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Research Application Summary

Effectiveness of on-farm raw milk cooling using solar refrigeration system in Nakuru County, Kenya

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Abstract

The Kenya dairy sector is one of the largest in Sub-Saharan Africa and it is dominated by small scale farmers. The sub-sector plays a crucial role in curbing food insecurity and creating employment in Kenya. However, evening milk which constitutes about 40% of the cow's production goes to waste due to lack of refrigeration facilities at the farm level. There is therefore need for on-farm milk cooling facilities that farmers can use to preserve evening milk. The Photovoltaics for Sustainable Milk for Africa through Refrigeration Technology (PV-SMART) project was initiated to provide on-farm milk cooling facilities for small scale and off-grid dairy farmers using modified off the shelf direct drive photovoltaic refrigerator (PVR) technology. Initial testing of these battery free solar farm milk coolers (FMC) was in Baringo and Nyandarua Counties and at Egerton University in Kenya. The current study was designed to study the microbiological and physico-chemical quality of raw milk from two farms stored in the FMC. Evening milk were sampled from the storage cans before and after refrigeration in the morning for analysis. Microbiological analysis was carried out using 3MTM Petrifilm plates. The study found out that there was no significant difference ($P< 0.05$) in milk quality before and after refrigeration. On average, there was an increase of 1.023 ± 0.997 and 0.950 ± 0.587 cfu/ml and 0.808 ± 1.273 and 0.914 ± 0.865 cfu/ml in Total Viable Counts (TVC) and Coliforms (CC) in Farm 1 and Farm 2, respectively. Results of This study reveal the possibility of improving the quality of milk marketed as well as improving the farmer's income through affordable on-farm solar milk refrigeration systems in Kenya.

Key Words: Diary farming, Egerton University, Kenya, mirobial contamination, milk quality, photovoltaics, solar refrigeration

Résumé

Le secteur laitier du Kenya est l'un des plus importants d'Afrique subsaharienne dominé par des petits agriculteurs. Ce sous-secteur joue un rôle crucial dans la lutte contre l'insécurité alimentaire et la création d'emplois au Kenya. Cependant, le lait approvisionné le soir qui constitue environ 40% de la production de la vache est gaspillé en raison du manque d'installations de réfrigération au niveau de la ferme. Il est donc nécessaire de disposer d'installations de refroidissement du lait à la ferme que les agriculteurs peuvent utiliser pour conserver le lait trait le soir. Le projet « Photovoltaics for Sustainable Milk for Africa through Refrigeration Technology (PV-SMART) » utilisant la technologie de réfrigérateur photovoltaïque à entraînement direct (PVR) modifié était lancé pour fournir des installations de refroidissement du lait à la ferme des petits producteurs laitiers qui se trouvent hors réseau. Les premiers tests de ces réfrigérateurs solaires sans batterie (FMC) se sont déroulés dans les comtés de Baringo et de Nyandarua et à l'Université d'Egerton au Kenya. La présente étude visait à analyser la qualité microbiologique et physico-chimique du lait cru de deux fermes stockées dans le FMC. Le lait approvisionné le soir était prélevé des bidons de stockage pour des analyses avant et après la réfrigération le matin. L'analyse microbiologique était réalisée à l'aide de plaques 3MTM Petrifilm. L'étude a révélé qu'il n'y avait pas de différence significative (P < 0,05) dans la qualité du lait avant et après la réfrigération. En moyenne, il y a eu une augmentation de 1,023 ± 0,997 et 0,950 ± 0,587 ufc/ml et de 0,808 ± 1,273 et 0,914 ± 0,865 ufc/ml du nombre totale de bactéries viables (TVC) et les Coliformes (CC) dans la Ferme 1 et la Ferme 2, respectivement. Les résultats de cette étude révèlent la possibilité d'améliorer la qualité du lait commercialisé ainsi que les revenus des agriculteurs grâce à des systèmes de réfrigération solaire du lait abordables à la ferme au Kenya.

