a), and pH values (b) in yogurt samples supplemented with different concentrations of cinnamon (CEO) and chamomile (ChEO) essential oils, and their mixture (CChEO) during fermentation.

of CEO and CChEO promoted acidification to a greater extent than higher doses, while treatment with ChEO has the opposite effect. In all cases, the lowest pH and highest acidity of treatments were recorded at the final sampling point of the experiment.

The incorporation of ChEO, CEO, and CChEO did not produce statistically significant differences in total solids ($F_{6,14}$=2.12, p=0.13), moisture ($F_{6,14}$=3.45, p=0.60), protein ($F_{6,14}$= 6.688, p = 0.00167, Milk-fat ($F_{6,14}$=2.15, p=0.50), Non-Fat solids ($F_{6,14}$=0.68, p=0.056) or ash content ($F_{6,14}$=0.88, p=0.54) compared with the control, indicating a stable physicochemical composition (Table 2). Total solids ranged from 12.10% to 12.73%, with CEO 0.10% showing the highest value, while moisture varied inversely (87.90–86.91%). Ash content did not differ significantly among treatments, although ChEO 0.10% showed the highest mean value 1.16 ± 0.40%.

Table 1. Changes in titratable acidity and pH of yogurt samples supplemented with different concentrations of cinnamon (CEO) and chamomile (ChEO) essential oils, and their mixture (CChEO) during shelf life.

Sample	Day 1		Day 21		Day 42	
	pH	Acidity	pH	Acidity	pH	Acidity
Control	4.65±0.08^{a}	0.78±0.03^{a}	4.53±0.01^{b}	0.87±0.02^{a}	4.56±0.01^{c}	0.87±0.00^{b}
ChEO 0.05 %	4.72±0.12^{a}	0.74±0.05^{a}	4.59±0.00^{a}	0.77±0.02^{c}	4.63±0.00^{a}	0.80±0.02^{d}
ChEO 0.10 %	4.69±0.10^{a}	0.75±0.09^{a}	4.56±0.01^{b}	0.84±0.01^{b}	4.59±0.01^{b}	0.84±0.01^{c}
CEO 0.05 %	4.58±0.18^{a}	0.83±0.05^{a}	4.47±0.00^{c}	0.92±0.09^{a}	4.45±0.00^{d}	0.91±0.03^{a}
CEO 0.10 %	4.68±0.04^{a}	0.71±0.07^{a}	4.57±0.05^{ab}	0.75±0.07^{c}	4.59±0.02^{b}	0.79±0.00^{d}
CChEO0.05 %	4.50±0.15^{a}	0.82±0.07^{a}	4.48±0.03^{c}	0.90±0.06^{a}	4.49±0.02^{c}	0.91±0.02^{a}
CchEO0.10%	4.62±0.14^{a}	0.75±0.06^{a}	4.57±0.03^{ab}	0.84±0.07^{bc}	4.55±0.05^{bc}	0.89±0.04^{ab}

Data are presented as mean ± standard deviation from three independent measurements. Different letters indicate statistically significant differences among treatments according to Tukey's test (p < 0.05) for each date evaluated in the study.

Table 2. Chemical composition of yogurt samples supplemented with concentrations of cinnamon (CEO) and chamomile (ChEO) essential oils, and their mixture (CChEO).

Sample	TS*	Moisture*	Ash*	Milk-fat *	Protein*	Non-fat solids*
Control	12.27±0.07[a]	87.74±0.06[a]	0.81±0.01[a]	3.45±0.15[b]	3.30±0.10[a]	8.82±0.15[ab]
ChEO 0.05 %	12.47±0.07[a]	87.54±0.08[a]	0.84±0.05[a]	3.60±0.10[ab]	3.12±0.17[a]	8.87±0.10[ab]
ChEO 0.10 %	12.20±0.02[a]	87.81±0.01[a]	1.16±0.40[a]	3.55±0.05[ab]	3.22±0.07[a]	8.65±0.05[b]
CEO 0.05 %	12.10±0.3[a]	87.90±0.3[a]	0.79±0.04[a]	3.55±0.05[ab]	3.18±0.22[a]	8.55±0.05[c]
CEO 0.10 %	12.73±0.33[a]	86.91±0.03[a]	0.85±0.02[a]	3.65±0.15[ab]	3.13±0.27[a]	9.08±0.15[a]
CChEO 0.05 %	12.56±0.15[a]	87.44±0.15[a]	0.78±0.12[a]	3.60±0.05[ab]	3.08±0.11[a]	8.90±0.05[ab]
CChEO 0.10 %	12.69±0.01[a]	87.31±0.01[a]	0.84±0.03[a]	3.65±0.01[a]	3.15±0.13[a]	9.04±0.01[a]

*Results are expressed as a percentage based on 100 mL of yogurt. Data are presented as mean ± standard deviation from three independent measurements. Different letters indicate statistically significant differences among treatments according to Tukey's test ($p < 0.05$) for each parameter evaluated in the study.

