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EvaKuula saves Ugandan smallholder farmers' evening milk

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ABSTRACT

Smallholder dairy farmers in rural settings of sub-Saharan Africa cannot get their evening milk to markets because of several reasons. They do not have access to grid electricity to power traditional refrigeration systems that preserve their milk for market the next day. They are not able to transport at night due to safety concerns and poor road conditions, especially in the peak production rainy season, marked by high abundance of fodder. A solution involving the combination of thermization (58–63 °C for 30 s) and low-cost evaporative cooling has been shown to be effective and has been successfully tested in the hands of 30 target users in Wakiso, Kiboga, and Rakai districts of Uganda. All cooled evening milk by these farmers has successfully entered the cold chain, after assessment with the Resazurin assay, commonly used for evaluating freshness by collection centers or buyers. Based on the cooling system (EvaKuula) fabrication costs and daily evening milk sales by the early adopters, a payback period of approximately 20 months is needed for farmers to completely own the EvaKuula, in a rent-to-own business model. Work is in progress to further scale-up the EvaKuula adoption in the region.

Introduction

The majority of Sub-Saharan Africans are smallholder farmers, estimated at 615 million, farming on area of 2–5 ha [1]. These farms represent 80% of the total farms on the continent [2] and thus supply an increasing amount of crop-, dairy- and meat-food products. For example, in Uganda, over the past years, the cattle population has grown at a rate of 7.4% per year from 5.96 million to 11.34 million from 1999 to 2008, whereas milk production has increased at an average rate of 4.96% per year from 637.8 million liters to 1.08 billion liters per year from 1999 to 2010 [3]. Mugisha et al. [4] have estimated that almost 10 animals per household are dairy breeds most of which are kept by smallholder farmers.

Dairy farming is very important to a number of Sub-Saharan African countries' economies since it provides relatively quick returns. Not only, does it provide families with a balanced, nutritious food, but also incomes from sales of extra milk which ensures household food security as well as poverty-reduction. However, as the case is in Uganda, these countries are currently registering high percentages of milk losses [5], where approximately 27% of all milk produced is lost at farm level through wastages (6%), spillages (11%) and spoilages (10%) during transportation to collection centers or markets. The milk losses are estimated to be equivalent to US$23 million per year in Uganda's case [6]. Unless, farmers are trained on better milk handling and most importantly gaining access to on-farm milk cooling technologies, Uganda and her counterparts will not be able to reverse the spoilage losses [7].

Most smallholder farmers live in rural areas served by poor road network and with close to no access to grid-electricity. During rainy seasons, when the milk yields are high and the feeder roads have deteriorated, the transportation of evening milk in the dark becomes extremely unsafe. More so the electric coolers (3000–5000 L capacities) located in the trading centers are oftentimes overwhelmed with volumes and therefore reject milk in excess of cooler capacity. The most affected farmers are those who live far from the collection centers, those who cannot transport the milk on time.

In absence of on-farm cooling, milk either gets spoilt or is processed into low valued products like traditional butter. The milk quality can deteriorate before it reaches the cold chain and farmers loose a substantial source of income [8], contributing to losses estimated as high as $90 million per year in the East African dairy sector [9]. These losses at the farm level have prompted farmers to use rudimentary methods such as boiling to extend the shelf life of milk. However, the cost of fuel can be high, as much as 10% of the milk value or $ 0.03 per liter [10]. Furthermore, boiling the milk affects its taste and its nutritional content; milk collection centers/buyers do not accept boiled milk and the public pays less for it, calling for affordable off-grid milk freshness

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preservation technology options. The capacity to cool fresh milk on farms soon after milking carries a great potential in improving the milk quality and quantity [11], by producing milk that meets international standards and getting both the morning and evening milk into the cold chain.

Previous solutions to on-farm milk cooling include the ammonia-based solar-powered Solar ISAAC [12], vapor compression solar-powered fridges [13], rapid milk chiller [14], and evaporative cooling CoolChurn [11,15]. The commercial success of these solution has been tempered by prohibitive costs and/or limited capacity, in the context of sub-Saharan smallholder farmers. We have specifically addressed these constraints, by designing and field-testing a solution based on two micro-biostatic steps of thermization (exposure to temperature–time combination of about 58–63 °C for 15 s) and evaporative cooling.

