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Research Article

Effect of Cleaning Milk Equipment with Plant Material on Microbial Load, Quality and Organoleptic Character of Milk

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Abstract

Ensuring the safety and quality of milk requires effective sanitation of milk-handling equipment to minimize microbial contamination. This study examined the antimicrobial effectiveness of Eucalyptus globulus and Ruta chalepensis as natural cleaning agents compared to conventional synthetic detergents. Equipment cleaned with plant-based solutions significantly reduced microbial loads, including total bacterial count (TBC), coliforms, and lactic acid bacteria (TLAB), with reductions exceeding those observed with conventional detergents ($p < 0.05$). Lower titratable acidity in milk processed using plant-treated equipment indicated delayed spoilage and extended shelf life. Sensory evaluation by trained panelists revealed improved flavor, texture, and overall acceptability in milk cleaned with plant-based agents, outperforming detergent-cleaned samples ($p < 0.05$). The antimicrobial properties of Eucalyptus globulus stem from its phytochemicals, such as eucalyptol and α-pinene, which disrupt bacterial cell membranes, effectively targeting gram-positive and gram-negative bacteria. Ruta chalepensis owes its antibacterial activity to phenolics and flavonoids, which inhibit bacterial growth through oxidative stress and enzyme disruption. These bioactive compounds contribute not only to reduced microbial loads but also to enhanced sensory qualities of milk, making the plant-based agents promising alternatives to chemical cleaners. The findings suggest that Eucalyptus globulus and Ruta chalepensis offer sustainable, eco-friendly solutions for dairy sanitation, effectively reducing microbial contamination while enhancing milk quality. These natural agents align with the growing consumer preference for environmentally sustainable practices in food production. Further research is recommended to optimize their application methods, evaluate residue safety, and investigate their long-term impact on milk-handling equipment and microbial resistance patterns. By integrating these plant-based solutions into dairy sanitation practices, producers can achieve safer, higher-quality milk while reducing reliance on synthetic chemicals.

Keywords

Eucalyptus Globulus, Ruta Chalepensis, Dairy Sanitation, Microbial Contamination, Sensory Evaluation, Food Safety

1. Introduction

Milk is a vital source of nutrition, providing essential proteins, fats, vitamins, and minerals necessary for human health. However, its composition also renders it highly susceptible to microbial contamination, necessitating stringent hygiene practices during its production and handling to prevent spoilage and ensure food safety [10]. The sanitation of milk-

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ing equipment serves as a critical control point in the dairy production chain, as inadequate cleaning can lead to the proliferation of pathogenic bacteria and spoilage organisms, compromising milk quality and safety [2].

In many rural and traditional dairy farming contexts, natural plant materials have been employed for cleaning milking equipment, reflecting indigenous knowledge systems that utilize locally available resources [1]. Among these plant materials, Eucalyptus globulus and Ruta chalepensis have garnered significant interest due to their established antimicrobial properties. Eucalyptus globulus**,** commonly known as eucalyptus, is renowned for its essential oil, which contains compounds such as eucalyptol and alpha-pinene that exhibit potent antibacterial activity against various pathogens, including Escherichia coli and Staphylococcus aureus [8].

Studies on Ruta chalepensis have confirmed its significant antibacterial properties against both Gram-positive and Gram-negative bacteria, attributed to its phytochemical constituents such as phenolics, flavonoids, and essential oils. The ethanolic extract of Ruta chalepensis has demonstrated effective antimicrobial activity, particularly in reducing microbial loads, which supports its potential as a natural cleaning agent in dairy sanitation practices [17, 7]. Specifically, its antibacterial efficacy has been shown against bacterial strains like Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa [5]. The essential oils of Ruta chalepensis also exhibit antibacterial effects, though their activity levels are moderate compared to conventional antibiotics [15].

While these findings underscore the promising antimicrobial potential of Ruta chalepensis, comparative analyses with conventional chemical cleaning agents remain limited. Traditional detergents often leave chemical residues in milk, posing health risks and degrading milk quality [12]. Ruta chalepensis and Eucalyptus globulus have shown significant potential as natural antimicrobial agents in reducing microbial contamination and enhancing the quality and safety of food products, including dairy. Studies on Ruta species emphasize their essential oils' effectiveness, attributed to bioactive compounds with broad-spectrum antimicrobial activities, suitable for replacing synthetic chemicals in agricultural and food safety applications [19]. Similarly, Eucalyptus globulus extracts have been recognized for their ability to decrease microbial loads, improve product shelf life, and enhance organoleptic properties, making them ideal alternatives to chemical preservatives. Their application in reducing spoilage microbes and extending the usability of horticultural and dairy products aligns with the growing demand for natural and sustainable solutions in food safety [20].

Therefore, it is essential to explore how cleaning with Ruta chalepensis**,** Eucalyptus globulus**,** and similar plant-based agents impacts both microbial contamination and the organoleptic properties of milk to establish their viability as safer alternatives for improving food safety and quality.

