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Enhancing the Shelf Life and Sensory Quality of Soy Milk Yoghurt through Lemongrass (Cymbopogon citratus) Extract for Improved Nutritional Utilization

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Abstract

Soy milk yoghurt is a nutritious, affordable plant-based dairy alternative, but lipoxygenase-derived beany off-flavours limit its acceptance. Lemongrass (Cymbopogon citratus) extract was evaluated as a natural flavour-masking and antimicrobial additive for soy yoghurt. Five formulations containing 0, 25, 50, 75, and 100 µL L^{-1} lemongrass extract (SYCO, SYT3, SYT5, SYT7, SYT9) were prepared in a completely randomized design and monitored over 15 days of refrigerated storage for total viable counts (TVC), yeast and mould loads (triplicate plate counts), and sensory acceptability (five-point hedonic scale, 10 trained panellists). SYT9 (100 µL L^{-1}) showed the numerically lowest microbial counts at Day 15, with TVC declining 80.2% from Day 1 and remaining 75.2% below the control; yeast and mould counts followed the same trend. These differences were not statistically significant (one-way ANOVA, $p > 0.05$ for all comparisons), likely reflecting the small number of replicates ($n = 3$) per treatment. SYT9 also achieved the highest scores for appearance, aroma, taste, mouthfeel, and overall acceptability throughout storage, while the unfortified control declined markedly on all sensory attributes. These results indicate that lemongrass extract consistently improved the sensory quality of soy yoghurt and produced a numerical, though not yet statistically confirmed, reduction in microbial load, supporting its potential as a low-cost, natural strategy for extending shelf life and nutritional utilization of soy-based dairy alternatives in resource-limited settings. Larger, adequately replicated trials are recommended to confirm the antimicrobial effect.

Keywords Lipoxygenase · Lemongrass extract · Malnutrition · Plant-based foods · Soy yogurt · Shelf-life extension

1. Introduction

In recent years, the global food sector has undergone a major transformation, shifting strongly towards healthier, plant-based, and naturally fortified products [1,2]. This shift has been driven by rising consumer demand for nutritious, minimally processed foods that combine functional and sensory quality, by growing awareness of the environmental footprint of animal-based

diets, and by public health strategies that promote affordable sources of dietary protein in both high- and low-income countries [3,4]. Within this transition, legumes occupy a central position because they deliver a favourable balance of protein, fibre, and micronutrients at a fraction of the resource cost of animal production, and because their cultivation can be integrated into smallholder farming systems that already dominate food production across sub-Saharan Africa.

Soybean (Glycine max) is one of the most widely cultivated legumes worldwide and plays a vital role in food and nutrition security owing to its high protein content (approximately 36–40% on a dry-weight basis), its favourable amino-acid profile, its essential fatty acids, and its diverse bioactive compounds, including isoflavones and saponins [5,6]. In sub-Saharan Africa, including Rwanda, soybean cultivation is expanding rapidly because of its potential to address protein-energy malnutrition and to contribute to Sustainable Development Goal 2 (Zero Hunger) [5,6]. National agricultural strategies in Rwanda have promoted soybean as a rotation and intercrop that improves soil fertility through biological nitrogen fixation while simultaneously supplying an affordable protein source to rural households. Despite this nutritional and agronomic importance, the downstream utilization of soybean in processed foods remains limited by an undesirable beany flavour, by anti-nutritional factors such as trypsin inhibitors and phytates, and by inadequate awareness among small-scale processors of diversified processing methods that could mitigate these constraints [7,8].

The beany off-flavour of soybean and its products originates primarily from the enzymatic activity of lipoxygenase, which oxidizes polyunsaturated fatty acids such as linoleic and linolenic acid during soaking, grinding, and milling to generate volatile carbonyl compounds, including hexanal, hexanol, and other short-chain aldehydes and ketones that are perceived as “grassy”, “beany”, or “green” notes [9,10]. Because this reaction begins as soon as plant cell membranes are disrupted, conventional processing steps such as soaking and blending — steps that are unavoidable in soymilk production — actively promote off-flavour formation rather than prevent it. This mechanistic detail is important because it clarifies why simple heat treatment or fermentation alone often fails to fully eliminate the beany note: pasteurisation denatures the enzyme but does not remove volatiles already formed, and lactic fermentation modifies the flavour profile without specifically targeting these compounds. Consequently, post-formation masking or complementary antioxidant strategies, such as the incorporation of aromatic plant extracts, are needed alongside conventional processing.

Soy-based beverages and fermented products such as soy milk yoghurt have emerged as promising, culturally adaptable alternatives to animal-based dairy, offering an affordable route to improved dietary protein intake in regions where fresh milk is expensive, seasonal, or difficult to store [11,12]. Lactic fermentation of soymilk with Lactobacillus and Streptococcus starter cultures additionally improves protein digestibility, reduces certain anti-nutritional factors, and can generate beneficial organic acids that extend microbial shelf-life. However, as in unfermented soymilk, the residual beany odour associated with lipoxygenase-derived volatiles continues to limit consumer acceptance of soy yoghurt, particularly among consumers accustomed to the flavour profile of dairy yoghurt [13,14]. Conventional mitigation strategies, including extended soaking, blanching, and fermentation time optimisation, improve sensory properties to some degree but rarely eliminate these undesirable traits [15,16]. This persistent

sensory barrier, more than any nutritional limitation, is what continues to restrict wider adoption of soy yoghurt as a mainstream dairy alternative in resource-limited settings.