Mots clés : Agriculture laitière, Université d'Egerton, Kenya, contamination microbienne, qualité du lait, photovoltaïque, réfrigération solaire

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Introduction

Kenya dairy industry is dominated by small holder dairy farmers who contribute upto 80% of Kenya's total milk production (Leone d al., 2014). It is one of the largest agricultural sub-sector, contributing 14% of the agricultural gross domestic product (GDP) and 4% to national GDP(KDB, 2014). Previous research estimates milk losses in Kenya to be 54.2 million liters of milk per year with most of these losses being experienced in the small-scale informal dairy sector. Evening milk which comprises 40% of the daily cow production mostly goes to waste due to lack of on-farm refrigeration (Foster *et al*., 2015). In a research carried out in rural and peri-urban areas in Nakuru county, on-farm milk cooling was not practiced at all. Furthermore, only 8% of milk vendors have refrigeration system facilities in rural areas (Wafida *et al*., 2016). Therefore there is the need for on-farm milk cooling strategies to curb the evening milk losses.

In 2012, Kenya was categorized amongst countries with the highest deficit in access to electricity with up to 31.2 million Kenyans not connected as only about 23% of the population is covered by the national grid. Of this, only 7% lies in the rural areas which are the key production zones for small scale dairy farming (International Energy Agency and World Bank, 2015). There is need to develop alternative sources of energy for off-grid smallholder dairy farmers in Kenya to facilitate on-farm milk cooling especially for evening milk that is delivered to the collection centers in the morning.

The Photovoltaics for Sustainable Milk for Africa through Refrigeration Technology (PV-SMART) project, under the United States Agency for International Development (USAID) Powering Agriculture Energy Grand Challenge Program (PAEGC) was designed to provide on-farm milk cooling for small scale, off-grid dairy farmers using modified off the shelf direct drive photovoltaic refrigerator (PVR) technology, coupled with innovative cooling and energy storage approaches to chill evening milk on the farm for later transportation the next morning to dairy collection centers. These solar farm milk coolers (FMC) are a unique refrigeration system that uses thermal ice storage in lieu of electrochemical batteries and can operate directly on power from a PV module powering a variable speed dc compressor (Foster *et al*., 2015). Since 2015, PV-SMART has field tested the FMC on 40 farms in Baringo and Nyandarua Counties, and at Egerton University in Kenya. Results reveal great potential for improvement of milk quality attracting premium prices for evening milk that was otherwise not sold at all or rejected on delivery to the dairies (Foster *et al*., 2015). The objective ofthe present study was to determine the microbiological and physicochemical quality of evening milk chilled using the FMC. The results reported herein demonstrate the efficiency of on-farm milk cooling using the solar farm milk coolers at Egerton University.

Methodology

The study was carried out at Egerton University in Kenya. Sample analysis was carried out at Guildford Dairy Institute, Egerton University, Kenya. The milk was obtained from two farms around Egerton University and stored in the FMC (BFRM105, SunDanzer Refrigeration Inc, USA). Ten litre aluminum cans were used to store the milk in the FMC. For comparison, a sample (control) was left unrefrigerated and also analyzed the following morning.

Prior to storage, samples were aseptically collected from each can after stirring using a plunger to obtain a homogenous sample. In the morning, milk was drawn from the FMC and homogenized again after which samples were drawn for analysis. All samples were immediately taken to the laboratories for analysis. To determine the rate of growth of bacteria in stored milk, sampling was done on the stored milk every 30 minutes for a period of six hour during storage.

Determination of milk quality. Total viable bacterial counts (TVC) and coliform counts (CC) were done following methods 991.14 and 990.12 (AOAC, 2005), respectively using 3MTM petrifilm plates. Samples were serial diluted as required and incubation done at 35°C for 24 h and at 35°C 48 h for CC and TVC, respectively. After incubation, colony forming units were counted and recorded.

Determination of butter fat, solids not fat, protein, and lactose content was carried out using automatic milk analyzer (Lactoscan MCC, Milkotronic, Bulgaria) calibrated for cow milk. Also, titratable acidity test was done according to Draaiyer *et al*., (2009). The pH was determine using a previously calibrated digital pH meter (Knick, Portamess, Germany). Additionally, alcohol test was done according to Draaiyer *et al*., (2009). On the other hand, temperature was determined using a hobo temperature data logger U23-003 (Onset, Massachusetts) firmly attached on the outside of the aluminum cans insulated to reflect the changes in internal temperature of the milk in the can during storage.

