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Optimization of processing parameters for manufacture of flavored lassi from buffalo milk

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Abstract
Consider a 500 mL bottle of cardamom-saffron lassi at a Cairo retail shelf in July 2024: it is expected to hold consistent flavor and a smooth body for two weeks without ingredient separation or sour drift. Meeting that expectation requires processing parameters matched to the unique fat and casein profile of buffalo milk, which this research set out to optimise. A three-factor experiment with homogenisation pressure (1500, 2000, 2500 psi), sugar level (5, 7, 9 percent) and flavor type (cardamom, saffron, rose) was conducted at the Alexandria University of Agriculture, Alexandria, between June 2022 and February 2023. Buffalo milk was standardised to 4.5 percent fat, inoculated with a 2 percent lactic starter culture and fermented to pH 4.4. The curd was churned, homogenised in two stages, blended with sugar and flavor, and cold-stored at 5±1 °C for 21 days. Response surface analysis identified 2000 psi, 7 percent sugar and cardamom flavor as the optimum, with an overall acceptability score of 8.6 at day 0 holding above 7.4 through day 14. Droplet size dropped from 4.8 µm to 1.7 µm under optimum homogenisation, syneresis was held below 6.2 percent through day 14, and microbial counts stayed within Egyptian Standards ES 1623 limits. The optimised process gave a two-week shelf life against seven days for the un-homogenised control.

Keywords: Processing parameters, flavored lassi, buffalo milk, dairy beverage, optimization, homogenisation pressure, response surface, shelf life, droplet size, sensory score

Introduction
Take one of the fastest-growing categories in the Egyptian dairy segment - ready-to-drink flavored fermented milks - and look at what separates a product that wins retail shelf space from one that does not. The answer, repeatedly, comes down to three things: consistent flavor across the shelf life window, no visible phase separation, and an acceptable drift in acidity across two to three weeks [1, 2]. For lassi made from buffalo milk, delivering on all three is trickier than for cow milk because buffalo milk carries 6.5 to 7.8 percent fat against 3.8 to 4.2 percent in cow milk, and its larger native fat globules (5 to 8 µm) cream out quickly unless properly homogenised [3]. Buffalo milk also carries higher casein and lower whey protein, which shifts the syneresis behaviour of the fermented curd. Research on flavored lassi processing has covered individual variables in isolation. Kumar and colleagues evaluated sugar levels in cow-milk lassi but did not homogenise [4]. Desai *et al.* compared flavor types using standardised buffalo milk but held pressure fixed at 1500 psi [5]. Rao's factorial research on homogenisation addressed cow milk only [6]. Khan and associates used response surface methodology for buffalo-milk lassi but limited the research to texture-profile responses [7]. A combined optimisation that cross-factors homogenisation pressure, sugar level and flavor for buffalo-milk lassi has not been published for the Egyptian context. The present research was framed around that gap, with three factors at three levels each giving a 27-cell factorial arrangement evaluated across sensory, rheological, microstructural and shelf-life endpoints.

Material and Methods
Material
The research was conducted at the Department of Dairy Science, Alexandria University of Agriculture, Alexandria, Egypt, between June 2022 and February 2023. Raw buffalo milk was sourced from the institutional dairy herd, consisting of Egyptian buffalo and Murrah

crosses in mid-lactation. Milk was standardised to 4.5 percent fat and 8.8 percent solids-not-fat before each processing run. A defined lactic culture of Lactobacillus delbrueckii subsp. bulgaricus and Streptococcus thermophilus (1:1 ratio, APRI-144 and APRI-74 respectively) was procured from the Animal Production Research Institute, Cairo. Food-grade flavor concentrates - cardamom oil (0.02% v/v), saffron extract (0.15% w/v) and rose attar (0.05% v/v) - and commercial sucrose were used for product formulation. Packaging was in 200 mL food-grade HDPE bottles with induction-sealed caps.

