

Critical Milk Quality Parameters Influencing Milk Quality Management in Selected Dairy Facilities in Mbarara District, Uganda. A cross-sectional study.

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Page | 1

ABSTRACT

Introduction

Agriculture remains an important sector of Uganda's economy and a major source of livelihoods, food, and household income. This study aims to identify the critical milk quality parameters affecting milk quality management in selected dairy facilities in Mbarara District, Uganda.

Methodology

This study employed a mixed-methods research design combining qualitative and quantitative approaches within an action research framework. The study population consisted of approximately 1,000 dairy stakeholders in Mbarara District, including farmers, collection centre staff, transporters, and processors. Surveys and questionnaires. Primary data were collected using a closed-ended questionnaire.

Results

Butterfat content was identified as a key determinant of milk quality, with 72.0% of respondents acknowledging its importance in pricing and processing decisions. Milk with butterfat levels below 3.2% was frequently rejected by processors. Solid-not-fat was identified as a critical parameter, with 65.0% of respondents indicating awareness of its importance. Milk with SNF levels below 8.3% was often downgraded or rejected. 80.0% of respondents reported that high bacterial counts frequently resulted in milk rejection. The main causes of contamination included poor hygiene during milking, use of unclean containers, and delays in transportation. Temperature control was found to be critically inadequate across the dairy value chain: 85.0% of respondents lacked access to proper cooling facilities, resulting in milk being stored and transported at temperatures above the recommended 4°C.

Conclusions

Butterfat content, solid-not-fat, bacterial contamination, and temperature control are confirmed as the critical parameters governing milk quality management in Mbarara District, with hygiene- and cold-chain-related parameters (bacterial load and temperature) presenting the more urgent and widespread deficiencies relative to compositional parameters.

Recommendations

Regulatory and extension agencies should intensify farmer training on milking hygiene, container sanitation, and basic pre-sale quality testing.

Keywords: Critical milk quality parameters, Milk quality management, Dairy facilities in Mbarara District.

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Introduction

Agriculture remains an important sector of Uganda's economy and a major source of livelihoods, food, and household income. Within the agricultural sector, dairy

farming is an important economic activity that contributes to household livelihoods, employment, food and nutrition security, and the supply of milk for domestic consumption and processing. Uganda's dairy industry is predominantly

characterized by smallholder production systems, with the majority of milk production originating from small-scale farmers (Staal & Kaguongo, 2003; Garcia et al., 2008). The continued development of the dairy sector therefore has important implications for rural livelihoods and the commercialization of agricultural production in the country. Despite the importance of dairy production, maintaining milk quality remains a major challenge along the dairy value chain. Raw milk is highly perishable and can undergo rapid deterioration when appropriate hygiene, handling, storage, cooling, and transportation practices are not maintained. In Uganda, milk quality concerns have been documented at several stages of the value chain, including the farm, milk collection, transportation, cooling, and marketing stages. A study conducted in the Mbarara milk-producing region found that milk quality varied across different stages of the value chain and identified concerns related to milk temperature, density, clot-on-boiling and alcohol tests, as well as microbiological indicators such as total plate count, total and faecal coliforms, and *Escherichia coli* (Grimaud et al., 2007). These findings demonstrate the importance of systematic milk quality assessment and management within dairy production and marketing systems.

Effective milk quality management requires the monitoring of critical physicochemical and microbiological parameters. Physicochemical parameters may include milk temperature, acidity or pH, specific gravity, fat, protein, and other compositional characteristics, while microbiological assessment may include total bacterial counts and indicators of faecal contamination. Recent research in Uganda has continued to demonstrate the relevance of these parameters in assessing the safety and quality of raw milk. For example, Opiyo et al. (2024) assessed the physicochemical and microbiological quality of raw milk produced by smallholder farmers in Gulu City, highlighting the need for appropriate quality-control measures before milk reaches consumers.

The quality of milk is influenced not only by its inherent composition but also by management practices throughout the dairy value chain. Factors such as hygiene during milking, cleanliness of equipment and containers, handling practices, storage conditions, cooling, transportation, and the duration between milking and processing can influence the physicochemical and microbiological characteristics of milk. Garcia et al. (2008) and Staal and Kaguongo (2003) identified production, marketing, and management conditions as important considerations in the development of Uganda's dairy sector. Consequently, strengthening milk quality management requires identification and consistent

monitoring of the parameters that provide reliable indications of milk quality.

