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Accelerating quality upgrading in Ugandan Dairy Value Chains - Preliminary results from a Value Chain Experiment

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Contents

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Abstract

Uganda's dairy sector faces persistent challenges in milk quality, particularly low butterfat and solids-not-fat (SNF) levels. This study uses a multilevel randomized control trial with interventions at both Milk Collection Center (MCC) and farmer levels to identify some of the barriers that prevent quality upgrading within dairy value chains. Innovations included milk analyzers, digital record-keeping, and farmer-focused educational campaigns.

Results showed significant improvements in milk quality at MCCs using analyzers, with higher butterfat and SNF levels and reduced adulteration. However, adoption varied widely, and uniform price setting by processors failed to incentivize quality improvements. Future efforts should focus on aligning financial incentives with quality, reducing adoption barriers, and fostering competitive markets to ensure sustainable quality upgrading in Uganda's dairy value chain.

Dairy value chains in Uganda

The Ugandan dairy subsector is a dynamic and rapidly growing sector, with its development closely linked to significant policy reforms. Notably, the privatization of the National Dairy Corporation and the enactment of the Dairy Industry Act of 1998 marked critical turning points for the industry. These reforms also led to the establishment of the Dairy Development Authority (DDA), a statutory body under the Ministry of Agriculture, Animal Industry, and Fisheries. The DDA has a dual mandate to regulate and promote the dairy sector, ensuring compliance with quality standards while supporting farmers and stakeholders through training, improved technologies, and market development initiatives.

The policy changes spurred an influx of foreign direct investment, particularly in Mbarara, a key town in southwestern Uganda (Van Campenhout, Minten, and Swinnen, 2021). This investment has fostered the emergence of a cluster of milk processors in the region, enhancing value addition and market access. Additionally, productivity in the sector has been bolstered by the widespread adoption of improved dairy breeds, such as Holstein Friesians and Jersey cows, significantly increasing milk yields and overall sector efficiency. Today, the dairy subsector is one of the main export earners of the country.

Dairy value chains in Uganda are diverse and can take various organizational forms, ranging from fully vertically integrated systems involving large processing companies to more fragmented structures dominated by small cooperatives and farmer groups. Despite these variations, a generic value chain, illustrated in Figure 1, consists of five main actors, each playing a distinct role in the production, transportation, and processing of milk.

1. Smallholder Farmers: At the upstream end of the chain are smallholder farmers, who are the primary producers of milk. These farmers deliver milk daily to milk collection centers (MCCs) either personally or by relying on intermediaries such as small traders or transporters.
2. Transporters and Traders: Transporters collect milk directly from farms and deliver it to MCCs for a fee. Unlike transporters, traders purchase milk from farmers with the intent to sell it at MCCs or to other traders for profit, thus functioning as commercial intermediaries within the chain.
3. Milk Collection Centers (MCCs): MCCs are critical nodes in the value chain. Their primary role is to bulk and chill milk, marking the start of the cold chain essential for maintaining milk quality. These centers are strategically distributed across rural areas, facilitating access for smallholder farmers.
4. Large Traders: Once milk is chilled and bulked at MCCs, large traders transport it to processing facilities. This step often involves the use of specialized milk tankers to preserve quality during transit.
5. Processors: Processors, concentrated in key towns such as Mbarara---Uganda's dairy hub---convert raw milk into value-added products with extended shelf lives, such as ultra-heat-treated (UHT) milk, powdered milk, and infant formula. These processors play a pivotal role in integrating Uganda's dairy sector into both domestic and export markets.

Figure 1: A generic dairy value chain

This layered and dynamic structure enables the participation of diverse stakeholders while presenting opportunities for efficiency improvements at various points along the chain.

Problem statement, hypotheses and solutions

Low butterfat and Solids-Not-Fat (SNF) levels remain persistent challenges in milk quality, presenting a critical issue within the dairy value chain. Processors express a willingness to pay higher prices for higher-quality milk, while farmers indicate that they would be willing to invest in improving milk quality if adequately compensated. Despite this mutual interest, a functioning market for milk quality is notably absent, preventing quality-based incentives from materializing.

One possible explanation for this disconnect is that milk quality is not readily observable across the value chain, as suggested by the first hypothesis. Milk is often bulked mid-stream, making it difficult to trace and reward quality at the individual farmer level. Testing typically occurs only at the processor stage, by which point the opportunity to attribute quality to specific suppliers is lost. The second hypothesis posits a mismatch in how quality is understood by key stakeholders. Farmers often associate quality with milk sanitation, while processors prioritize compositional attributes such as butterfat and SNF content. This misalignment further complicates e orts to align incentives and establish a quality-focused market.