Incorporating natural flavouring and preservative agents derived from aromatic plants has therefore become an attractive strategy for simultaneously improving palatability and shelf stability without resorting to synthetic additives, which are often costly, subject to import restrictions, and increasingly viewed unfavourably by "clean-label"-conscious consumers [17]. Lemongrass (Cymbopogon citratus), widely grown across tropical regions including Rwanda, is particularly well suited to this role: it is valued for its pleasant citral-dominant aroma, its antimicrobial and antioxidant properties, and its adaptability to diverse agro-ecological conditions, requiring minimal inputs and thriving on marginal land [18,19]. In Rwanda, the promotion of climate-resilient crops and natural bio-preservatives aligns with national priorities for sustainable food systems, as articulated in the country's First Biennial Update Report under the UNFCCC [20,21]. Beyond its established role in African traditional medicine, lemongrass is increasingly used as a food additive: alongside essential nutrients such as lipids, proteins, fibre, and minerals, its leaves contain a diverse range of bioactive phytochemicals, including flavonoids, terpenoids (notably citral), phenols, saponins, and tannins [22,23]. Citral, the dominant terpenoid in lemongrass essential oil, is understood to exert its antimicrobial effect primarily by disrupting the lipid bilayer of microbial cell membranes, increasing membrane permeability and causing leakage of intracellular contents, while flavonoids and phenolic compounds are thought to act synergistically through antioxidant and enzyme-inhibitory mechanisms. This dual functionality — simultaneously masking the beany odour of soy through its own strong aroma and extending shelf life through its antimicrobial phytochemistry — makes lemongrass a strategic, low-cost candidate for developing an eco-friendly solution to two of the main barriers limiting soy yoghurt adoption.

A growing body of literature has examined lemongrass extracts and essential oils in dairy and plant-based matrices, generally reporting improvements in microbial safety, oxidative stability, and consumer acceptance [24,25]. However, much of this work has either studied lemongrass essential oil in isolation from a full storage-stability trial, or has evaluated microbial and sensory outcomes separately rather than jointly, and few studies have systematically varied lemongrass extract concentration across a full dose gradient while monitoring both microbiological and sensory endpoints of a soy-based yoghurt over an extended storage period. Moreover, very few of these studies originate from, or have been validated under, the specific raw-material and climatic conditions of East Africa, where lemongrass and soybean are both locally abundant and where the practical case for a low-cost, natural bio-preservative is strongest. This represents a clear gap that the present study addresses.

The objective of this study was therefore to evaluate the role of lemongrass leaf extract, applied across a five-level concentration gradient (0–100 μL L^{-1}), in improving the sensory attributes, microbial stability, and nutritional appeal of soy milk yoghurt over 15 days of storage. We hypothesised that increasing lemongrass extract concentration would be associated with a consistent, dose-dependent decline in microbial load (TVC, yeast, and mould) and with improved or better-sustained sensory acceptability relative to an unfortified control, reflecting the combined antimicrobial and flavour-masking action of the extract. By integrating a

culturally familiar, locally sourced plant additive into a soybean-based product, this research responds to consumer demand for safe, nutritious, and naturally preserved foods, while contributing evidence-based strategies for combating malnutrition and food insecurity in Rwanda and comparable developing-region contexts. The remainder of this article is organised as follows: Section 2 describes the materials and methods used for yoghurt formulation, microbiological analysis, and sensory evaluation; Section 3 presents the results, discusses them against the existing literature, and reports a reanalysis of the statistical outcomes; and Section 4 concludes with recommendations for future research and practical application.

2. Materials and methods

2.1 Study area

This study was conducted at the National Industrial Research and Development Agency (NIRDA), within Ngoma sector, Huye District, Southern Province, Rwanda. It is positioned between approximately 2°36′ S and 2°45′ S latitudes, and 29°40′ E and 29°50′ E longitudes. It experiences a temperate tropical highland climate, characterized by warm temperatures with moderate humidity. The average annual rainfall ranges between 1,000 mm and 1,200 mm, and the average temperature is around 21.5 °C. The climate is generally favourable for agriculture, with alternating wet and dry seasons [15]. Samples were sourced and the experiment was conducted using a completely randomized design (CRD). Five treatments were used: SYCO, SYT3, SYT5, SYT7, and SYT9.

NIRDA was selected as the study site because it hosts both the fermentation and microbiology laboratory facilities required for this work under a single institutional roof, minimizing sample transport time and the associated risk of microbial or sensory drift between procurement, processing, and analysis. A completely randomized design was chosen, rather than a randomized block design, because all yoghurt batches were prepared from a single pooled soymilk source under uniform laboratory conditions, so no blocking factor (e.g., separate production days or operators) needed to be controlled for.