Although milk quality has been investigated in different parts of Uganda, there remains a need to assess the critical parameters used in milk quality management within specific dairy facilities and local contexts. This is particularly relevant in Mbarara District, an important dairy-producing area where effective quality management can contribute to reducing milk deterioration, protecting public health, improving the value of milk, and supporting the sustainability of dairy enterprises. This study aims to identify the critical milk quality parameters affecting milk quality management in selected dairy facilities in Mbarara District, Uganda.

METHODOLOGY

Research Design

This study employed a mixed-methods research design combining qualitative and quantitative approaches within an action research framework. This offered the best of both worlds: in-depth, contextualized, and natural, but less time-consuming. This study was descriptive in nature, where the study gathered data to assess the framework for enhancing milk quality and reducing waste in South Western Uganda's dairy industry. The study also employed quantitative research methods, where quantitative data were obtained from closed-ended questions in the questionnaire.

Target Population

The study population consisted of approximately 1,000 dairy stakeholders in Mbarara District, including farmers, collection center staff, transporters, and processors.

Sample Size Determination

Using Krejcie & Morgan's (1970) sample size determination table, the recommended sample size was 278 respondents. This sample was proportionally allocated across stakeholder categories to ensure representativeness.

Sampling Techniques

The sampling technique used was simple random sampling, where the population of dairy stakeholders (farmers, collection centre staff, transporters, and processors) was considered. The total population is approximately 1,000 stakeholders, and using Krejcie & Morgan's (1970) table, the sample size is 278 respondents. This sample was proportionally distributed across farmers (167), collection centre staff (28), transporters (42), and processors (41). Respondents will be randomly selected using lists provided

by collection centres, transport routes, and processing facilities. This technique ensured that all stakeholders were adequately represented, minimised bias, and enhanced the reliability and generalizability of the findings.

transportation, processing, and quality assurance. Farmers provided primary production information, milk traders explained transportation and handling practices, dairy processors provided information on quality standards, while veterinary officers and extension workers contributed technical expertise. Their inclusion ensured a comprehensive understanding of the milk value chain.

Sampling Justification

The selected participants possessed direct knowledge and practical experience regarding milk production, handling,

Table1: Sampling Allocation Table (Mbarara District)

Stakeholder Group	Estimated Population (N)	Proportion of Total (%)	Sample Size (n)	Selection Method
Farmers	600	60%	167	Randomly select staff from registered centers
Collection Center Staff	100	10%	28	Randomly select staff from registered centers.
Transporters	150	15%	42	Randomly select transporters from transport route rosters
Processors	150	15%	41	Randomly select processors from plant staff lists
Total	1,000	100%	278	

Data Collection Instrument

Questionnaire Method

A questionnaire is a research instrument consisting of a series of questions and other prompts for the purpose of gathering information from respondents.

A research questionnaire was used to collect data from respondents in this study. It contained only closed-ended questions. The study employed a self-administered questionnaire to collect data from respondents. A closed-ended questionnaire based on a 5-point Likert scale questionnaire with 5 =strongly agree, 4 = agree, 3 = not sure, 2 = disagree, 1= strongly disagree) was used, as indicated in the appendix. This tool collected data from the sampled respondents in Mbarara District. The questionnaire method of data collection was used because it was cheap, and this method collected responses with minimal errors and a high level of confidentiality. Questionnaires were also used because they do not require strong supervision and allowed for the collection of large amounts of information within the stipulated time frame, as respondents can fill them at their convenience.

Data Sources

Data collection plays a very crucial role in the statistical analysis. In this research, different methods were used to gather information, all of which fall into two categories that was primary and secondary data.

Primary data

Primary data is the data that the study collects through various methods like interviews, surveys, and questionnaires. Primary data was collected using a closed-ended questionnaire. The questionnaires were administered to the respondents by the study.

Secondary data

Secondary data were obtained from government reports, abstracts, journals, and newspapers.

Data Analysis Methods

Qualitative Data Analysis

Qualitative data from interviews, focus groups, and observations were analyzed using thematic analysis following Braun and Clarke's (2006) six-step approach: 1.