To address these challenges, two solutions are proposed. First, milk quality must be made observable throughout the entire value chain. This could involve the deployment of portable testing equipment or digital tracking systems that allow quality to be assessed and recorded at multiple points, from farm to processor. Second, farmers need to be sensitized to the importance of compositional quality. Providing them with education on what compositional quality entails, its relevance to processors, and practical methods for improvement could bridge the knowledge gap and align farmer practices with market demands. By implementing these solutions, the dairy sector can move toward creating a sustainable market for milk quality that benefits both farmers and processors.

Innovation bundles for addressing milk quality challenges

In response to the first challenge of unobservable milk quality in the Ugandan dairy value chain, we designed an innovation bundle targeting Milk Collection Centers (MCCs). This bundle aims to enhance transparency, improve record-keeping, and empower both MCC managers and farmers by making milk quality measurable and visible. The bundle consists of three key components:

1. Milk Analyzer: A central component of the innovation bundle is the installation of a milk analyzer at MCCs. This machine assesses milk quality based on a set of compositional parameters, such as butterfat content and solids-not-fat. The testing process is non-destructive and takes less than one minute per sample, enabling rapid and accurate quality evaluation of all milk collected. By providing immediate feedback, the milk analyzer helps ensure that quality standards are met and maintained. More information on the milk analyzer can be obtained from the manufacturer's website.
2. IT-Mediated Record-Keeping System: We developed an Android application for MCC managers to facilitate digital record-keeping. The app replaces the traditional paper notebooks used for tracking milk deliveries and payments. In addition to recording quantities and prices, the app allows MCC managers to store and monitor quality parameters obtained from the milk analyzer. This digital system enhances efficiency and transparency, providing both MCC managers and farmers with reliable records that integrate milk quality metrics. The android app can be downloaded from google play store.
3. Farmer Engagement through Advertisements: To address potential power imbalances emerging from the installation of milk analyzers and ensure farmers are equally informed, we introduced a poster campaign at MCCs. The posters advertise the availability of free milk quality testing for farmers. By making this service widely known, the campaign aims to empower farmers with knowledge about their product quality, fostering trust and collaboration between farmers and MCC managers.

Together, these three components form a comprehensive strategy to make milk quality observable and actionable, creating incentives for improved practices throughout the dairy value chain. This package will constitute our first treatment in the eld experiment below and will be referred to as T1.

To bridge the gap in how milk quality is understood between farmers and processors, we designed an intervention aimed at improving farmers' knowledge of compositional quality and its importance in the dairy value chain. This treatment combines information dissemination, practical advice, and tangible support to drive behavioral changes. It consists of three components:

1. Educational Video: A short, engaging video was developed to explain the concept of compositional milk quality parameters such as butterfat and protein content and why it matters for both farmers and processors. The video also highlights practical management practices and inputs that farmers can adopt to improve milk quality, such as better feeding strategies, enhanced herd health, and proper milking hygiene. The video is designed to be accessible and appealing, ensuring key messages resonate with the target audience.
2. Cartoon Handout: To reinforce the information provided in the video, we created a handout in the form of a cartoon summary. The cartoons provide a visual, easy-to-understand recap of the key points, serving as a

quick reference for farmers after watching the video. This format ensures the information remains accessible even to farmers with limited literacy.

3. Improved Pasture Seeds: To make the knowledge actionable, each participating farmer received a bag of improved pasture seeds. By planting these seeds, farmers can enhance the nutritional value of their pastures, a critical factor in increasing the compositional quality of milk. This practical input complements the educational components, enabling farmers to directly apply the recommendations provided.

This treatment, henceforth referred to as T2, aims to align the understanding of milk quality between farmers and processors while equipping farmers with the tools and knowledge to improve milk quality in a sustainable manner.

Experimental Design

We use a field experiment to test the effectiveness of the innovation bundle. We use a split plot trial design with interventions at two levels of the value chain. The design is illustrated in Figure 2.

The design follows the value chain structure previously outlined, where the first treatment (T1) is implemented at the MCC level. Within each MCC, the second treatment (T2) is randomized at the individual farmer level. Specifically, half of the farmers are assigned to receive the video treatment, while the other half are randomized into the control group. Additionally, within each milk collection center, half of the farmers connected to that MCC receive the video treatment, while the other half are in the control group. To explore heterogeneity in treatment effects, we also stratify basing on the way farmers are connected to the MCC either directly or via a trader.