Microbiological stability. At D+1 microbial counts of all samples were below the detection limit. By D+21, total aerobic mesophilic bacteria (TAB) and Total coliforms (TC) remained undetectable, whereas molds and yeasts (MY) appeared in the control (410 CFU/g). In contrast, CEO 0.05% and CChEO 0.05% maintained undetectable MY levels, indicating early antifungal activity. At D+42, the control showed a marked increase in MY (5.6×10^6 CFU/g), while CEO 0.05% and CChEO 0.05% continued to inhibit fungal growth (Table 3). All treatments remained free of detectable TAB and TC throughout storage, confirming the good practices during elaboration of products.

The radar chart (Figure 2) shows that texture scores were similar among treatments, although CEO, particularly at 0.05%, showed slightly higher values ($F_{6,203}$=2.50,

Table 3. Microbial counts (CFU/g) in yogurt samples supplemented with different concentrations of cinnamon (CEO) and chamomile (ChEO) essential oils, and their mixture (CChEO) stored at 4 °C on days 1, 21, and 42.

Day		Control	ChEO 0.05%	ChEO 0.10%	CEO 0.05 %	CEO 0.10 %	CChEO 0.05 %	CChEO 0.10%
1	TAB	Absent	Absent	Absent	Absent	Absent	Absent	Absent
	MY	Absent	Absent	Absent	Absent	Absent	Absent	Absent
	TC	Absent	Absent	Absent	Absent	Absent	Absent	Absent
21	TAB	Absent	Absent	Absent	Absent	Absent	Absent	Absent
	MY	410	40	380	Absent	30	Absent	80
	TC	Absent	Absent	Absent	Absent	Absent	Absent	Absent
42	TAB	Absent	Absent	Absent	Absent	Absent	Absent	Absent
	MY	5.6×10^6	1.5×10^4	4.0×10^4	Absent	1.0×10^4	Absent	3.5×10^4
	TC	Absent	Absent	Absent	Absent	Absent	Absent	Absent

TAB: Total aerobic mesophilic bacteria; MY: Molds and yeasts; TC: Total coliforms; Absent: below detection limit.

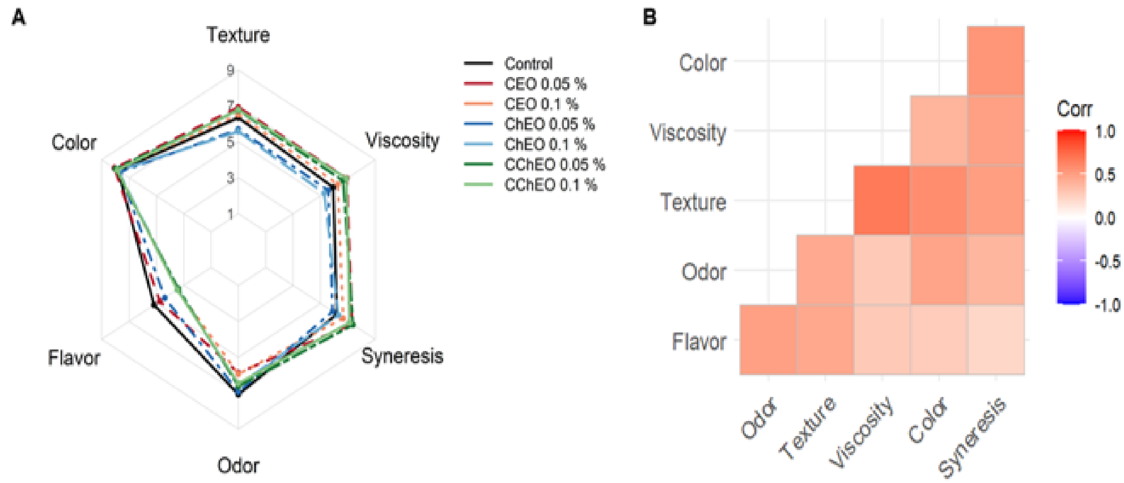

Figure 2. Sensory profile and Pearson correlation analysis of yogurt samples supplemented with cinnamon essential oil (CEO), chamomile essential oil (ChEO), and their mixture (CChEO) on day 6 of storage. (A) Radar plot of sensory attributes. (B) Pearson correlation heatmap among sensory parameters.