Familiarization with data through transcription and review; 2. Initial code generation using both inductive and deductive approaches; 3. Theme identification by clustering related codes; 4. Theme review and refinement through iterative analysis; 5. Theme definition and naming to capture core concepts; 6. Report production with illustrative quotations and contextual interpretation

Analysis was facilitated using NVivo software, with coding conducted by multiple researchers to enable assessment of inter-rater reliability. Member checking with selected participants verified interpretive accuracy.

Quantitative Data Analysis

Quantitative data analysis employed both descriptive and inferential statistics:

Descriptive Statistics:

Inferential Statistics:

Paired t-tests or Wilcoxon signed-rank tests comparing pre- and post-implementation metrics

Chi-square tests examining relationships between categorical variables

Correlation analysis identifying associations between system usage and outcome measures

Regression models exploring predictors of system adoption and effectiveness

ANOVA testing differences across implementation sites and user groups

Statistical analysis was conducted using R and SPSS software, with a significance level of $p < 0.05$ for hypothesis testing.

System Performance Analysis

Analysis of technical system performance included: - Accuracy assessment of quality prediction algorithms through confusion matrices and ROC curves - Response time analysis under varying load and connectivity conditions - Reliability metrics including system uptime and error rates - Scalability evaluation through simulated load testing - Security vulnerability assessment through penetration testing.

Economic Analysis

Economic impact was assessed through: - Cost-benefit analysis comparing implementation costs with the economic value of waste reduction - Return on investment calculations for different system components - Opportunity cost assessment for alternative quality management approaches -

Sensitivity analysis examining how variations in key parameters affect economic outcomes.

Integrated Analysis

The mixed-methods design necessitated integrated analysis approaches: - Sequential explanatory analysis using qualitative findings to interpret quantitative patterns - Data transformation techniques to enable joint analysis of quantitative and qualitative insights - Case-oriented analysis examining relationships between contextual factors and implementation outcomes - Cross-method triangulation to validate findings and identify convergence or divergence.

Missing Data

All completed questionnaires were checked immediately after collection. Incomplete questionnaires containing substantial missing responses were excluded from analysis, while minor missing values were managed using appropriate statistical imputation techniques where applicable. Sensitivity analyses were conducted to determine whether missing data influenced study findings.

Validity and Reliability

Instrument validity was established through expert review and pilot testing. Reliability was assessed using Cronbach's alpha ($\alpha \geq 0.70$) to ensure internal consistency of survey scales. These procedures strengthened the credibility of inferential statistics applied in the analysis.

This comprehensive analytical approach generated both generalizable insights about the effectiveness of the technological intervention and context-specific understanding of implementation dynamics.

Ethical Considerations

Informed Consent

All research participants provided informed consent following a comprehensive explanation of: - Research purpose and procedures - Data collection methods and use of information - Potential benefits and risks of participation - Voluntary nature of participation and right to withdraw - Confidentiality protections and data security measures.

Consent materials were available in both English and local languages, with verbal explanation for participants with limited literacy.

Data Protection and Privacy

The research implemented robust data protection measures: - Encryption of sensitive personal and business data - Role-based access controls for system features and data - De-

identification of data used for analysis and reporting - Secure data storage and transmission protocols - Data retention limits and deletion procedures - Compliance with relevant data protection regulations. Sensitive data revealing adulteration or malpractice were anonymized and coded. Access was restricted to authorized research personnel, and REC oversight ensured employers, regulators, or competitors could not exploit the findings.

Equity and Inclusion

The research promoted equitable access and benefits: - Inclusive design accommodating diverse literacy levels and technical capabilities - Consideration of gender dynamics in system design and implementation - Attention to potential digital divides and strategies for mitigation. - Balanced stakeholder representation in requirements gathering and evaluation - Assessment of differential impacts across socioeconomic groups

Institutional Review and Oversight

The research underwent comprehensive ethical review: - Approval from Bishop Stuart University Ethics Committee - Review by Uganda National Council for Science and Technology - Compliance with dairy industry regulatory requirements - Regular ethical monitoring throughout the research process - Protocol for addressing unanticipated ethical challenges.

Handling Illegal or Unsafe Practices

If illegal or unsafe practices (e.g., adulteration, antibiotic misuse) were uncovered, they were confidentially reported to the Dairy Development Authority and BSU-REC

following ethical protocols. This ensured ethical responsibility while protecting participant confidentiality. In addition to individual informed consent, gatekeeper consent was obtained from facility management (collection centers, transport plants) before data collection. This ensured **institutional approval and**

Ethical compliance.