This design allows us to examine outcomes at different levels of the value chain. At the MCC level, we can assess the impact of the T1 intervention on MCC-level outcomes. Furthermore, we can analyze the effects of the second treatment (T2) on farmers connected to the MCC, either directly or through a trader. However, the impact of the farmer-level treatment (T2) can only be evaluated by examining outcomes at the individual farmer level.

Sample and timeline

The eld experiment was conducted in four districts of Southwestern Uganda: Ntungamo, Mbarara, Kazo, and Kiruhura. The study began with a comprehensive census of all milk collection centers (MCCs) in the region, which yielded a total of about 130 MCCs. Half of these were randomly selected to receive T1, while the other half served as the control. In each of the 130 MCCs, we randomly selected 20 farmers who deliver milk to the center. Of these 20 farmers, 10 were randomly assigned to the video treatment (T2), while the remaining 10 served as the control group.

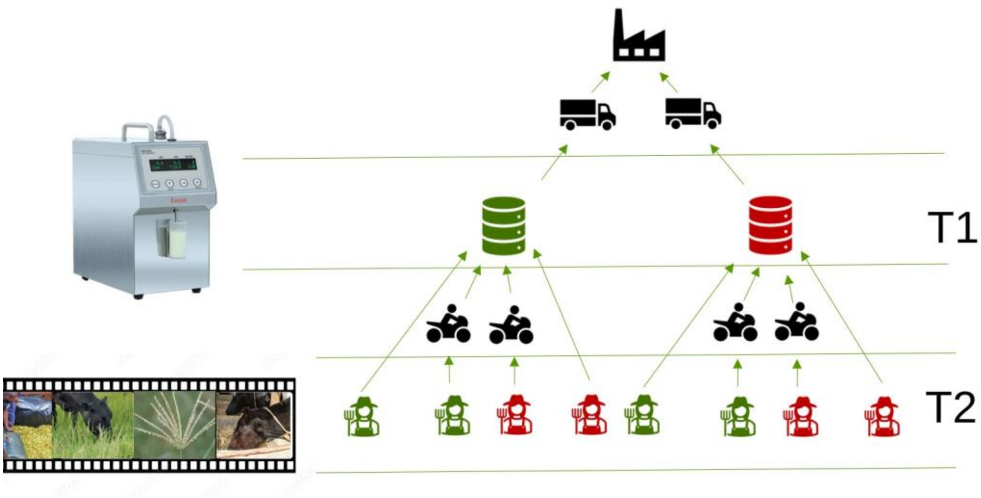

Figure 2: Experimental Design

Figure 3 shows randomization in three of the four districts for T1 and T2 at both the MCC and farmer level. The first map to the left of the Figure 3 shows the locations of the MCCs and their treatment status for T1. The second panel shows the treatment status for T1 for the farmers that are connected to the MCCs, which is clustered at the MCC level as T1 is implemented at that level. The third panel shows treatment allocation of T2 among farmers linked to MCCs, which is at the individual level.