$p=0.24$). The control and CEO 0.05% samples obtained the highest scores in flavor (close to 5, "neither like nor dislike"), while higher EO concentrations resulted in lower acceptability ($F_{6,203}=3.41$, $p=0.003$). No significant differences were observed in color among treatments ($F_{6,203} = 0.29$, $p = 0.940$), indicating that the incorporation of chamomile essential oil (ChEO), cinnamon essential oil (CEO), and their combination (CChEO) did not affect the visual appearance of the yogurt samples.

Regarding the odor, the control and CEO-treated samples were better accepted, whereas ChEO and CChEO had lower scores ($F_{6,203}=1.83$, $p=0.094$). Significant differences were observed in syneresis, consistent with the stable physicochemical results ($F_{6,203}=3.51$, $p=0.0026$). Perceived viscosity was higher in samples containing CEO 0.10% and CChEO 0.10% ($F_{6,203}=4.96$, $p=0.0009$). Overall, CEO, alone or combined, had a more favorable impact on sensory attributes, while ChEO alone negatively affected flavor and odor.

Discussion

According to international standards, including the Codex Alimentarius (26), a product can only be denominated as "yogurt" when it is obtained through the fermentation of milk by the specific symbiotic cultures *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*, and when it reaches the characteristic titratable acidity (0.06% of lactic acid) and texture associated with this process (27). In the present study, fermentation followed the conventional microbiological sequence: *S. thermophilus* initiated rapid lactose metabolism, producing lactic acid and causing a decrease in pH during the early stages of fermentation. This initial acidification created favorable conditions for the activation and subsequent dominance of *L. delbrueckii* subsp. *bulgaricus* (4, 7), which continued lactic acid production until the final pH reached values between 4.4 and 4.6.

This pH range, together with the observed coagulation, viscosity development, and characteristic sensory properties, confirms that the obtained product fulfills the physicochemical and microbiological criteria required for its classification as yogurt. Furthermore, the standardized composition of the milk met the minimum requirements for fat, protein, and non-fat solids, ensuring adequate substrate availability for fermentation and subsequent gel formation (4, 12, 23). Although essential oils were incorporated as natural functional additives, they did not alter the fundamental fermentation pathway nor interfere with the obligatory metabolic activity of the yogurt starter cultures. Therefore, all formulations produced in this study can be correctly classified and designated as yogurt according to the Codex Alimentarius (26).

Moreover, acidity is a critical factor influencing both the shelf life and consumer acceptability of yogurt. In the present study, titratable acidity increased in all samples during storage. However, no significant differences were observed among the treatments and the control in the fresh product (D+1), indicating that the acidity increase was associated with natural post-acidification rather than with the addition of essential oils. A similar trend was reported by Yangilar and Yildiz (3), who observed elevated titratable acidity in both control yogurt and yogurt supplemented with ginger and chamomile EOs. Therefore, the observed increase in acidity can be attributed to the continued metabolic activity of lactic acid bacteria (28) present in all samples, and not to the essential oils. The low acidity caused by CEO 0.10% treatment at the end of storage, may be related to an inhibitory effect on the fermentative activity of the yogurt microbes, probably related to the presence of cinnamaldehyde in this EO (27, 28).

Yogurt is highly valued for its nutritional composition, particularly in terms of minerals, proteins, and carbohydrates (1-3). In this context, the present results indicate that the incorporation of chamomile and cinnamon essential oils did not significantly modify these parameters when compared to the control. These findings support the notion that the addition of the evaluated essential oils does not compromise the compositional integrity of yogurt, highlighting their potential suitability as natural preservatives. This is consistent with the findings of Kamel et al. (2), who reported no significant differences in the bromatological composition of yogurt supplemented with rosemary EO during storage.