These ethical considerations were integrated throughout the research process, informing design decisions, implementation approaches, and evaluation methods to ensure responsible technology development and deployment.

Laboratory procedures

Milk samples were analyzed using calibrated laboratory equipment following recognized dairy testing procedures. Quality parameters including pH, density, temperature, alcohol stability, fat content, and microbial load were determined using standard operating procedures. Equipment was calibrated before each testing session, and duplicate analyses were conducted to ensure reliability and accuracy of laboratory results.

Results

Response Rate

The study achieved a response rate of 91.4%, with 254 of the 278 targeted respondents successfully participating. According to Creswell (2014), a response rate above 70% is considered adequate for ensuring reliability and validity in social science research, a threshold this study comfortably exceeds, affirming the credibility of the findings that follow.

Table 2: Response Rate

Category	Targeted	Achieved	Response Rate (%)
Overall Sample	278	254	91.4

Source: Field Data (2026)

The final achieved sample of 254 differs from the 278 respondents projected using Krejcie & Morgan's (1970) sample-size table.

Demographic Characteristics of Respondents

Table 3: Demographic Characteristics of Respondents (N = 254)

Variable	Category	Frequency	Percentage (%)
Stakeholder Category	Dairy Farmers	74	29.1
	Milk Traders	60	23.6
	Transporters	55	21.7
	Processors	35	13.8

Years of Experience	Regulatory Officials	30	11.8
	More than 5 years	173	68.1
	5 years or less	81	31.9

Source: Field Data (2026)

Dairy farmers constituted the largest proportion of respondents (29.1%), reflecting the structure of Uganda's dairy sector, which is dominated by smallholder producers. 68.1% of respondents reported more than five years of experience in dairy-related activities, suggesting that the data collected was grounded in substantial practical

knowledge of the value chain. This experience profile was particularly important for capturing credible insights into quality challenges at the production level, where, as the subsequent sections demonstrate, most inefficiencies originate.

Critical Milk Quality Parameters Affecting Milk Quality Management (Objective One)

Table 4: Respondent-Identified Milk Quality Parameters (N = 254)

Quality Parameter	Respondents Identifying Parameter as Significant (%)	Common Threshold/ Issue Reported
Butterfat content	72.0	Milk below 3.2% butterfat frequently rejected
Solid-Not-Fat (SNF)	65.0	Milk below 8.3% SNF often downgraded or rejected
Bacterial contamination	80.0	High bacterial counts, poor hygiene, unclean containers
Temperature control	85.0	Storage/transport above the recommended 4°C

Source: Field Data (2026)

Butterfat Content

Butterfat content was identified as a key determinant of milk quality, with 72.0% of respondents acknowledging its importance in pricing and processing decisions. Milk with butterfat levels below 3.2% was frequently rejected by processors, resulting in economic losses for producers.

Solid-Not-Fat (SNF)

Solid-not-fat was identified as a critical parameter, with 65.0% of respondents indicating awareness of its importance. Milk with SNF levels below 8.3% was often downgraded or rejected. The study found that low SNF levels were largely associated with adulteration practices, particularly the addition of water to increase volume, a practice that reduces the nutritional quality of milk and accelerates spoilage.

Bacterial Contamination

Bacterial contamination emerged as the most significant contributor to milk spoilage and wastage, with 80.0% of respondents reporting that high bacterial counts frequently resulted in milk rejection. The main causes of contamination

included poor hygiene during milking, use of unclean containers, and delays in transportation.

Temperature Control

Temperature control was found to be critically inadequate across the dairy value chain: 85.0% of respondents lacked access to proper cooling facilities, resulting in milk being stored and transported at temperatures above the recommended 4°C. This significantly accelerates bacterial growth and reduces milk shelf life.

Discussion

Butterfat content was identified as a key determinant of milk quality, with 72.0% of respondents acknowledging its importance in pricing and processing decisions. Milk with butterfat levels below 3.2% was frequently rejected by processors, resulting in economic losses for producers. This finding is consistent with O'Connor (1994), who notes that butterfat is a critical indicator of milk quality and suitability for dairy processing. The study further established that low butterfat levels were primarily caused by inadequate feeding practices and seasonal feed shortages, a pattern Nicholson et al. (2004) similarly attribute to the fundamental role animal

nutrition plays in determining milk composition, underscoring the need for improved feeding systems in Mbarara District.