Food spoilage-causing microorganisms will not immediately multiply when introduced in an environment; they have a tendency to stabilize for a given environment before reacting (homeostasis). When this process is altered, bacteria will spend energy in maintaining their physiological structure rather than multiplying. As a result, microorganisms will delay in the lag phase or even die before reestablishment [16]. Therefore, when thermization is performed on fresh milk, it reduces the number of spoilage microbes in the milk by a significant amount and evaporative cooling provides an environment of low temperature that is not conducive for rapid growth, hence maintaining "freshness" attributes.

Evaporative cooling occurs when warm dry air is blown across a wetted medium. Sensible heat in the air is utilized to evaporate water in contact with the air, resulting in a drop in air dry bulb temperature and a corresponding increase in relative humidity. The general concept is that a mild heat treatment of milk to 58–63 °C, followed by cooling to approximately 10 °C degree below room temperature saves the evening milk. The heat treatment is mild and does not result in pasteurizing of the milk and the growth of the remaining spoilage microorganisms is slowed by the evaporative cooling temperature to the extent that milk is still "fresh" the next day and can enter the cold chain. The 10 °C below room temperature is achievable in low-cost evaporative coolers such as those reviewed by Ndukwu and Manuwa [17], the most well-known of which is the clay pot-in-pot (Zeer pot), based on a design that was first presented by Mohammed [18]. The innovation in our solution comes in two ways. First, we have scaled down thermization to 20-liters capacity to be operated in the context of a smallholder farm, without complicated electrical control systems as practiced on European or North American large dairies. We achieve this with a "thermization" drum. Second, we have seamlessly coupled thermization with evaporative cooling. Taken together we address the prohibitive cost constraint associated with other solutions reviewed above. The main purpose of this paper is to provide solution proof-of-concept at both the laboratory and the field (in the hands of users) levels.

Materials and methods

EvaKuula kit and process

We have "branded" combined thermization and evaporative cooling the "EvaKuula process" or "*evakuuling*" that is performed by the "EvaKuula kit". The kit consists of two main components; the thermization unit (Fig. 1 – comprising of a deep round aluminum pan (48 cm in diameter and 46 cm deep) and wooden insulation drum; and an evaporative cooling unit (Fig. 2) – comprising a wind-powered mechanical air extraction fan, inside and outside water troughs, surrounded by pads on each side of the cooling chamber, that can be made of charcoal, jute, or any other suitable material. The thermization unit can accommodate one 20-liter milk can at a time, but the evaporative cooler can accommodate four 20-liter cans at a time. Therefore, the maximum EvaKuula capacity is 80-liters. The 60-liters overcomes the capacity limitation we experienced with the CoolChurn we introduced in Western Uganda [11].

Thermization was achieved by heating water in the deep pan over a biogas burner to boiling (approximately 96 °C). The deep pan was quickly transferred to the wooden insulation drum and a can filled with a desired quantity of milk or milk-simulating water, at an initial room temperature of approximately 22 °C was inserted in the hot water in the deep pan. The drum "air tight" cover was put in place, to minimize heat losses to the surroundings. Both the temperatures inside and outside the milk can were monitored and recorded using thermocouples attached to a data logger (Omega, model HH309A). Milk was kept in the thermization drum till it reached at least 58 °C and was quickly transferred to the evaporative cooler. Milk-simulating water experiments were conducted for longer time periods of approximately 45 min. Milk was maintained in the evaporative cooler water trough for at least 12 h or till the next day.

Quantity of thermization water

The amount of water required to thermize a given quantity of milk was calculated as follows. Parameters used were: room temperature, $\theta_1 = 24\,^\circ\mathrm{C}$; water boiling temperature, $\theta_2 = 96\,^\circ\mathrm{C}$; final equilibrium temperature (milk and thermization water), $\theta_3 = 63\,^\circ\mathrm{C}$; mass of the aluminum deep pan, $M_s = 6$ kg; mass of the aluminum alloy milk can, $M_c = 4$ kg; specific heat capacity of water, $C_w = 4200$ J/kg/K; specific heat capacity of aluminum, $C_a = 910$ J/kg/K; specific heat capacity of milk, $C_m = 3800$ J/kg/K; density of milk, $D_m = 1020\ \mathrm{kg/m^3}$; volume of 20 L of milk, $V_m = 0.02\ \mathrm{m^3}$; and mass of 20 L of milk, $M_m = D_m x V_m = 1020x0.02 = 20.4$ kg.