Statistical analysis. The study employed a completely randomized design with seven replications. Lab analysis were carried out in triplicate. Data analysis was done using Statistical Analysis System, SAS software version 9.2 (SAS Institute Inc, 2006) to carry out analysis of variance (ANOVA). Subsiquently, means that were statistically different were separated using Least Significant Difference (LSD) test at P -- 0.05 level of significance.

Results and discussion

Physicochemical and microbial quality. The mean composition of the milk was 4.080 ±0.091 for percent butter fat, 4.301 ± 0.021 for percent lactose content, 2.870 ± 0.013 for percent protein content, and 7.862 ± 0.032 for total solids not fat (SNF). The density of milk was 1.029 ± 0.001 g/cm. The results of physicochemical and microbial quality analysis for both evening and morning milk are shown in Table I. On average, milk was under refrigeration for 15.084 ± 0.240 hours. Significant differences ($P< 0.05$) were observed in milk quality between the two farms indicating differences in milk handling practices. The acidity of milk in Farm I was 0.162 + 0.01, significantly higher than the acidity of milk from Farm 2 which was 0.155 + 0.01 in the evening before refrigeration. However, both samples were acceptable as per the Kenya Bureau of Standards (KEBS) which recommend fresh milk acidity to be between 0.15 - 0.18. In the morning, an increase in acidity and thus a decrease in pH was observed in all samples. In addition, Total Viable Counts (TVC) and Califoums Counts (CC) were much higher in farm 1 than in farm 2. However, there was no significant difference in microbial counts and acidity between morning samples and evening samples in both farms. Therefore, minimal or no change was observed in the quality of milk stored under refrigeration in the FMC. According to KEBS (2007), milk from farm 1 would be rejected in the evening as well as in the morning based on the TVC and CC counts. However, milk from farm

2 would be acceptable even after cold storage.

Samples left at room temperature, i.e., 18-21°C had significantly different acidity and microbial counts between evening and morning samples. This implies that there was significant deterioration of quality of milk samples that were left at room temperature. This is because chilling retards bacterial growth. Samples left on the bench would permit faster, and continuous growth of any contaminating bacteria leading to increased microbial content and therefore the observed acidity and pH of the milk. These samples would be rejected in the morning based on KEBS standards.
Milk handling practices determine the initial microbial quality of milk. The type and cleanliness of milking equipment, milking personnel, and the milking environment affect the quality of the initial milk quality (Ndungu *et al*., 2016; Wanda *et al*., 2016). From these results, on-farm milking practices need improvement through farmer training on clean milk production to improve the quality of the resulting milk (Ndungu *et al*., 2016). This is because refrigeration only inhibits further deterioration of the milk. Initial quality of raw milk will determine the final quality even after refrigeration.

Table 1. Comparison of evening and morning milk

	FARM 1		FARM 2		CONTROL	
	Evening	Morning	Evening	Morning	Evening	Morning
Room Temperature (oC)	19.033 ± 2.75	17.386 ± 2.54	20.556 ± 1.61	19.111± 0.83	19.139± 2.33	18.112 ± 1.81
Milk Temperature (oC)	29.587 ± 1.70	3.497 ± 1.91	28.444 ± 2.28	0.176 ± 0.09	29.505± 1.64	17.200 ± 3.09
Acidity (% Lactic acid)	0.162 ± 0.01	0.174 ± 0.01	0.155 ± 0.01	0.164 ± 0.01	0.161 ± 0.01	0.195 ± 0.02
pH	6.636 ± 0.08	6.594 ± 0.16	6.592 ± 0.04	6.572 ± 0.04	6.635 ± 0.08	6.241 ± 0.72
Coliforms (Log10 cfu/ml)	6.709 ± 1.81	7.098 ± 1.66	2.365 ± 0.51	3.278 ± 0.85	4.073 ± 0.76	8.581 ± 0.85
TVC (Log10 cfu/ml)	8.000 ± 1.71	9.507 ± 1.88	4.362 ± 0.46	5.312 ± 0.70	2.003 ± 0.55	7.360 ± 1.03

Data presented as mean ± standard deviation.