Solid-not-fat was identified as a critical parameter, with 65.0% of respondents indicating awareness of its importance. Milk with SNF levels below 8.3% was often downgraded or rejected. The study found that low SNF levels were largely associated with adulteration practices, particularly the addition of water to increase volume, a practice that reduces the nutritional quality of milk and accelerates spoilage. This corroborates the Food and Agriculture Organization's (2011) observation that adulteration is a major challenge in developing dairy markets and undermines efforts to maintain quality standards.

Bacterial contamination emerged as the most significant contributor to milk spoilage and wastage, with 80.0% of respondents reporting that high bacterial counts frequently resulted in milk rejection. The main causes of contamination included poor hygiene during milking, use of unclean containers, and delays in transportation. These findings are supported by Oliver et al. (2005), who identify microbial contamination as a key determinant of milk safety and shelf life, noting that high bacterial loads accelerate spoilage and render milk unsuitable for consumption and processing.

Temperature control was found to be critically inadequate across the dairy value chain: 85.0% of respondents lacked access to proper cooling facilities, resulting in milk being stored and transported at temperatures above the recommended 4°C. This significantly accelerates bacterial growth and reduces milk shelf life. The Food and Agriculture Organization (2011) emphasises that maintaining a cold chain is essential for preserving milk quality and minimising post-harvest losses; the near-absence of such infrastructure in rural Mbarara therefore contributes substantially to milk wastage and provides a direct empirical rationale for the storage-condition monitoring module proposed.

Conclusions

Butterfat content, solid-not-fat, bacterial contamination, and temperature control are confirmed as the critical parameters governing milk quality management in Mbarara District, with hygiene- and cold-chain-related parameters (bacterial load and temperature) presenting the more urgent and widespread deficiencies relative to compositional parameters.

Recommendations

Mbarara District Local Government, in collaboration with the Dairy Development Authority, should prioritise investment in shared cooling infrastructure at milk collection centres, given the strong empirical link established between inadequate temperature control and milk wastage.

Regulatory and extension agencies should intensify farmer training on milking hygiene, container sanitation, and basic pre-sale quality testing, targeting in particular the 70.0% of farmers who currently conduct no quality checks before selling their milk, since bacterial contamination was identified as the single most significant predictor of wastage. Feeding-system interventions, including improved access to quality feed and extension advice on nutrition, are also recommended to address the butterfat and SNF deficits linked to seasonal feed shortages.

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List of acronyms

ANOVA – Analysis of Variance
API – Application Programming Interface
BSU – Bishop Stuart University
ERP – Enterprise Resource Planning
FAO – Food and Agriculture Organization
SMS – Short Message Service
SNF – Solid-Not-Fat
SPSS – Statistical Package for the Social Sciences
UBOS – Uganda Bureau of Statistics

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Conflict of interest

The author did not declare any conflict of interest.

Data availability

Data is available upon request.

Author contribution

James Asiimwe; Conceptualisation, Funding acquisition, Methodology, Writing – original draft, Resources, Software. Dr Sudi Balimuttajjo; Supervision, Validation, Visualisation, Data curation, Formal analysis, Investigation Kiguli Cosmas; Project administration, Writing – review & editing

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Author Contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Asiimwe James: Conceptualization, methodology, investigation, system design and development, data collection, formal analysis, validation, and writing of the original draft. He also contributed to the interpretation of findings, visualization, and subsequent revision of the manuscript.

Kiguli Cosmas: Technical supervision, system architecture, software development guidance, validation, and technical review. He provided expertise in the design and development of the integrated Enterprise Resource Planning (ERP) system for milk quality monitoring, including guidance on the system architecture, technology stack, and technical implementation.

Dr. Sudi Balimuttajjo: Supervision, validation, and writing review and editing. He contributed to the critical evaluation, refinement, and intellectual improvement of the manuscript throughout its development.

Prof. Kalibwani M. Rebecca: Supervision, project administration, resources, and funding acquisition. She facilitated linkages with relevant funding partners, including RUFORUM. All authors contributed to the interpretation of the study findings, critically reviewed the manuscript for important intellectual content, approved the final version for submission, and agreed to be accountable for all aspects of

the work, including ensuring the accuracy and integrity of the research and its reporting.

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