By equating the heat lost by thermization water to heat gained by [aluminum deep pan + aluminum alloy can + milk in the can + heat lost to the surrounding (assumed to be 5% of heat lost by thermization water)], Eq. (1) below is obtainable.

$$M_w = \left[\frac{(M_sC_s + M_cC_c + M_mC_m)(\theta_3 - \theta_1)}{0.95C_w(\theta_2 - \theta_3)}\right] \tag{1}$$

Setting

$$\begin{aligned} K_x &= (M_sC_s + M_cC_c + M_mC_m)(\theta_3 - \theta_1) \\ K_x &= 39(M_sC_s + M_cC_c + M_mC_m) \end{aligned} \tag{2}$$

And

$$\begin{aligned} C &= 0.95C_w(\theta_2 - \theta_3) \\ C &= 131,670\,KJ \end{aligned}$$

Eq. (1) can be simplified to Eq. (3) below, where M_{wx} is the quantity of water required to thermize M_m milk in Eq. (2).

$$M_{W_x} = \left[\frac{K_X}{C}\right] \tag{3}$$

Any corresponding thermization water quantity can be calculated by inserting the target milk quantity (Mm) in Eq. (2) divided by the specific heat capacity of water as shown in Eq. (3).

Quantity of evaporative cooling water for the inside trough

The amount of water required to extract the heat from thermized milk, to provide gentle cooling, was computed as follows. Parameters used were: initial temperature of cold water in the trough = initial temperature of water in the trough, $\theta_1 = 22\,^\circ\mathrm{C}$; final temperature of thermized milk = final temperature of milk in the can, $\theta_2 = 63\,^\circ\mathrm{C}$; final constant temperature of thermized milk, $\theta_3 = 19\,^\circ\mathrm{C}$; mass of the inside trough, $M_t = 15$ kg. Mass of the aluminum can, mass of the aluminum deep pan, and specific heat capacities of water, aluminum, and milk, as well as density of milk, used in Eqs. (1)–(3) were used here.

It was assumed that: [{heat lost by thermized milk + heat lost by the milk can} = {heat gained by water in the inside trough + heat