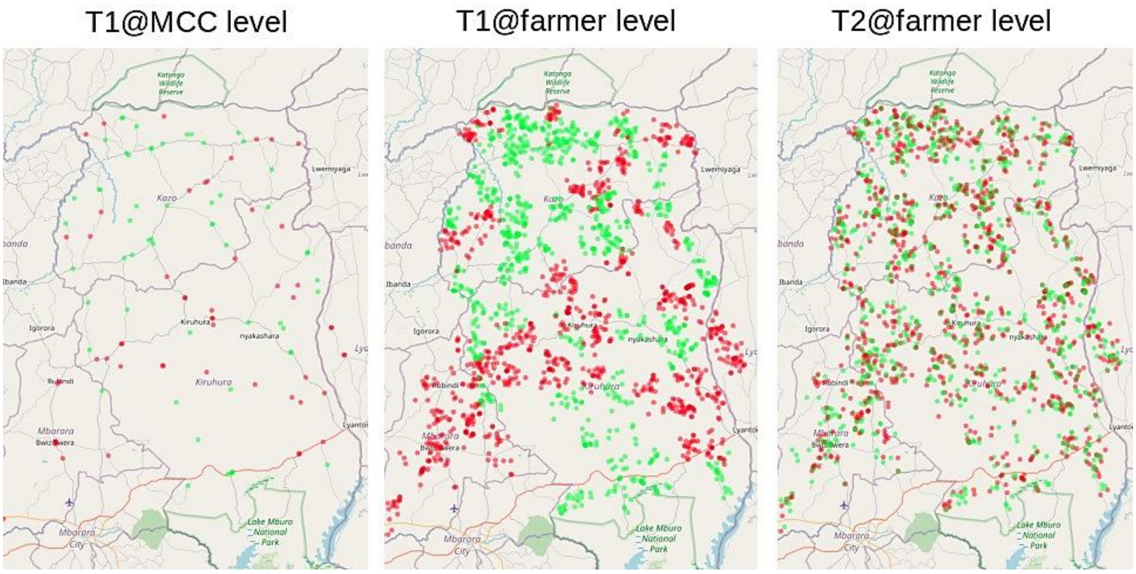

Figure 3: Sampling at MCC and farmer level

Figure 4 shows the timeline of the project. We started with a scoping study, which informed the research questions and formulation of hypotheses in August 2022. This led to the design of the innovation bundle in September. Baseline data was collected towards the end of 2022. At this time, the intervention at the farmer level (T2) was implemented for the first time.

The intervention at the MCC level was more complex than the information treatment and so we linked up with DDA before rolling out T1 in October 2023. From this point onward, we monitored project implementation (which included analysis of data that was coming in through the Android app) and did a qualitative midline in March 2024. Roughly one year after T1, we collected endline information. We also organized a scaling preparedness workshop in October 2024.

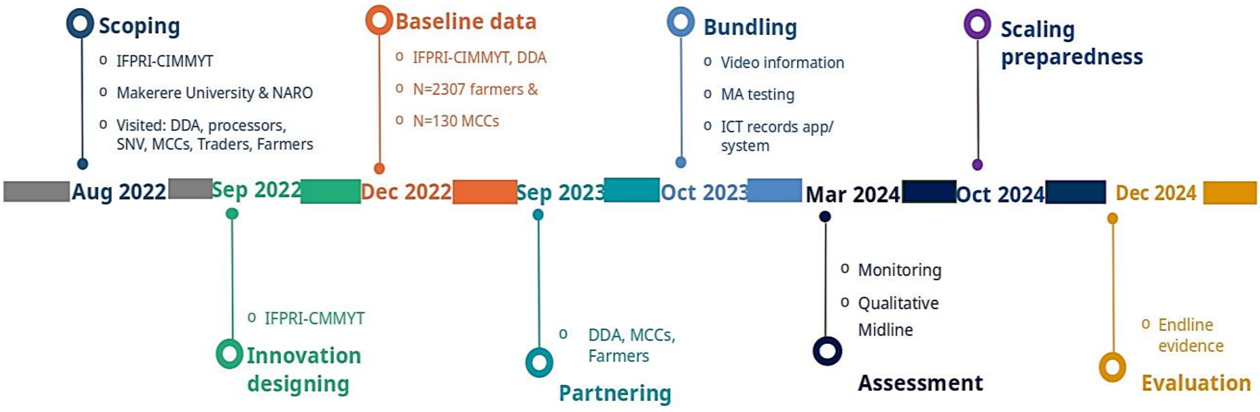

Figure 4: Project timeline

Results

Use of bundle components

We begin by examining the utilization of selected components within the bundle, focusing on data collected from Milk Collection Centers (MCCs). At this level, we only focus on T1, the intervention at the MCC level. As illustrated in Figure 5, which presents simple differences between treatment and control groups, the results reveal a significant increase in the likelihood of milk analyzers (MAs) being used. This increase is evident both for testing milk delivered to the MCC and for milk sold onward, such as to processors or large traders. Specifically, the data show that the probability of incoming samples being tested with a milk analyzer rises by approximately 55 percentage points when an MA is installed at the MCC.

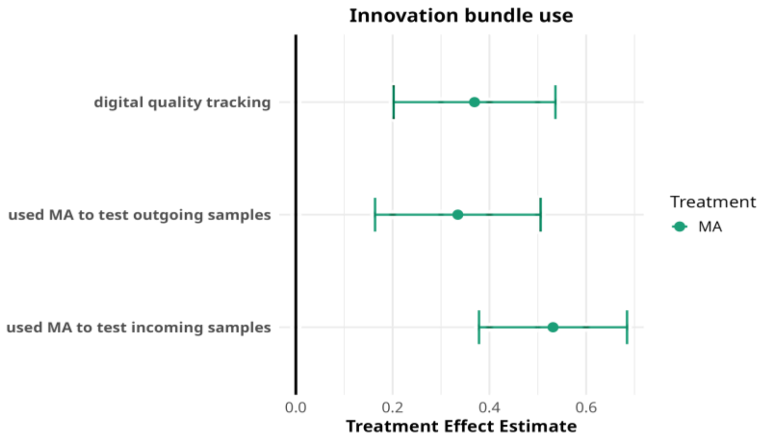

Figure 5: Use of Innovations at MCC level

Similarly, there is a substantial increase of about 35 percentage points in the likelihood of milk being tested during sales transactions. In addition to testing, MCC managers appear to value the digital tracking of milk quality facilitated by the Android app. This is reflected in an approximately 40 percentage point increase in app usage among the treatment group.