2.2 Source of soybean and lemongrass leaves

Samples of 6 kg dried soybeans were purchased from a traditional market in Huye District, Rwanda, and fresh lemongrass leaves were purchased from the Rwanda Agriculture and Animal Resources Development Board (RAB), which sells fruits and other plant produce to the public. The soybean samples were transported in a temperature-controlled container to ensure optimal conditions. Both the soybean and lemongrass leaves were sent to NIRDA laboratories for further processing, preparation, analysis, and evaluation in relation to yoghurt production.

Soybean was purchased from a traditional market to reflect the raw material that small-scale processors and households in Rwanda routinely use, which is the intended end-user context of this study. Lemongrass was used fresh (rather than sourced dried or pre-processed) specifically to preserve the volatile citral fraction responsible for its antimicrobial and aromatic activity, since this fraction degrades rapidly once leaves are cut and begin to wilt.

2.3 Soybean preparation and extraction of soy milk

Soymilk was obtained by soaking 500 g of soybeans in 2,000 ml of water for 12 hours at 25 °C. This was followed by draining the water from the soybean and rinsing with cold water. The soaked beans were blended with 200 ml of water until completely pulverized. A muslin cloth was used to filter the extract, which was then pasteurized at 65 °C for 30 minutes to obtain soy milk [16].

The 12-hour soak was used to sufficiently hydrate and soften the cotyledon for efficient blending while remaining within a duration reported to limit further activation of lipoxygenase relative to prolonged soaking; the subsequent cold-water rinse was included to remove surface-released off-flavour precursors before blending. Pasteurization at 65 °C for 30 minutes was selected as a temperature sufficient to inactivate lipoxygenase and reduce the background microbial load of the soymilk base, while remaining low enough to avoid excessive protein denaturation that could otherwise compromise the yoghurt's final texture.

2.4 Preparation of lemongrass extract

Lemongrass leaves were purchased fresh, sorted, cleaned, and cut into small pieces, then mixed with distilled water (150–200 g in 500 mL); the resulting mixture was distilled using a Clevenger apparatus at 100 °C. The vaporized distillates were condensed, and the resulting concentrated extract (essential oil) was derived from the lemongrass leaves and stored in a refrigerator at 4 °C [17].

Steam (hydro-)distillation via a Clevenger apparatus was chosen over solvent extraction because it yields a food-grade essential oil fraction free of residual organic solvent, which is an important consideration given the extract's intended use as a direct food additive. Refrigeration of the extract at 4 °C immediately after distillation was used to limit oxidative loss of citral prior to its incorporation into the yoghurt formulations.

2.5 Preparation of lemongrass-enriched soybean-based yoghurt

Pasteurized milk (65 °C, 30 minutes) was cooled to 40 °C and inoculated with 0.033 g of starter culture composed of Lactobacillus delbrueckii subsp. bulgaricus and Streptococcus thermophilus per litre of soymilk. This was followed by incubation at a maximum of 40 °C for 6 hours until the milk reached a custard-like consistency to form yoghurt [18]. The soy yoghurt was divided into five equal portions of 4 litres each. Treatments were prepared using lemongrass extract at ratios ranging from 0 to 100 µl per litre of yoghurt, producing formulations named SYCO (control, 0 µL L^{-1}), and SYT3, SYT5, SYT7, and SYT9, containing 25, 50, 70, and 100 µL L^{-1} of lemongrass extract, respectively.

Cooling to 40 °C before inoculation was necessary because this is the optimal growth temperature range for the Lactobacillus and Streptococcus starter pairing; inoculating at a higher temperature would risk culture inactivation, while a lower temperature would slow fermentation and extend processing time unnecessarily. The five-level concentration gradient (0, 25, 50, 70, and 100 µL L^{-1}) was designed to capture a dose-response relationship across the

full practical range, from no lemongrass (control) to the highest concentration judged unlikely to impart an overpowering lemongrass flavour that would itself reduce sensory acceptability.

2.6 Determination of microbial population and sensory attributes over 15 days of storage

For yeast and mould counts, yoghurt samples were first homogenized to ensure even distribution of microorganisms. Sterilized tools and aseptic procedures were used throughout to avoid contamination. Buffered peptone water was used as diluent to prepare serial dilutions and keep bacterial counts within a detectable range. Diluted samples were plated on Potato Dextrose Agar (PDA), appropriate for mould and yeast enumeration using pour-plate and spread-plate techniques. Plates were incubated for 1 to 15 days at the optimal temperature for yeast and mould growth (25 and 30 °C). Microbiological counts for yeast and mould were performed manually using a colony counter. For total plate count, each yoghurt sample was analysed in triplicate. Peptone water was used to prepare serial dilutions from 10^1 to 10^9, and 1 ml of each dilution was placed in a petri dish; 1 g of cultured soy yoghurt was aseptically withdrawn and diluted tenfold using sterile peptone water [20]. Colony-forming units (CFU) were determined using the standard plate-count formula (Eq. 1).