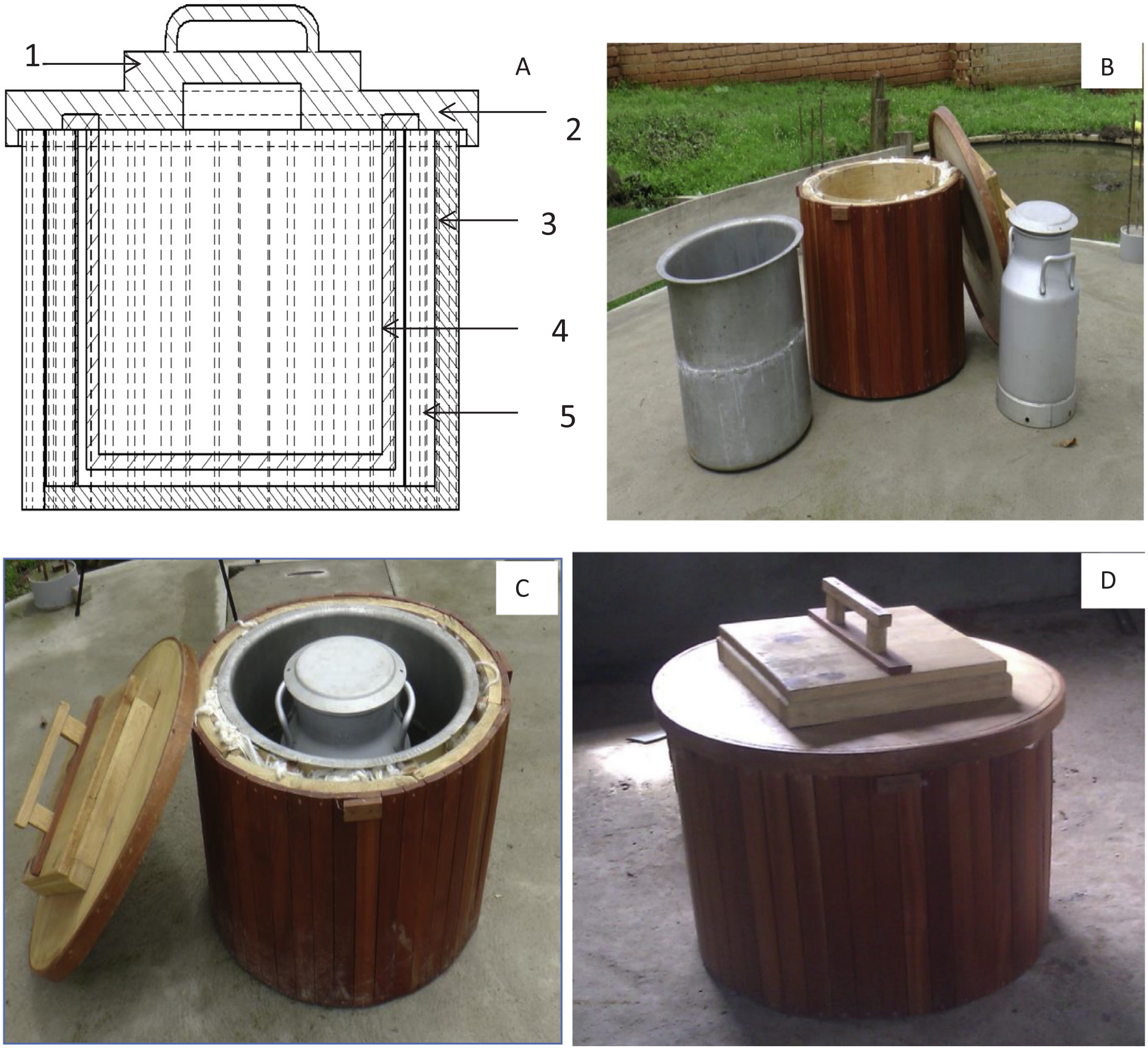

Fig. 1. Thermization component of the EvaKuula kit. A) Schematic drawing of the thermization unit showing: 1- wooden drum cover, 2- space to accommodate the milk can-cover, 3- reinforcing small wood pieces, 4- deep pan, and 5- insulation cotton waste filled space; B) Separated unit components; C) Assembled unit where the deep pan (48 cm diameter and 46 cm height) is fitted inside the wooden drum and the milk can is placed inside the deep pan; and D) All components are together during thermization. Working engineering drawings are available from the corresponding author on request.

gained by the inside trough + heat lost to the cooling chamber (5% of heat lost by thermized milk)}], yielding Eq. (4) below.

$$M_w = \left[\frac{[(M_tC_t + M_wC_w)(\theta_1 - \theta_3)] - M_cC_c(\theta_2 - \theta_3)}{0.95C_w(\theta_2 - \theta_3)}\right] \tag{4}$$

Setting

$$K_y = [(M_tC_t + M_wC_w)(\theta_1 - \theta_3)] - M_cC_c(\theta_2 - \theta_3) \tag{5}$$

$$C = 0.95C_w(\theta_2 - \theta_3),$$

Eq. (4) is simplified to Eq. (6) below, where M_{wy} is the water needed in the inside trough for cooling the thermized milk.

$$M_{Wy} = \left[\frac{K_y}{C}\right] \tag{6}$$

For different quantities of milk, the corresponding quantity of water can be adjusted by inserting the right amount of milk in Eqs. (4) and (5).

The performance of the evaporative cooler was assessed by monitoring and recording time-temperature profiles with and without loads (milk/milk-simulating water in cans), conducted during day and overnight. The evaporative cooler was placed in a grass thatched roof open structure with free air flow to prevent direct sunlight to the cooler and also allow for free fan rotation from the wind movement. Before testing the cooler, a stabilization of the cooler was performed by continuously running the cooler while wetting charcoal pads for 24 h. The experimental procedures mostly concentrated on the cooler's performance during day for 12 h over 30 days. Dry run experiments without loads were also conducted during the hot dry season as it was viewed as the best conditions to yield the high-end evaporative cooling across the cooler walls. The water quantity for the inside trough depended on the quantity of thermized milk/water to be cooled and was calculated with Eqs. (5) and (6).