Furthermore, total aerobic mesophilic bacteria (TAB) and total coliforms (TC) remained below detection limits in all treatments, thereby confirming the microbiological safety and hygienic quality of the formulated yogurts. The antifungal activity observed can be primarily attributed to cinnamaldehyde, the main bioactive compound in cinnamon essential oil. In this context, cinnamaldehyde disrupts fungal cell membranes by inhibiting ergosterol biosynthesis, increasing membrane permeability, and promoting the leakage of intracellular contents. In addition, it interferes with essential enzymatic processes and induces oxidative stress, ultimately leading to fungal growth inhibition and cell death (29-30). Interestingly, antifungal effects were only observed at the 0.05% concentration of CEO and the CChEO mixture, whereas an increase in CEO concentration to 0.10% resulted in reduced fungal and yeast inhibition. This phenomenon may be explained by possible interactions between essential oil components and the yogurt matrix (31, 32), which could limit their bioavailability or antimicrobial efficacy at higher concentrations.

Sensory attributes of yogurt, particularly flavor, odor, viscosity, texture, and syneresis, remained stable across all treatments, consistent with the physicochemical results, indicating that the concentrations of essential oils used affect product acceptability. Although yogurts supplemented with CEO 0.05%, showed slightly higher texture scores, no significant differences were observed among treatments ($F_{6,196} = 2.50$, $p = 0.24$), suggesting that the addition of essential oils did not significantly influence texture perception. Additionally, CEO 0.05%, was among the best rated in terms of overall acceptability, with flavor values comparable to the control and close to the neutral point of the hedonic scale. In contrast, formulations containing chamomile essential oil (ChEO), either alone or combined, received lower scores for flavor ($F_{6,203}=3.41$, $p=0.003$) and odor ($F_{6,203}=1.83$, $p=0.094$). This reduction in acceptability is likely associated with the herbaceous and slightly bitter notes characteristic of ChEO, which may have interfered with the typical sweet–acid profile of yogurt. Perceived viscosity was highest in samples containing 0.10% EOs, suggesting a possible interaction between oil components and the protein network (32), which enhanced the perceived body of the product without increasing syneresis.

These findings suggest a non-linear dose–response behavior, in which increasing the concentration of essential oils does not necessarily enhance antimicrobial performance. Interactions between hydrophobic EO compounds and milk proteins or fat globules may reduce the availability of bioactive molecules, partially explaining the lower antifungal effectiveness observed at 0.10% CEO.

Overall, these findings indicate that CEO, particularly at 0.05%, represents the most promising treatment in terms of sensory acceptance, while higher concentrations and ChEO formulations may negatively impact flavor and aroma. This highlights the importance of optimizing essential oil type and concentration to balance microbial stability with consumer acceptance. These trends were consistently perceived by consumers, as evidenced by the acceptable panel variability observed in the sensory evaluation. The Root Mean Square Error divided by the Scale Length (RMSL) ranged from 0.173 to 0.206, indicating adequate discrimination ability and consistency among consumer responses.

In this sense, Pearson's correlation matrix revealed strong positive correlations between texture and viscosity, as well as between texture and syneresis, indicating that textural perception was influenced by multiple interconnected attributes. Likewise, odor was strongly associated with flavor, suggesting that aroma–flavor interactions played a key role in consumer acceptance. These relationships help explain the superior sensory performance of CEO 0.05% and demonstrate that yogurt acceptability depends on the combined interaction of sensory attributes rather than on individual characteristics alone.

Conclusions

The addition of cinnamon and chamomile essential oils did not affect yogurt fermentation or its basic composition. A concentration-dependent effect was observed during storage, where CEO 0.05% and CChEO 0.05% enhanced post-acidification and effectively inhibited mold and yeast growth for up to 42 days, while maintaining microbiological safety. Sensory analysis showed that yogurt supplemented with 0.05% CEO achieved the highest acceptability, whereas higher concentrations or the addition of ChEO reduced flavor and odor acceptance. These results indicate a non-linear dose–response effect, suggesting that higher essential oil concentrations do not necessarily improve yogurt performance, likely due to interactions with the yogurt matrix. Overall, cinnamon essential oil at 0.05% appears to be the most effective natural alternative to extend yogurt shelf life without compromising sensory quality, contributing to the development of safer, clean-label dairy products.

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Conflict of interest

The authors declare that they have no conflicts of interest.

Contribution by the authors

JJBF, XAF: conception, research design, development and validation of the methodology, formal analysis and interpretation of data; review, editing, and approval of the final version of the manuscript. OIG, CEOC, LMG, SIG: conduct of experiments and data collection; drafting of the original manuscript; review, editing, and approval of the final version of the manuscript.

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