Days 1, 7, and 15 were selected as sampling points to capture, respectively, the immediate post-production microbial baseline, a mid-storage checkpoint representative of typical retail shelf time in the study region, and the end of a 15-day storage horizon considered representative of realistic household storage for a refrigerated dairy-alternative product.

$$Colony\ forming\ unit\ \left(\frac{CFU}{ml}\right) = \frac{Number\ of\ colonies}{Volume\ of\ inoculum}\ X\ Dilution\ factor$$

Equation (1) Colony-forming units (CFU mL^{-1}) = (number of colonies × dilution factor) / volume plated

2.7 Sensory evaluation

A total of 10 trained volunteer panellists, familiar with and regular consumers of soybean products, were invited to evaluate the samples in triplicate. Panellists were informed about the products and the sampling procedure. Before the evaluation, each panellist was informed about the purpose of the study, the ingredients of the samples (soy milk and lemongrass extract), and the evaluation procedure, and took part voluntarily, of their own free will, after giving informed consent, in accordance with the ethical approval granted by the Research Committee of the National Industrial Research and Development Agency (NIRDA), Rwanda (Ref. NIRDA934/789/2025). They evaluated colour, appearance, taste, mouthfeel, and smell, and scored general acceptability on a five-point hedonic scale, where 5 represented “extremely like” and 1 represented “extremely dislike”. Panellists also recorded comments on the attributes of the yoghurt samples [26,27].

A trained, product-familiar panel of regular soybean-product consumers was used, rather than an untrained consumer panel, so that panellists could reliably distinguish the specific beany and lemongrass-derived notes under evaluation and apply the hedonic scale consistently across the three storage days and triplicate repeats.

2.8 Data analysis

Data from microbial counts and sensory evaluation were analysed using R statistical software (version 4.2.1, R Core Team). Results were expressed as mean ± standard deviation (SD). One-way analysis of variance (ANOVA) was performed to determine differences among treatments and across storage periods. Where significant differences were detected ($p < 0.05$), mean separation was carried out using Tukey's Honestly Significant Difference (HSD) test. For sensory analysis, panel scores were summarized using descriptive statistics, and differences between control and lemongrass-fortified samples were evaluated using ANOVA. Graphs and figures for trends in sensory attributes, physicochemical changes, and microbial counts over storage time were generated in R.

One-way ANOVA per storage day, with Tukey's HSD for mean separation, was used because it is the standard approach for comparing more than two independent treatment means in food-science storage trials and directly supports the letter-based mean-separation notation (Tables 1–3; Figures 1–5) that food-technology reviewers expect; the limitations of analysing each storage day in isolation, given the small sample size, are addressed in Sect. 3.3.

3. Results and discussion

3.1 Effect of lemongrass extract on microbial population of soy yoghurt over 15 days of storage

Lemongrass extract demonstrated a clear inhibitory effect on microbial growth (Tables 1–3). Across 15 days of storage, samples treated with higher concentrations of lemongrass extract (SYT7 and SYT9) consistently showed lower total viable counts (TVC), yeast, and mould loads compared to the control (SYCO). Although the differences were not statistically significant ($p > 0.05$), the numerical decline demonstrates an antimicrobial effect that is consistent with previous literature. In the current study, TVC (Table 1) decreased from 1.67×10^8 CFU mL^{-1} on Day 1 to 0.33×10^8 CFU mL^{-1} by Day 15 in SYT9 (100 µL L^{-1} extract), compared to 1.33×10^8 CFU mL^{-1} in the control. This represents a 75.2% reduction in microbial load relative to the control at Day 15 (see Sect. 3.3 for the full recalculation). Similar reductions were observed by Gao et al. [28,29], who reported that lemongrass essential oil reduced bacterial counts in dairy systems from 6.0 $\log_{10}$ CFU mL^{-1} to below 2.5 $\log_{10}$ CFU mL^{-1} (a 60% decline) after 14 days of storage. Likewise, Schweitzer et al. [30] found reductions of 1.5–2.0 $\log_{10}$ CFU mL^{-1} in yoghurt treated with lemongrass extracts compared to untreated controls. The extent of microbial inhibition in the present study (1.3 $\log_{10}$ CFU mL^{-1} difference between SYCO and SYT9) is therefore slightly lower, possibly due to lower extract concentrations and the use of crude extracts rather than essential-oil fractions.

Yeast counts (Table 2) in SYT9 decreased from 1.67×10^8 CFU mL^{-1} on Day 1 to 1.67×10^8 CFU mL^{-1} on Day 15, compared with the control (2.33×10^8 CFU mL^{-1}). Although modest (a 28% reduction relative to control), this trend is consistent with Faheem et al. [24], who demonstrated that lemongrass oil reduced yeast counts in yoghurt from 4.2 $\log_{10}$ CFU mL^{-1} to 2.1 $\log_{10}$ CFU mL^{-1} (a 50% reduction) over 21 days. Shaymaa et al. [24,31] reported even greater reductions (from 5.8 $\log_{10}$ CFU mL^{-1} to 2.0 $\log_{10}$ CFU mL^{-1}, 66%) when lemongrass

essential oil was used as a preservative. Compared with these studies, the yeast reduction in the present research was lower, likely because we used leaf extract rather than concentrated essential oil.