Data was collected to establish time-temperature profiles of the evaporative cooler chamber air (cooler temp), inside trough water, air temperature outside the evaporative cooler (room temp), and thermized milk/milk-simulating water, where applicable. Data was recorded at 15-min intervals.

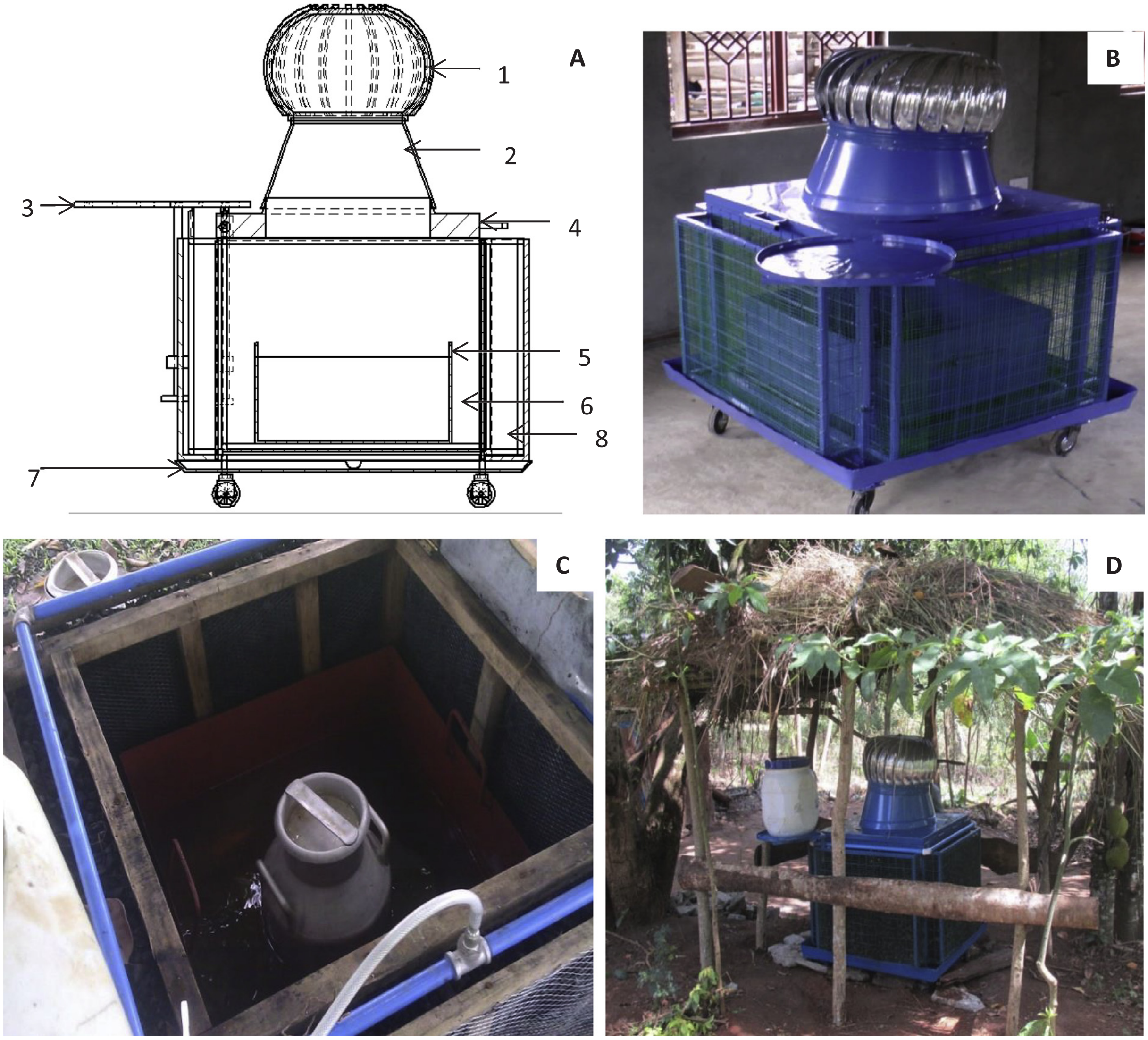

Fig. 2. Evaporative cooling component of the EvaKuula kit. A) Schematic drawing of the cooler showing the main parts: 1- wind-operated suction fan, 2-suction duct, 3- tank support, 4- cooler cover, 5- inside water trough, 6- cooler chamber (76 cm high × 82 cm wide × 82 cm long), 7- outside water trough, 8- charcoal pad; B) Assembled evaporative cooler unit; C) Milk can placed inside the trough for gentle cooling of the thermized milk; and D) Cooler in operation at smallholder Farmer #1 farm. The grass-thatched shade prevents direct sunlight to charcoal pads, which are water soaked using the pipe system and the water reservoir/tank (white with blue cover). Working engineering drawings are available from the corresponding author on request. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

"Evakuuled" milk quality assessment with the Resazurin assay

We use the term "evakuuled" milk to refer to fresh milk that has undergone thermization followed by evaporative cooling as described in this study. Milk obtained from a neighboring and own Smallholder Fortunes farms was collected. Thermization and evaporative cooling were performed with 10 L of milk in the EvaKuula kit. Milk quality was assessed with the