Despite these notable gains, it is important to highlight that the adoption of these technologies is not universal. Assuming near-zero usage of milk analyzers and the Android app in control MCCs, the observed rates of adoption in treatment MCCs fall significantly short of full utilization. Based on expectations, usage rates for both tools should have approached 100 percent, yet the data suggests substantial gaps in their consistent application.

The heterogeneity in the use of milk analyzers can be further explored by analyzing data submitted through the Android app over the course of the project. While some MCCs consistently tested and recorded incoming milk samples, others exhibited irregular patterns in their behavior. This variability is illustrated in the right panel of Figure 6, which provides two contrasting examples.

The first example, MCC 1, is a cooperative MCC with approximately 25 to 30 members. At this MCC, milk from all members is tested almost daily, with a few exceptions on days when not all members deliver milk typically on Sundays or when occasional samples are missed. The consistency observed at MCC 1 demonstrates a systematic and routine application of milk testing, likely driven by the cooperative structure and its operational norms.

In contrast, MCC 2 displays a much higher degree of variability in its milk testing and submission practices. On many days, only 5 to 10 samples were tested and recorded, whereas on other days, substantially larger numbers of samples were analyzed. Notably, on one day, more than 100 samples were tested and submitted. This erratic pattern suggests less structured operations, which could be influenced by factors such as fluctuating milk supply, staff availability, or varying adherence to testing protocols.

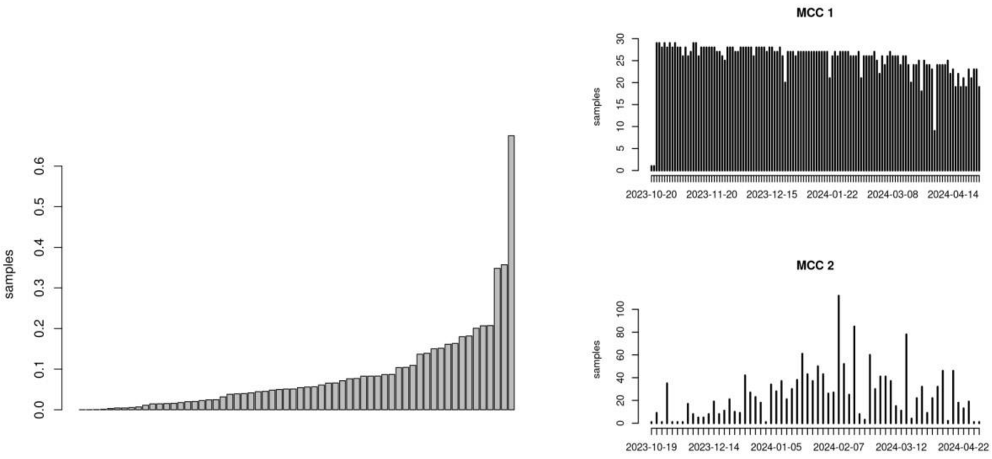

Figure 6: Use of Milk Analyzers (submissions)

These contrasting examples highlight the substantial variation in how MCCs implement and utilize milk analyzers, even within a structured intervention framework.

The bar chart on the left in Figure 6 illustrates the percentage of samples tested for each of the 65 treatment MCCs included in our study. This metric was estimated using the number of farmers who delivered milk during the baseline period and the average number of submissions recorded by each MCC through the Android app. The chart reveals that a substantial number of MCCs reported very low testing rates. Strikingly, only one MCC tested more than 50% of its incoming milk, and overall, just about 8% of samples were tested across all treatment MCCs.

However, this low testing rate does not necessarily indicate that intervention lacks impact. The presence of a milk analyzer at an MCC may still influence farmer and MCC behavior indirectly. The mere possibility that poor milk quality could be exposed through testing may act as a deterrent to practices such as adulteration or mishandling, thereby driving improvements in milk quality even without extensive use of the analyzer itself.

We can also assess the use of the innovation bundle components at the farmer level. Recall that at this level, we can measure impact of both the MCC level intervention (T1) and the farmer level intervention (T2), as well as the combination of the MCC and farmer level interventions (T1+T2). Figure 7 thus reports three impact estimates for each outcome considered.