Rate of milk cooling. The FMC is able to cool 20 - 25 litres of the milk to below 10 °C in a span of 4 h as shown in Figure 1. At temperatures below 10 °C, there is a significant reduction in the rate of microbial growth. Further cooling to temperatures below 4 °C occurs during storage. This in effect would achieve near zero change in microbial quality of refrigerated milk which explains the minimal change in acidity and the eventual pH of the milk after 4 h in storage. Morning FMC milk is collected at temperatures below 4 °C.

Milk quality changes during storage. Table 2 show the mean change in milk temperature, titratable acidity, pH, TVC and CC during storage. There was a significantly greater ($P< 0.05$) reduction in milk temperatures in refrigerated samples than the samples stored without refrigeration. The increase in titratable acidity was highest in the samples stored at room temperature. Despite the high microbial load, some of these milk samples would be accepted based on account of the percent lactic acid concentration. All refrigerated milk samples from both farms passed all the platform tests despite the high microbial content in the milk from farm I, an indication that the current platform tests may not be sufficient.

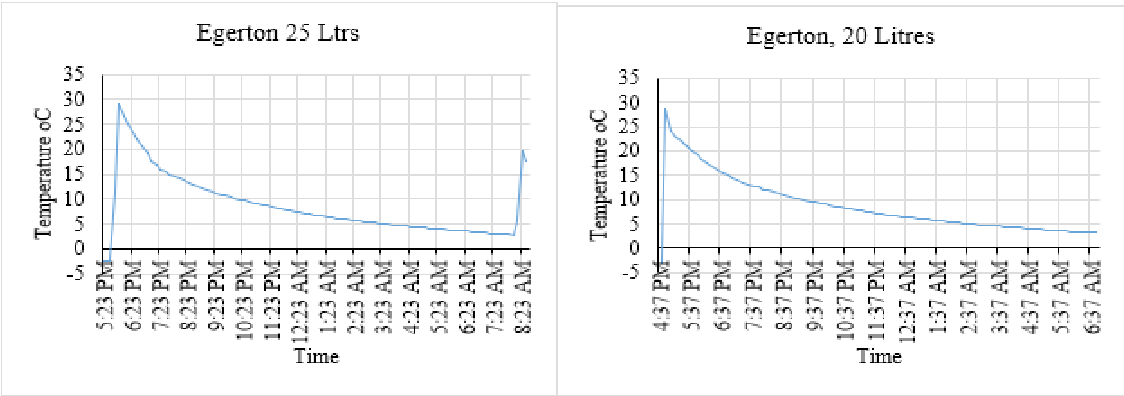

Figure 1. Raw milk cooling at Egerton University FMC units. FMC can cool 20 — 25L evening milk down to 10 QC within 3 - 4 hours.

Table 2. Raw milk quality change during storage

	FARM1	FARM2	Control
Time in storage (hrs)	14.946 ± 0.168a	15.361 ± 0.298a	14.946 ± 0.168a
Titratable acidity (%)	0.012 ± 0.012b	0.009 ± 0.006b	0.033 ± 0.022a
pH	-0.042 ± 0.170a	-0.021 ± 0.018a	-0.239 ± 0.167b
Log10 CC	0.808 ± 1.273b	0.914 ± 0.865b	3.373 ± 1.403a
Log10 TVC	1.023 ± 0.997b	0.950 ± 0.587b	3.946 ± 1.015a

Means followed by the same letter (s) along the rows are not significantly different at $p< 0.05$.

There were no significant differences in TVC and CC between refrigerated samples from both farms. These samples on average had about I log increase in both TVC and coliform counts during storage. Figure 2 shows the growth of TVC in solar refrigerated milk for a period of six hours. The rate of growth of bacteria in milk during storage was found to be 0.017cfu/mUmin. Rapid reduction in the rate of growth of bacteria is observed in the first 116.9 minutes. During this period, acidity continues to increase as well, as shown in Figure 3. Beyond this time, increase in bacterial growth is negligible.