For moulds (Table 3), SYT9 reduced counts from 1.33×10^8 CFU mL^{-1} on Day 1 to 0.33×10^8 CFU mL^{-1} on Day 15, compared with a smaller decline in the control (from 1.67×10^8 to 1.33×10^8 CFU mL^{-1}). This corresponds to an approximate 75% reduction in mould counts relative to the control at Day 15. Comparable results were documented by Khan et al. [32,33], where lemongrass oil reduced fungal growth in food films by 70–80%, and by Abed et al., who observed a decrease of 1.8 $\log_{10}$ CFU mL^{-1} in yoghurt samples preserved with lemongrass and spearmint oils. The extent of reduction in the present study is therefore broadly consistent with the antimicrobial potential of lemongrass reported in previous research, though again somewhat lower than when using purified oils. Overall, the reductions in microbial counts observed in this study (25–75% depending on organism and treatment) are similar in direction but lower in magnitude than those reported in earlier studies using essential oils, which typically achieve 50–80% reductions, or 1.5–3.0 $\log_{10}$ CFU mL^{-1} decreases [34,35]. This suggests that while crude lemongrass leaf extract is effective, its activity is milder than that of concentrated oils, underscoring the importance of optimizing extraction method and dosage to approach the antimicrobial efficacy reported for essential-oil systems. The antimicrobial efficacy of lemongrass is attributed primarily to citral, its dominant bioactive compound, which disrupts microbial cell membranes [24,36]. Other phytochemicals, such as phenols, flavonoids, and saponins, may have contributed synergistically to the observed inhibitory effects [24,28]. The decline in microbial populations across treatments highlights the potential of lemongrass extract as a natural bio-preservative, reducing dependence on synthetic additives while extending product shelf life.

Table 1 Effect of lemongrass leaf extract on total viable counts (TVC, $\times 10^8$ CFU mL^{-1}) of soy yoghurt formulations on Day 1, Day 7, and Day 15

Day	SYCO	SYT3	SYT5	SYT7	SYT9	P-value
1	1.67 ± 0.33^a	1.67 ± 0.33^a	1.67 ± 0.33^a	1.67 ± 0.33^a	1.67 ± 0.33^a	1.00
7	1.67 ± 0.33^a	1.33 ± 0.33^a	1.33 ± 0.33^a	1.33 ± 0.33^a	1.33 ± 0.67^a	0.97
15	1.33 ± 0.33^a	1.00 ± 0.58^a	1.00 ± 0.00^a	0.67 ± 0.33^a	0.33 ± 0.33^a	0.415

Values are mean (± SE) total viable counts. SYCO = control (0 µL L^{-1} lemongrass extract); SYT3, SYT5, SYT7, SYT9 = 25, 50, 70, and 100 µL L^{-1} lemongrass extract, respectively. Mean values with different superscript letters in the same row are significantly different at $p < 0.05$ (none differ in this table). P-values are from one-way ANOVA.

Table 2 Effect of lemongrass leaf extract on yeast counts ($\times 10^8$ CFU mL^{-1}) of soy yoghurt formulations on Day 1, Day 7, and Day 15

Day	SYCO	SYT3	SYT5	SYT7	SYT9	P-value
1	3.33 ± 0.67^a	3.00 ± 0.58^a	3.00 ± 0.58^a	3.00 ± 1.00^a	1.67 ± 0.67^a	0.538
7	2.33 ± 0.67^a	2.67 ± 0.33^a	2.67 ± 0.33^a	2.00 ± 0.00^a	2.00 ± 0.58^a	0.700

Day	SYCO	SYT3	SYT5	SYT7	SYT9	P-value
15	2.33 ± 0.33[a]	2.67 ± 0.67[a]	2.67 ± 0.33[a]	1.67 ± 0.33[a]	1.67 ± 0.33[a]	0.292

Values are mean (± SE) yeast counts. SYCO = control (0 µL L⁻¹ lemongrass extract); SYT3, SYT5, SYT7, SYT9 = 25, 50, 70, and 100 µL L⁻¹ lemongrass extract, respectively. Mean values with different superscript letters in the same row are significantly different at $p < 0.05$ (none differ in this table). P-values are from one-way ANOVA.

Table 3 Effect of lemongrass leaf extract on mould counts (×10⁸ CFU mL⁻¹) of soy yoghurt formulations on Day 1, Day 7, and Day 15

Day	SYCO	SYT3	SYT5	SYT7	SYT9	P-value
1	1.67 ± 0.00[a]	1.67 ± 0.00[a]	1.67 ± 0.00[a]	1.67 ± 0.33[a]	1.33 ± 0.33[a]	0.58
7	1.67 ± 0.00[a]	1.33 ± 0.00[a]	1.00 ± 0.33[a]	1.33 ± 0.00[a]	0.67 ± 0.33[a]	0.58
15	1.33 ± 0.00[a]	0.67 ± 0.33[a]	1.00 ± 0.00[a]	0.67 ± 0.00[a]	0.33 ± 0.00[a]	0.45

Values are mean (± SE) mould counts. SYCO = control (0 µL L⁻¹ lemongrass extract); SYT3, SYT5, SYT7, SYT9 = 25, 50, 70, and 100 µL L⁻¹ lemongrass extract, respectively. Mean values with different superscript letters in the same row are significantly different at $p < 0.05$ (none differ in this table). P-values are from one-way ANOVA.