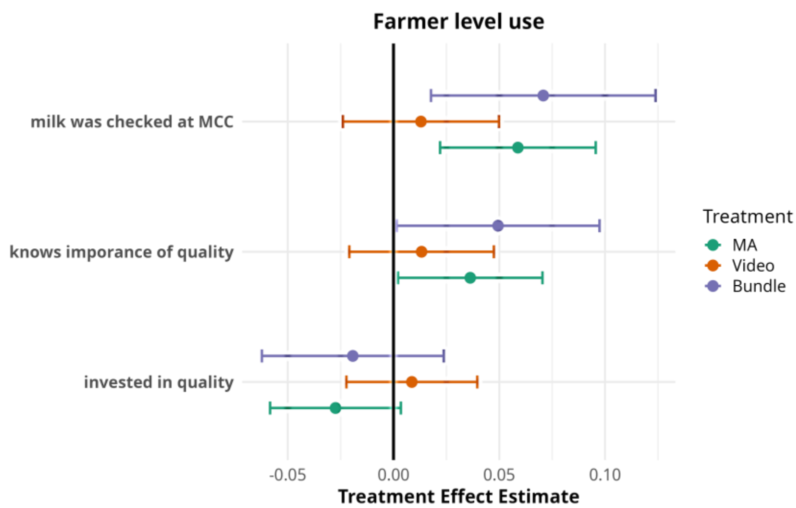

Figure 7: Use of Innovations at farmer level

Figure 7 shows that the likelihood that a farmer's milk was tested increased by approximately 6 percentage points, consistent with previous observations. Some farmers, however, ceased delivering milk to treatment MCCs, which may partially explain these modest gains (see section 6.2 below). While there was a slight improvement in farmers' awareness of compositional milk quality, the introduction of MAs has not yet led to noticeable investments in improving milk quality, such as for instance the use of controlled grazing or feed supplements.

We do not find a significant impact of the information intervention (T2) (and the impact of the T1+T2 does generally not di er from T1 alone). This is especially surprising for the outcome that measures investment in quality since T1 recommends several of the investments that are in the outcome.

Switching

During qualitative data collection at midline, farmers reported that they had largely stopped adding water to milk, a practice previously common. However, some farmers who were either unwilling or unable to adapt to the new requirements ceased delivering milk altogether. This finding is corroborated by survey data, which shows a reduction in the likelihood of farmers continuing to deliver to the same MCCs in treatment MCCs (Figure 8). This trend was particularly pronounced during the wet season, when MCCs implemented stricter quality enforcement protocols.

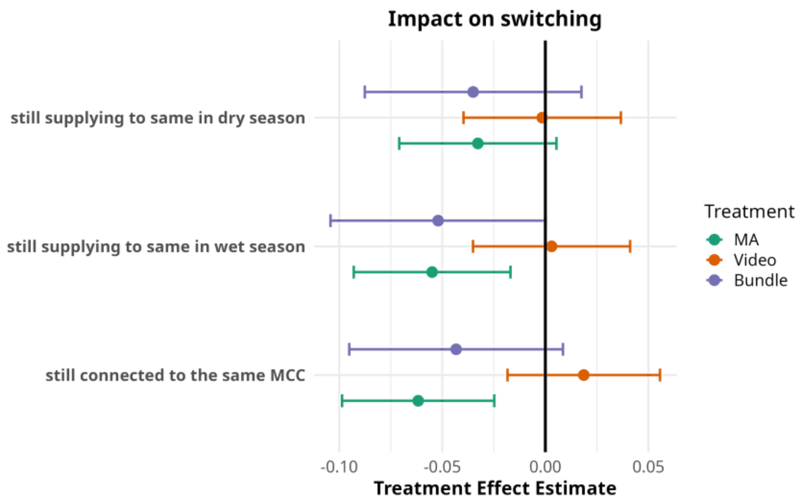

Figure 8: Switching

Quality

To objectively measure compositional quality, enumerators used milk analyzers to test all incoming milk during a full day at both treatment and control MCCs. While this exercise proved logistically challenging, it provided objective data on several compositional quality indicators. The results (Figure 9, in dark green indicated T) show that butterfat and solids-not-fat (SNF) levels were significantly higher in treatment MCCs, while the proportion of added water was lower. Additionally, milk rejection rates were higher at treatment MCCs, reflecting stricter quality standards.