2. Materials and Methods

2.1. Study Design

A controlled experimental design was employed to compare the efficacy of cleaning milk-handling equipment using plant-based cleaning solutions against a commercial detergent. The parameters evaluated included microbial load, titratable acidity, and organoleptic quality of milk. Milk samples processed using equipment cleaned with each method were analyzed for microbial contamination, acidity levels, and sensory attributes. This comparative assessment enabled evaluation of the effectiveness and sensory impacts of the cleaning treatments.

2.2. Plant Materials

Eucalyptus globulus (Eucalyptus): Leaves of Eucalyptus globulus, known for their antimicrobial properties, were locally sourced. After thorough washing, a 1:10 w/v infusion was prepared by boiling 100 g of leaves in 1 L of distilled water for 30 minutes. The solution was cooled, filtered, and used as a cleaning agent for milk-handling equipment [11].

Ruta chalepensis (Rue): Ruta chalepensis leaves were prepared similarly, using a 1:10 w/v ratio. The leaves were boiled for 30 minutes, cooled, filtered, and used as a cleaning solution. This plant was selected for its traditional antimicrobial use and reported antibacterial efficacy [18].

2.3. Microbial Load Assessment

Milk samples were aseptically collected and analyzed for microbial contamination using the following parameters:

1) Total Bacterial Count (TBC)
2) Coliform Count
3) Total Lactic Acid Bacteria (TLAB)

Microbial analysis followed the American Public Health Association (APHA) standards [3]. Samples were serially diluted, plated on appropriate agar media—Plate Count Agar (PCA) for TBC, MacConkey Agar for coliforms, and MRS Agar for TLAB—and incubated at 37 ℃ for 24–48 hours. Colony-forming units (CFUs) were counted and expressed as CFU/mL. For statistical comparisons, microbial counts were log-transformed.

2.4. Titratable Acidity Assessment

Titratable acidity was measured to evaluate milk freshness and quality:

10 mL of milk was titrated with 0.1 N NaOH using phenolphthalein as an indicator.

The acidity percentage was calculated as follows:

$$\text{Tiiratable Acidity } (\%\ lactic\ acid) = \frac{mL\ of\ NaOH \times Normality\ of NaOH \times 90}{Volume\ of\ milk\ sample}$$

The results were expressed as a percentage of lactic acid for comparison between treatments [16].

2.5. Sensory Evaluation

A sensory panel consisting of 10 trained individuals assessed the organoleptic properties of milk samples, including:

1) Flavor
2) Texture
3) Overall Acceptability

Milk samples were presented randomly in a blind taste test to prevent bias. Panelists independently evaluated each sample using a 9-point hedonic scale [23].

2.6. Data Management

Data from microbial counts, titratable acidity, and sensory evaluations were securely stored in a digital database with unique identifiers assigned to each sample. Validation checks ensured data accuracy and consistency. Statistical software (SPSS) was used for data management and analysis, and regular backups were maintained to prevent data loss.

2.7. Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) to assess differences among treatment groups. Tukey's post hoc test was applied to identify specific differences, with a significance level of $p < 0.05$. Results were presented with corresponding p-values to facilitate comparison of microbial load, titratable acidity, and sensory quality [9].

3. Results

3.1. Microbial Load

Milk handled with equipment cleaned using plant materials exhibited a significantly lower microbial load compared to milk from equipment cleaned with conventional detergent. *Eucalyptus globulus* and *Ruta chalepensis* showed the most effective antimicrobial activity, significantly reducing TBC, coliform, and TLAB counts compared to other plant treatments and detergent ($p<0.05$ for all comparisons).

Table 1. *Provides details of microbial counts across the treatments.*

Treatment	TBC (CFU/ml)	Coliform (CFU/ml)	TLAB (CFU/ml)
Detergent-cleaned	6.2×10^4	3.5×10^3	4.8×10^4
Eucalyptus globulus	3.4×10^4 ($p<0.05$)	1.2×10^3 ($p<0.01$)	2.0×10^4 ($p<0.01$)
Ruta chalepensis	3.1×10^4 ($p<0.01$)	1.1×10^3 ($p<0.01$)	2.3×10^4 ($p<0.05$)

3.2. Titratable Acidity

Titratable acidity measurements showed that milk handled with equipment cleaned using plant infusions of Eucalyptus globulus and Ruta chalepensis had significantly lower acidity compared to milk from detergent-cleaned equipment ($p<0.05$), indicating slower acidification and potentially extended shelf life.

Table 2. *Details the titratable acidity percentages for each treatment.*

Treatment	Titratable Acidity (% lactic acid)
Detergent-cleaned	0.16 ± 0.02
Eucalyptus globulus	0.12 ± 0.01 ($p<0.05$)
Ruta chalepensis	0.11 ± 0.01 ($p<0.05$)

3.3. Sensory Evaluation

Milk handled with equipment cleaned using plant materials scored higher for flavor, texture, and overall acceptability compared to detergent-cleaned samples ($p<0.05$). *Eucalyptus globulus* and *Ruta chalepensis* produced the highest scores in flavor and overall acceptability ($p<0.05$ for pairwise comparisons).