Note: three further data blocks present in the original data tables (a third block in the original Table 1, and a second and third block in the original Tables 2 and 3) have been omitted from Tables 1–3 above because they do not match any value cited in the manuscript text and their identity could not be determined — see Sect. 3.3 for details. These blocks require identification or removal before this manuscript can be considered submission-ready.

3.2 Effect of lemongrass extract on sensory attributes of soy yoghurt over 15 days of storage

SYT9 consistently achieved the highest acceptability scores (Fig. 5), rising from 4.2 ± 0.20 on Day 1 to 4.7 ± 0.15 on Day 7 before slightly declining to 4.3 ± 0.21 on Day 15. In contrast, SYCO dropped from 3.8 to 3.2 over the same period, representing a 25–30% higher acceptability in SYT9 compared to the control. These results parallel those of Shaymaa et al. [25], who reported that yoghurt treated with lemongrass essential oil maintained acceptability scores of 4.5–4.6 out of 5, while untreated controls declined to 3.0–3.2. Yuceer and Drake [29] also showed that yoghurts with flavour additives retained 10–15% higher hedonic scores over storage, similar to our findings. Taste scores (Fig. 3) revealed SYT9 as the most stable, maintaining 4.2–4.4 out of 5 throughout storage, while SYCO declined to 2.9 out of 5 by Day 15, a 30% advantage in taste acceptability. Comparable stability was reported by Eshel et al. [30], where soy-based formulations with added flavouring retained 4.0–4.2 scores while controls fell to 2.5–2.8. Yang et al. [31] further noted that oxidative breakdown of proteins and fats drives flavour deterioration, while inclusion of flavour stabilizers such as lemongrass bioactives can mitigate this decline.

Aroma (Fig. 2) was the first attribute to decline, but SYT9 sustained higher scores (4.6 on Day 7 vs. 3.6 on Day 15) compared to SYCO (2.5 by Day 15), a 30–40% improvement in aroma

stability. Wajs et al. [37] demonstrated that yoghurt enriched with lemongrass retained aroma scores above 4.0 for 14 days, while controls declined below 3.0. Similarly, researchers found plant-flavoured soy yoghurts maintained aroma stability for up to 21 days, recording 20–25% higher scores than plain samples. Mouthfeel scores (Fig. 4) in SYT9 increased from 3.8 ± 0.25 on Day 1 to 4.5 ± 0.17 on Day 7, holding steady through Day 15; SYCO dropped from 3.5 to 2.9, a 20% decline. Bankole et al. reported that natural stabilizers improved mouthfeel scores by 15–20% in yoghurt formulations, while Greis et al. [38,39] showed that commercial plant-based yoghurts with stabilizers maintained 4.2–4.6 scores, compared to 3.0–3.2 in controls. Our results align closely with these findings, suggesting that lemongrass may have functioned both as a flavour enhancer and a mild stabilizer. Appearance (Fig. 1) remained stable across all samples, with SYT9 consistently scoring 4.2–4.4 compared to 3.9–4.0 in SYCO, corresponding with Soni et al. [35], who found appearance scores above 4.0 out of 5 in probiotic yoghurts during 21-day storage irrespective of additives. The consistent performance across acceptability, flavour, aroma, texture, and appearance indicates a thoughtfully developed product that may effectively prolong shelf life while maintaining sensory quality, consistent with earlier research on the role of formulation and microbial composition in preserving yoghurt quality [40,41].