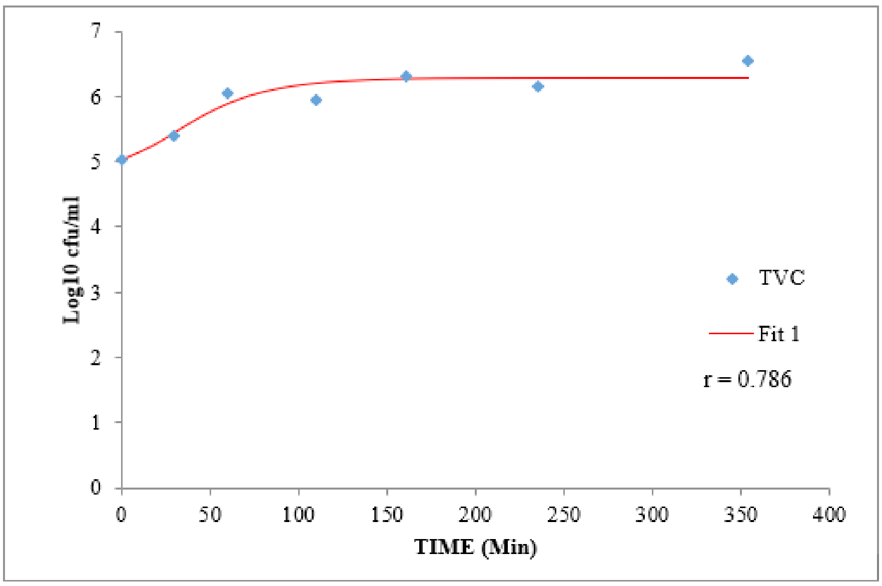

Figure 2. Growth of TVC in solar refrigerated milk

The growth of bacteria also depends on the amount of lactoperoxidase enzyme available to enhance preservation of the milk. Lactoperoxidase system preserves milk in the first three hours of milking. Thus cooling to 7°C should be achieved within those three hours. Since the entire batch of milk would take some time to cool in the FMC, milk must therefore be immediately put in the cooler to effectively ensure preservation of the quality of the milk. In the samples left at room temperature, bacteria increased by over three log cycles and resulting in greater increase in acidity and the subsequent decrease in pH leading to rejection of the milk.

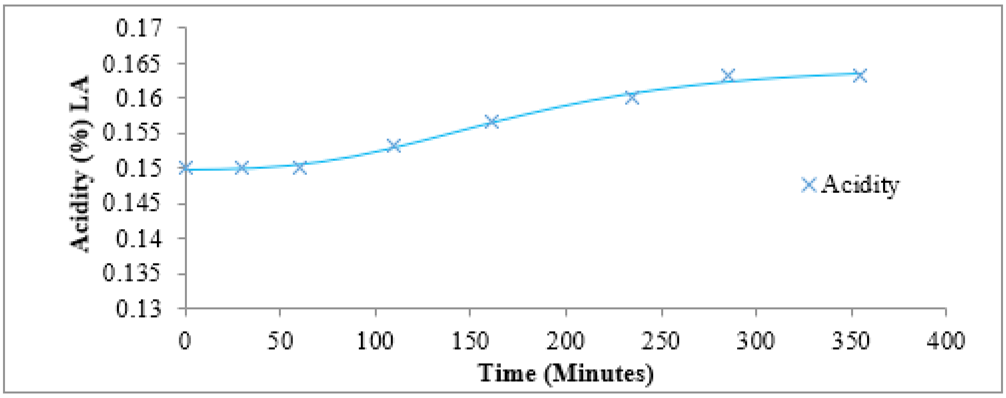

Figure 3. Acidity development in solar refrigerated samples

Conclusion

This study showed that the farm milk cooler (BFRM105, SunDanzer Refrigeration Inc, USA) was able to maintain the microbial and physicochemical quality of evening raw milk. The initial quality is an important determinant of the final quality of the refrigerated raw milk. The acidity and alcohol tests used as determinants of initial milk quality were not sufficient in describing the quality of raw milk. TVC and CC should be used.

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