Resazurin reduction assay – a measure of microbial biochemical activity. Resazurin assay is one of the most common milk-quality testing methods used by milk collection centers and buyers in Uganda; milk scoring between 5 and 6 is acceptable for entry into the cold chain. The assay gives a rough quantitation of the total amount of microorganisms present in the milk. Milk quality was assayed before and after "Evakuuling". A sample of 50 ml was needed from each milk batch.

Results and discussion

Thermization temperature profiles

We studied the effectiveness of the thermization with water in the milk can (simulating milk). Time-temperature profiles for milk-simulating water are presented in Fig. 3A (10-liters), 3B (15-liters), and 3C (20-liters). The milk-simulation water reached 58 °C after 17.0 ± 0.6, 19.7 ± 1.2, and 41.0 ± 0.6 min for 10-, 15-, and 20-liter volumes, respectively. The final temperatures (after 45 min) were 61.8 ± 0.1, 59.8 ± 0.1, and 58.2 ± 0.1 °C for 10-, 15-, 20-liter volumes, respectively. The numbers presented above are mean ± standard error, n = 3. As shown above, the final temperatures of the milk-simulating water ranged between 58 and 62 °C, well within the standard thermization temperature range of 58–63 °C as reported by Lewis and Deeth [19] and Hudson et al. [20]. Based on these results, the performance of the thermization component of the EvaKuula kit was considered satisfactory. We confirmed this observation with 10 L of milk as shown in the time-temperature profile presented in Fig. 3D. Once the milk