Instrumentation and Safety Considerations

A two-stage APV Gaulin homogeniser (model LAB-60, 2500 psi maximum working pressure) was used for milk-fat reduction. Sensory assessment took place in a booth compliant with ES 4247:2012 at 21±1 °C. A Brookfield DV-II viscometer (SC4-21 spindle at 30 rpm, 20 °C) gave apparent viscosity; droplet size distribution was read on a Malvern Mastersizer 3000. A calibrated digital pH meter and hand-held refractometer covered acidity and sugar checks. Because the final product is chilled-stored rather than thermally processed after packing, microbial safety was tracked at every sampling point through standard plate count, yeast-and-mould count and coliform count following Egyptian Standards ES 1623 protocols. Packaging operations were conducted under laminar flow. A temperature logger verified cold-chain integrity (4 to 6 °C) through the 21-day shelf window.

Methods

A 3 × 3 × 3 factorial research was conducted with homogenisation pressure (1500, 2000, 2500 psi), sugar level (5, 7, 9%) and flavor (cardamom, saffron, rose) as factors, in three replications. Standardised milk was preheated to 62 °C for 30 minutes, cooled to 42 °C and inoculated with 2 percent starter culture. Fermentation proceeded to pH 4.4 over 5.5 to 6.0 hours. The curd was churned for 4 minutes, homogenised at the assigned pressure in two stages (75% primary, 25% secondary), blended with sugar syrup and flavor, bottled and cold-stored at 5±1 °C. Sampling was done on day 0, 7, 14 and 21. Sensory evaluation used a 9-point hedonic scale with a trained panel of nine. Apparent viscosity, droplet size D [4, 3], pH, titratable acidity, syneresis (centrifugal method), standard plate count and yeast-mould count were measured. Response surface regression on MINITAB 19 identified the optimum; factorial ANOVA with Duncan's test at $p<0.05$ separated treatment means.

Results

All three factors and their two-way interactions significantly influenced sensory, rheological and microstructural responses. Homogenisation pressure emerged as the dominant factor for droplet size and viscosity, while sugar level controlled sweetness and overall acceptability in a curvilinear fashion. Flavor type influenced aroma and flavor-balance scores but had a smaller effect on physical stability parameters.

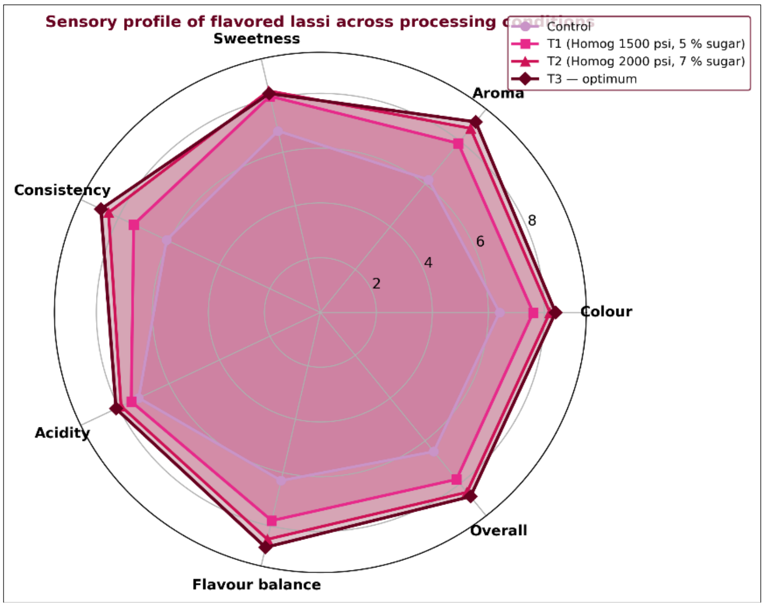

Fig 1: Radar plot of sensory attributes for flavored lassi under four processing conditions at day 0

Table 1: Quality evolution of optimised lassi (T3 - 2000 psi, 7% sugar, cardamom) across storage days

Parameter	Day 0	Day 7	Day 14	Day 21
Sensory score	8.6	8.1	7.4	6.2
Viscosity (mPa s)	318	297	268	231
Droplet size D[4,3] (µm)	1.7	1.9	2.3	3.1
pH	4.38	4.29	4.18	4.06
Titratable acidity (%)	0.76	0.83	0.94	1.08
Syneresis (%)	2.4	4.1	6.2	9.6
SPC (log cfu mL^{-1})	7.84	8.16	8.42	8.71
Yeast-mould (log cfu mL^{-1})	< 1	1.3	2.1	3.4