Table 3. *Sensory evaluation indicators of traditional plants used to clean milk equipment.*

Treatment	Flavor (mean ± SD)	Texture (mean ± SD)	Overall Acceptability (mean ± SD)
Detergent-cleaned	5.5 ± 0.8	6.0 ± 0.6	5.8 ± 0.7
Eucalyptus globulus	8.0 ± 0.5 ($p<0.05$)	8.2 ± 0.4 ($p<0.05$)	8.1 ± 0.4 ($p<0.05$)
Ruta chalepensis	8.1 ± 0.4 ($p<0.01$)	8.4 ± 0.3 ($p<0.01$)	8.3 ± 0.3 ($p<0.01$)

4. Discussion

4.1. Antimicrobial Efficacy of Plant-Based Cleaning Agents

This study demonstrates that *Eucalyptus globulus* and *Ruta chalepensis* effectively reduce microbial contamination on dairy equipment, enhancing milk quality. The antimicrobial properties of these plants are attributed to their rich phytochemical composition. *Eucalyptus globulus***,** known for its high content of 1,8-cineole, disrupts bacterial cell membranes, effectively targeting both gram-positive and gram-negative bacteria [22, 11]. Similarly, *Ruta chalepensis* contains bioactive alkaloids, flavonoids, and phenolics, providing broad-spectrum antimicrobial activity by targeting bacterial enzymes and cell walls [21]. The combined effects of these plants suggest a sustainable alternative to synthetic detergents in food safety applications.

4.2. Impact on Milk Quality and Stability

The observed reduction in microbial counts, including total bacterial count (TBC), coliforms, and lactic acid bacteria, underscores the effectiveness of plant-based cleaning agents. This microbial inhibition contributes to milk stability by delaying spoilage and reducing acidification rates, as evidenced by lower titratable acidity in milk handled with plant-cleaned equipment. These findings align with studies showing that natural antimicrobials effectively reduce microbial loads and slow milk spoilage processes [13, 21].

4.3. Enhancing Sensory Attributes of Milk

Equipment cleaned with *Eucalyptus globulus* and *Ruta chalepensis* yielded milk with superior sensory qualities, including improved flavor and texture, compared to detergent-cleaned equipment. The absence of chemical residues and the presence of natural bioactive compounds likely enhance the organoleptic properties of the milk. Previous research corroborates that plant-based sanitizers improve sensory scores, making them appealing for consumer-oriented dairy production [13].

4.4. Phytochemical Mechanisms and Broader Implications

The antimicrobial efficacy of *Eucalyptus globulus* stems from its terpenoid-rich composition, particularly 1,8-cineole, p-cymene, and α-pinene, which exhibit potent antibacterial, antioxidant, and antibiofilm activities [22]. Similarly, the antimicrobial properties of *Ruta chalepensis* are attributed to phenolic compounds, which disrupt microbial growth through oxidative stress mechanisms and enzyme inhibition. The antibacterial potential of *Eucalyptus globulus* oil can also be enhanced in synergy with antibiotics, highlighting its role in combating resistant strains like MRSA [13].

The findings of this study are consistent with recent advancements in plant-based antimicrobial research. These results support the integration of *Eucalyptus globulus* and *Ruta chalepensis* into dairy sanitation protocols, offering a natural, effective, and consumer-preferred alternative to chemical cleaning agents. Further research is warranted to optimize application techniques and assess long-term impacts on dairy product quality and safety.

4.5. Conclusion and Recommendations

This study underscores the efficacy of Eucalyptus globulus and Ruta chalepensis as natural cleaning agents for milk-handling equipment, offering significant advantages over conventional detergents. The notable reduction in microbial load, lower titratable acidity, and enhanced sensory qualities of milk processed with equipment cleaned using these plant infusions validate their potential for use in sustainable dairy sanitation practices.

5. Recommendations

1) Integration into Dairy Practices

Adopt Eucalyptus globulus and Ruta chalepensis infusions as alternatives to chemical detergents in small-scale and traditional dairy operations.

2) Optimization of Application Methods

Investigate and standardize optimal concentrations, preparation methods, and cleaning durations for plant infusions to maximize antimicrobial efficacy while maintaining economic feasibility.

3) Safety and Residue Testing

Conduct additional studies to evaluate the safety of plant-based cleaning agents, including testing for potential residues in milk, to ensure compliance with food safety regulations.

4) Long-Term Impact Studies

Evaluate the long-term effects of using plant-based agents on dairy equipment, including their impact on material durability and microbial resistance patterns.

5) Consumer Awareness and Acceptance

Promote awareness of the benefits of natural cleaning agents to consumers and dairy producers. Highlighting their environmental sustainability, safety, and ability to improve milk quality can encourage widespread adoption.

Abbreviations

APHA	American Public Health Association
CFU	Colony-Forming Units
MRSA	Methicillin Resistant Staphylococcus Aureus
MRS	De Man, Rogosa, and Sharpe
PCA	Plate Count Agar

TBC	Total Bacterial Count
TLAB	Total Lactic Acid Bacteria

Conflicts of Interest

The authors declare no conflicts of interest.

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