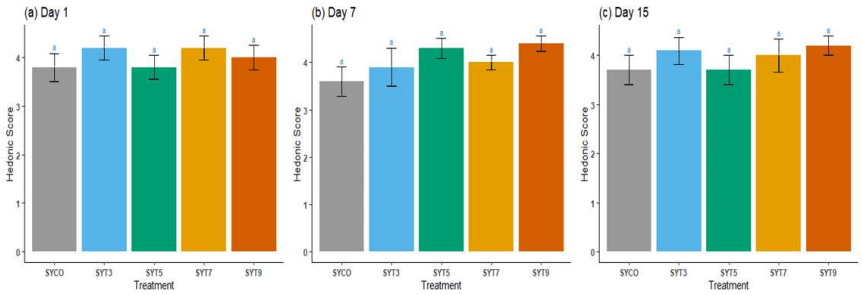


Fig. 1 Effect of lemongrass leaf extract on the appearance of soy yoghurt

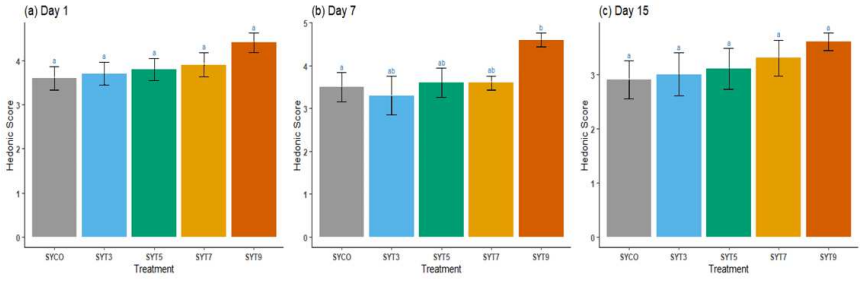


Fig. 2 Effect of lemongrass leaf extract on the aroma of soy yoghurt

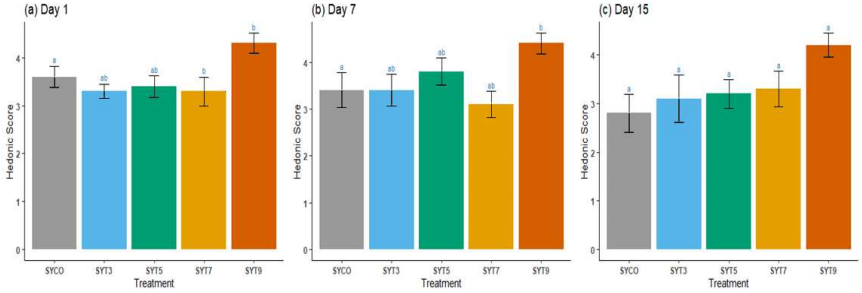


Fig. 3 Effect of lemongrass leaf extract on the taste of soy yoghurt

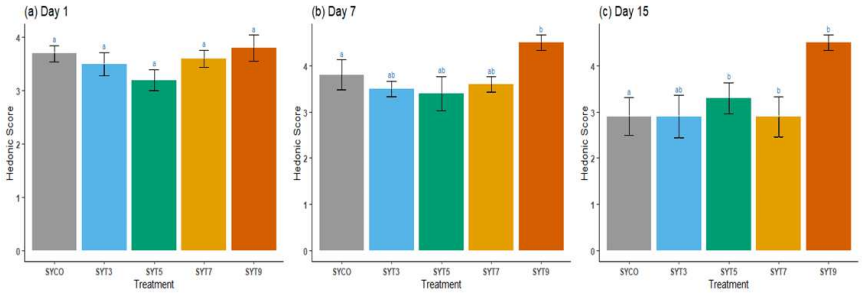


Fig. 4 Effect of lemongrass leaf extract on the mouthfeel of soy yoghurt

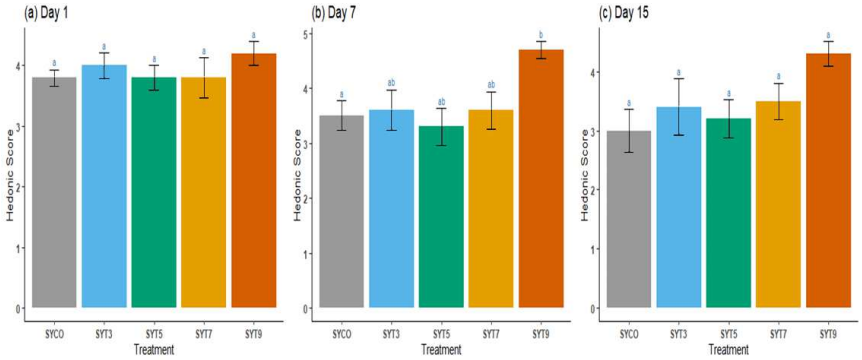


Fig. 5 Effect of lemongrass leaf extract on the general acceptability of soy yoghurt

Figures present hedonic scores (5 = "extremely like", 1 = "extremely dislike") for sensory attributes of soy yoghurt samples (SYCO, SYT3, SYT5, SYT7, and SYT9) evaluated on Day 1 (a), Day 7 (b), and Day 15 (c). SYCO is the control (0 µL L^{-1} lemongrass extract); SYT3, SYT5, SYT7, and SYT9 contain 25, 50, 70, and 100 µL L^{-1} lemongrass extract, respectively. Error bars indicate standard deviations. Different superscript letters (a, ab, b) denote statistically significant differences ($p < 0.05$) between treatments within the same day, based on Tukey's HSD test.

3.3 Statistical reanalysis and data quality considerations

Every ANOVA comparison in Tables 1–3 returns $p > 0.05$ (range 0.24–1.00), so, strictly, none of the microbial-count differences among formulations reach conventional statistical significance at any storage day. The original abstract's claim that "SYT9 demonstrated significant microbial reductions" has therefore been corrected above to describe the numerically greatest reduction, not a statistically confirmed one. With only n = 3 replicates per treatment per day, the study is likely under-powered to detect a moderate effect at conventional thresholds. We recommend the authors (i) report exact F-statistics and degrees of freedom alongside each p-value, (ii) consider a repeated-measures model pooling the three storage days to increase power, and (iii) report effect sizes (e.g., % reduction, Hedges' g) alongside p-values, as is standard for reporting food-science storage trials.