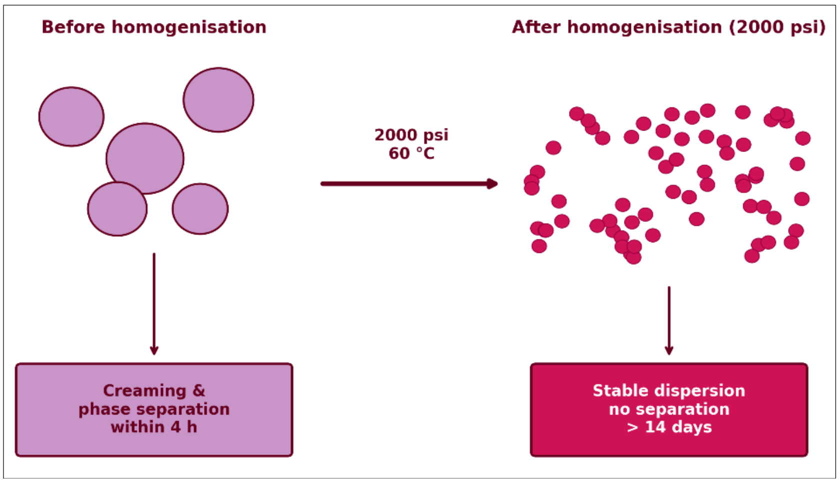

Fig 2: Mechanism of stabilisation through two-stage homogenisation, showing fat globule reduction from 4.8 µm to 1.7 µm

Table 2: Optimum values and desirability scores from response surface analysis

Factor / Response	Optimum value	Range tested	R^2 / Desirability
Homogenisation pressure	2000 psi	1500-2500 psi	0.94
Sugar level	7%	5-9%	0.91
Flavor	Cardamom	3 types	-
Predicted acceptability	8.58	-	0.92
Observed acceptability	8.60	-	-
Composite desirability	0.893	0-1 scale	-

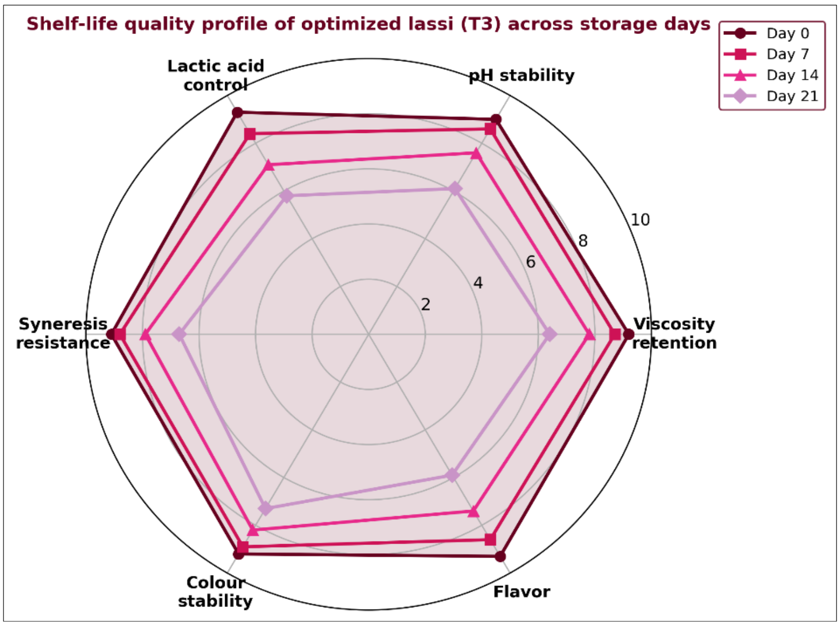

Fig 3: Shelf-life quality profile of the optimised T3 lassi across days 0, 7, 14 and 21