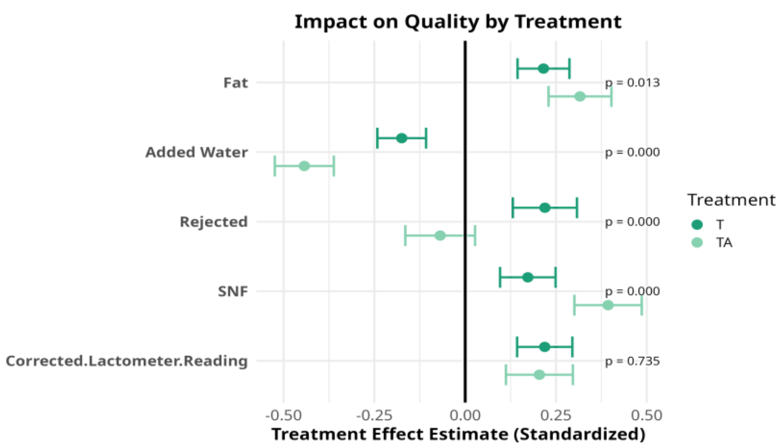

Figure 9: Impact on Quality

Figure 9 further illustrates the differences between treatment and control groups as measured by enumerators during testing at both treatment and control MCCs. In addition to these enumerator-collected data, we also have compositional quality data for treatment MCCs submitted by MCC managers via Android application. This additional dataset could provide insights into potential differences between treatment and control MCCs.

However, data collected through the Android application may be subject to selection bias. Managers might selectively test or report results, potentially focusing on high-quality samples or suspected cases while underreporting poorer outcomes. This could lead to overrepresentation of favorable results. Our analysis supports this concern (see TA in Figure 9): managers tend to report better results through the Android app compared to the enumerator-collected measures in the treatment MCCs.

Simple t-tests confirm significant differences between treatment MCC measures collected by enumerators and those reported through the Android app, except for density (Corrected Lactometer Reading), which shows no significant difference between the two data sources.

Impact on Freshness

In addition to influencing compositional quality, the intervention was hypothesized to influence milk freshness. Farmers who traditionally skim butterfat from milk often allow the milk to rest for extended periods to facilitate butterfat separation. By discouraging this practice, the intervention could potentially encourage earlier delivery of milk to the MCCs. Faster delivery would enable prompt chilling of the milk, thereby enhancing its freshness.

To evaluate this, we compared the cumulative distribution of milk deliveries throughout an average day between treatment and control MCCs (Figure 10). If the intervention resulted in faster deliveries, the cumulative distribution for treatment MCCs would shift leftward compared to control MCCs. However, our analysis shows no evidence of such a shift. Therefore, we conclude that the intervention (T1) is unlikely to have a significant impact on milk freshness.

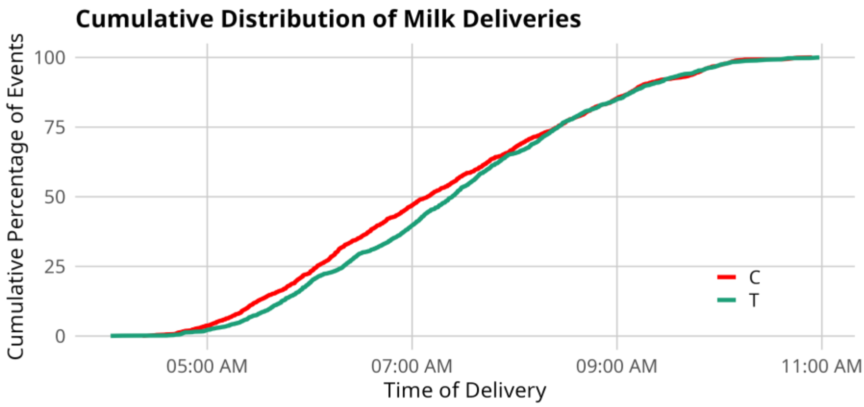

Figure 10: Cumulative distribution of milk deliveries

Impact on prices

Regarding price effects, no significant changes were observed at the MCC level, either in the prices received from processors or those paid to farmers (Figure 11).

Similarly, at the farmer level, there were no significant differences in prices reported during wet and dry seasons (Figure 12). However, a statistically significant increase was noted when farmers were asked about the price of their most recent transaction. However, the increase of about 15 UGX per liter is very small, amounting to about 1.5 percent of the price in the control group. Once again, we find no significant effect of T2 on prices.