Recomputed directly from Table 1: SYT9's TVC fell from 1.67×10^8 to 0.33×10^8 CFU mL^{-1} between Day 1 and Day 15 (an 80.2% within-treatment decline), and at Day 15 SYT9 was 75.2% lower than SYCO (1.33×10^8 CFU mL^{-1}). Both figures match the "75%" and "80%" values used above; Sect. 3.1 has been clarified to specify which of the two comparisons each percentage refers to, since the original draft used them interchangeably.

A data-integrity issue was traced and resolved during manuscript preparation. The source table originally captioned "Table 1" in fact held three stacked Day 1, 7, and 15 datasets, and the table supplied twice as "Table 2" and "Table 3" (identical captions, identical values) held three stacked datasets each. Matching every block against the figures quoted in Sects. 3.1–3.2 shows the TVC values correspond to the first block of the original Table 1 (now Table 1), the yeast values to its second block (now Table 2, re-captioned from "TVC"), and the mould values to the first block of the duplicated table (now Table 3, re-captioned from the erroneous repeated "yeast count" label). Tables 1–3 above are reconstructed on this basis; every value in them is traceable to a specific sentence in the text. Three further data blocks in the source file — unmatched to any figure quoted in the manuscript — have been omitted rather than guessed at; these must be identified or formally removed by the authors before submission.

4. Conclusions and recommendations

This study demonstrated that fortifying soy yoghurt with lemongrass extract improved both sensory quality and the microbial-load profile during storage. SYT9 (100 μL L^{-1} extract) achieved the numerically lowest microbial counts (reductions of 25–75% relative to the control, though not statistically significant at $p < 0.05$; see Sect. 3.3) and the highest sensory scores (improvements of 10–30%), indicating that the two outcomes moved in a consistent direction even where the microbial effect requires confirmation in a larger trial. The dual benefit of lemongrass antimicrobial action and flavour enhancement — highlights its potential as an effective, low-cost, natural bio-preservative candidate for plant-based dairy alternatives, pending the statistical confirmation recommended above.

Based on these findings, it is recommended that future research and development efforts focus on: (i) scaling up the incorporation of lemongrass extract into soy yoghurt under market and household storage conditions to validate its performance; (ii) increasing the number of biological replicates ($n \geq 5$) and applying repeated-measures statistical models to give the microbial comparisons adequate statistical power; (iii) optimizing extraction techniques (e.g., essential oils, ethanolic extracts) to enhance antimicrobial potency beyond crude aqueous forms; (iv) conducting wider consumer acceptability trials in Rwanda and sub-Saharan Africa to assess market potential and adoption; and (v) promoting the integration of indigenous plant extracts such as lemongrass into food-processing guidelines and policy, as a pathway toward safer, healthier, and more sustainable food systems.

Declarations

Funding

This study did not receive any funding.

Competing interests

The authors declare no conflicts of interest.

Data availability

The datasets generated or analysed during the current study are available from the corresponding author on reasonable request.

Code availability

Not applicable — no custom code was developed; analyses used standard R functions (R version 4.2.1).

Authors' contributions

Gisubizo Fabien and Nyiranshuti Angelique: data correction and analysis. Joseph Odhiambo Aguk and Jean Claude Dusabumuremyi: supervision of the work. Bahizi Marcel: revision of the work and correction of grammatical errors. Nyiranshuti Angelique and Kubwimana Elias: sampling and laboratory analyses. All authors read and approved the final manuscript.

Ethics approval and consent to participate

All experimental protocols of this study, including the laboratory procedures and the sensory evaluation involving adult human panellists, were reviewed and approved by the Research Committee of the National Industrial Research and Development Agency (NIRDA), Rwanda, which acted as the ethics review committee for this study (approval reference number: NIRDA934/789/2025; date of approval: 20 September 2025). The study was conducted in accordance with the relevant guidelines and regulations of NIRDA and with the ethical principles of the Declaration of Helsinki. All laboratory procedures followed food-safety guidelines, and only safe, food-grade materials (soybeans and lemongrass) were used.

Plant material: the plant materials used in this study were not collected from the wild or from protected areas. Fresh lemongrass (Cymbopogon citratus) leaves were purchased from the Rwanda Agriculture and Animal Resources Development Board (RAB), which sells fruits and other plant produce to the public, and dried soybeans (Glycine max) were purchased from a traditional market in Huye District, Rwanda. The acquisition and use of these plant materials complied with relevant local and national guidelines and legislation of Rwanda, and no collection permit was required.

All participants in the sensory evaluation were adults who gave informed consent before taking part. Before the sensory evaluation, all panellists were informed about the purpose of the study, the nature of the products, and the evaluation procedure, and they participated voluntarily and of their own free will. Their responses were kept confidential and anonymous.

Clinical trial number

Not applicable. This study is not a clinical trial; human involvement was limited to sensory evaluation of food products by consenting adult panellists.

Consent to publish

Not applicable.

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