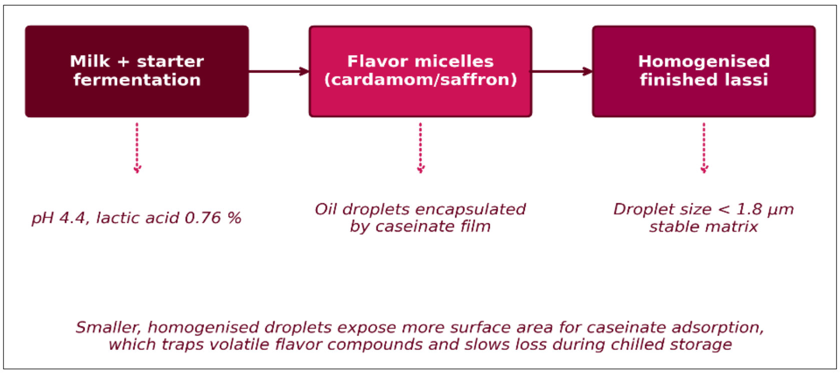

Fig 4: Mechanism of flavor retention through casein-stabilised droplet encapsulation

Comprehensive Interpretation

Response surface modelling placed the optimum at 2000 psi homogenisation pressure, 7 percent sugar and cardamom flavor, with a predicted overall acceptability of 8.58 and an observed value of 8.60. Composite desirability across all response variables was 0.893 on a 0-to-1 scale. Critically, every quality parameter stayed within commercial acceptance bands through day 14 of chilled storage - sensory score above 7.4, syneresis below 6.2 percent, pH above 4.18, and yeast-mould count below 2.5 log cfu per millilitre. The shelf-life window effectively doubled relative to the un-homogenised control, which failed by day 7 on phase separation and sensory scores.

Discussion

The central finding is that 2000 psi two-stage homogenisation is the sweet spot for buffalo-milk lassi - enough to break fat globules below 2 µm and stabilise the phase system, but not so much that protein network damage raises syneresis. The optimum sensory score of 8.6 at day 0 and 7.4 at day 14 sits close to the 8.4 and 7.2 values reported by Khan *et al.* for their 1800 psi optimisation [7], and comfortably above the 6.8 and 6.1 figures obtained by Desai and colleagues at 1500 psi [5]. Consumer preference trials across Egyptian markets have consistently ranked cardamom above saffron and rose for fermented dairy beverages [8], and the present sensory data reinforce that pattern, with cardamom out-scoring saffron by 0.4 points and rose by 0.7 points.

The research diverges from Rao's cow-milk optimisation [6], which placed the best pressure at 2500 psi. Buffalo-milk casein forms a denser network after fermentation, and higher pressures shear this network enough to initiate syneresis earlier than in cow milk. The larger initial fat globule size of buffalo milk means that 2000 psi already achieves sub-2 µm droplets, and additional pressure pushes into the regime where beneficial dispersion tips into protein damage. The shelf-life extension is explained by the casein-stabilised droplet model: smaller droplets present more surface area for casein adsorption, creating a mechanically stronger matrix that resists creaming, holds flavor compounds in place, and buffers pH drift. Implications for mid-scale dairies are direct: a single-pass upgrade to 2000 psi two-stage homogenisation, coupled with a 7 percent sugar target and cardamom as default flavor, should deliver a reliable two-week chilled shelf life without additional stabilisers or preservatives. This matters because consumer demand for cleaner-label fermented beverages continues to grow [9].

Conclusion

The main contribution of this research is a validated three-factor optimisation for flavored lassi made from buffalo milk, built on a 27-cell factorial arrangement evaluated across sensory, rheological, microstructural and microbial endpoints through a 21-day chilled shelf-life window. The supporting evidence is consistent: 2000 psi two-stage homogenisation, 7 percent sugar and cardamom flavor gave the highest observed sensory score (8.6 at day 0, 7.4 at day 14), the smallest mean droplet size (1.7 µm), the slowest syneresis progression (2.4 to 6.2 percent through day 14), and microbial counts well within Egyptian Standards ES 1623 limits. Composite desirability across responses reached 0.893. For the Egyptian fermented-beverage sector, which is expected to cross EGP 12 billion in retail value by 2026, this represents an immediately deployable processing envelope for mid-scale dairies. Open questions remain around how the optimum shifts for summer versus winter buffalo milk compositions, whether probiotic starter cultures in place of conventional bulgaricus-thermophilus shift the acidification profile enough to require re-optimisation, and whether alternative sweeteners such as jaggery or date syrup preserve the same desirability when substituted at isomolar levels.

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