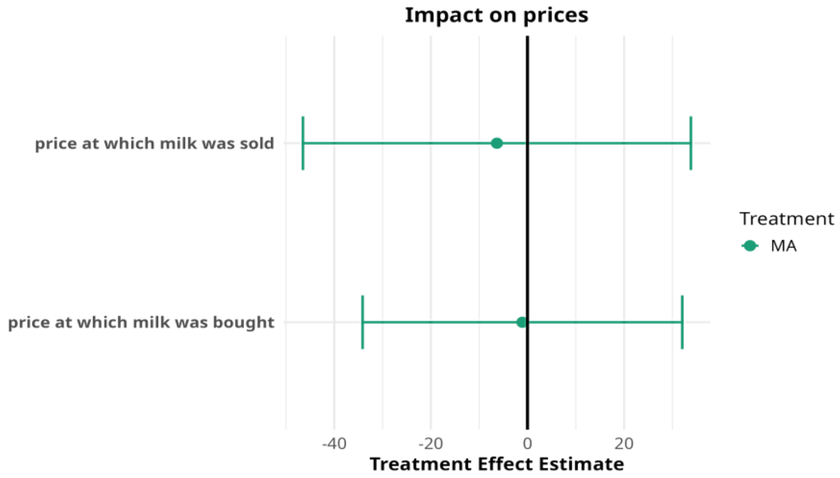

Figure 11: Impact on prices (MCC level)

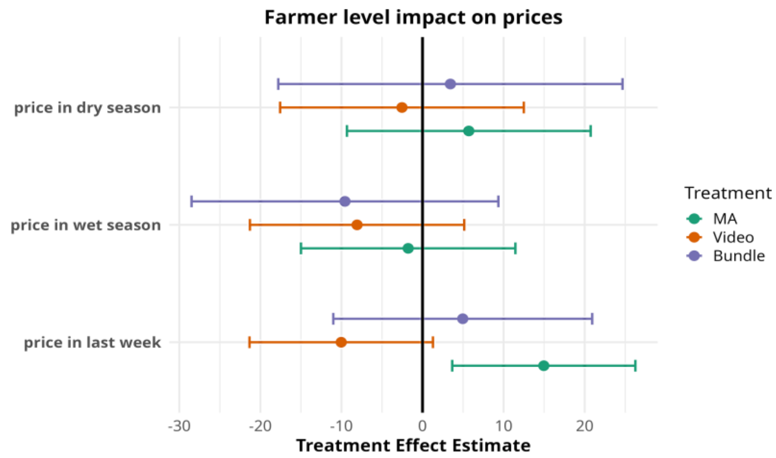

Figure 12: Impact on prices at farmer level

Conclusion

This study explored the potential of targeted interventions to accelerate quality upgrading in Uganda's dairy value chain. Using a field experiment, we introduced innovations at the MCC and farmer levels, including milk analyzers, digital record-keeping tools, and farmer training. The intervention aimed to address persistent challenges related to milk quality by making it observable, actionable, and incentivized. This comprehensive design allowed us to assess impacts at multiple levels of the value chain, providing robust insights into what drives or limits quality improvements.

The findings largely confirm insights gathered during the qualitative midline assessment (Ariong et al., 2024). The milk analyzer (MA) innovations were well-received and widely used, with stakeholders appreciating their ability to enhance transparency and enforce quality standards. As a result, compositional milk quality improved significantly, particularly in treatment MCCs, which recorded higher butterfat and solids-not-fat (SNF) levels and lower adulteration rates. Despite these gains, price effects remain limited and lagging, reflecting the broader structural issue of uniform pricing by processors that fails to reward quality improvements.

The training intervention (T2), focused on raising awareness and promoting quality-enhancing practices at the farmer level, showed no significant impact. While farmer awareness of compositional quality increased modestly, there was little evidence of behavioral changes, such as investment in better feeding or grazing practices. This suggests that information alone is insufficient to drive change without stronger economic incentives or additional support mechanisms.

The current price-setting mechanism is a critical bottleneck. Processors continue to publish uniform prices for milk, undermining the alignment of quality improvements with financial rewards. However, recent developments indicate potential shifts in the market. Two of Uganda's largest processors are piloting quality-based payment systems, directly rewarding farmers who supply milk of higher-quality. One MCC recently started selling milk to one of the large processors through their quality-based milk payment system. Additionally, a large new processor specializing in infant formula production that is entering the market has already started contacting MCCs to gauge their interest in supplying milk under a quality-based payment system.

These findings highlight both the progress made and the challenges that remain. While the interventions demonstrated the possibility of successful improvement of milk quality and increasing transparency, systemic changes particularly in pricing mechanisms are essential to sustain and scale these improvements. Future e orts should focus on supporting emerging market trends, addressing adoption barriers, and ensuring that economic incentives align with quality-based practices, ultimately bene ting all stakeholders across the dairy value chain.

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