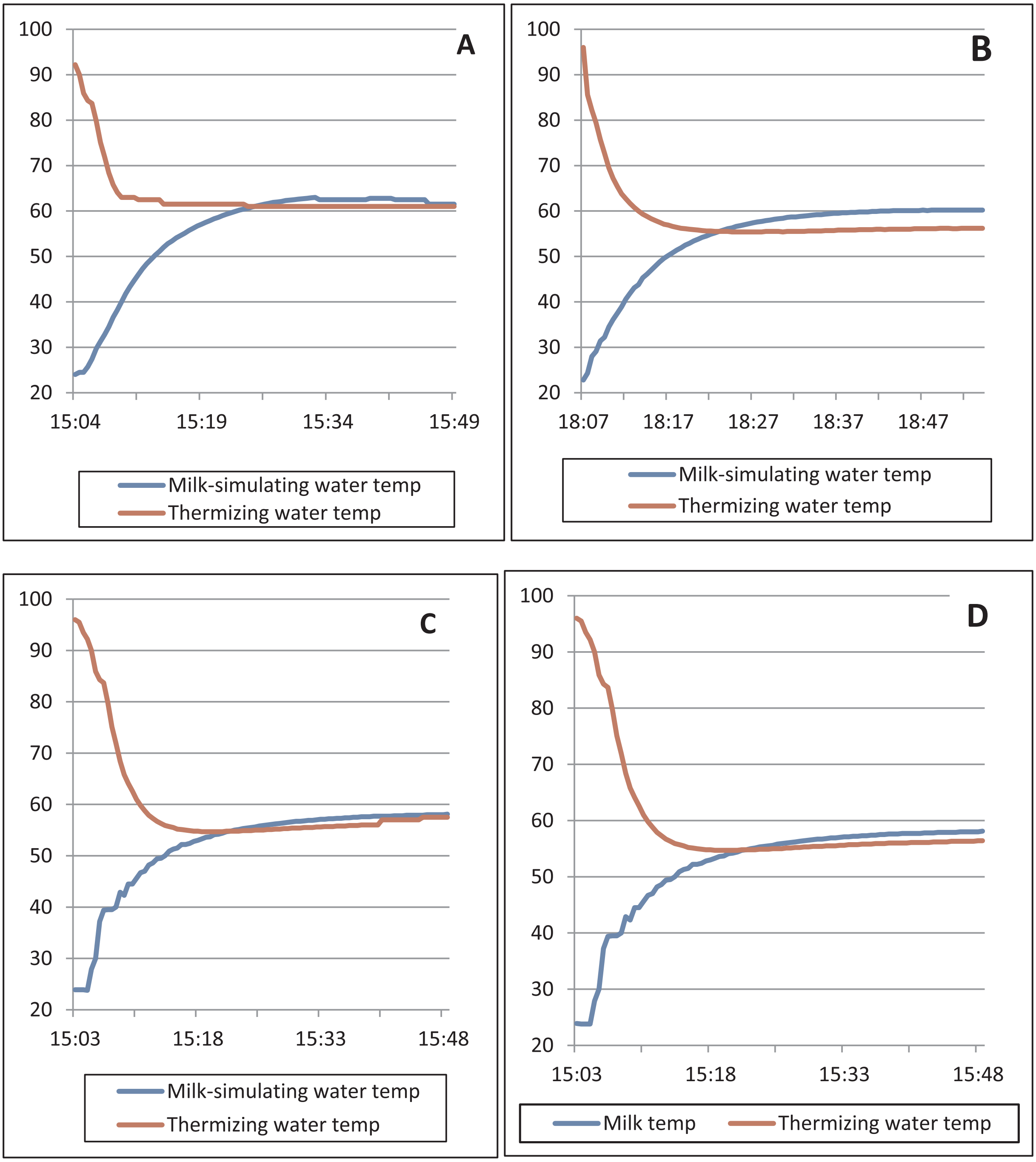

Fig. 3. Thermization time-temperature profiles. A) simulation with 10 L of water; B) simulation with 15 L of water, C) simulation with 20 L of water and D) thermization with 10 L of fresh milk. The initial temperatures of thermization hot water and thermized milk/water were 96 °C and 24 °C, respectively. There was an exponential decrease in temperatures of thermization water as most of the heat was absorbed by the milk/milk-simulating water. The final temperatures attained were 58 °C (for 10-liter milk load and 20-liter water load) and 63 °C for 10-liter water load, well within thermization range.

reached the thermization temperature of 58 °C (44 min), it was held at this temperature for 30 s as called for in thermization. The slight difference in milk and milk-simulating water temperature profiles is attributable to differences in thermo-physical properties. In industrial thermization, the come-up time is typically short due to use of efficient heat exchangers. It is not clear what the effect of the long come-up time is, in our setting, on phosphatase enzyme activity. Phosphatase activity is used as a marker for pasteurization. Future studies will explore this question and ways to shorten the come-up time, such as using more thermization hot water and/or minimizing heat loss through the thermization drum insulation.

Evaporative cooling temperature profiles

As with thermization, we studied evaporative cooling with time-temperature profiles of water in the inside trough, with and without load (milk-simulating water in a can). The results are presented in Fig. 4. No-load run results during the day are presented in Fig. 4A; a drop of 14 ± 4 °C, below room temperature, was achieved. This result is consistent with work published by Wayua et al. [21], where drops of 11 °C below room temperature were achieved. As shown, the evaporative cooler maintained the trough water temperature below 22 °C despite the high room temperatures above 35 °C. This experiment was

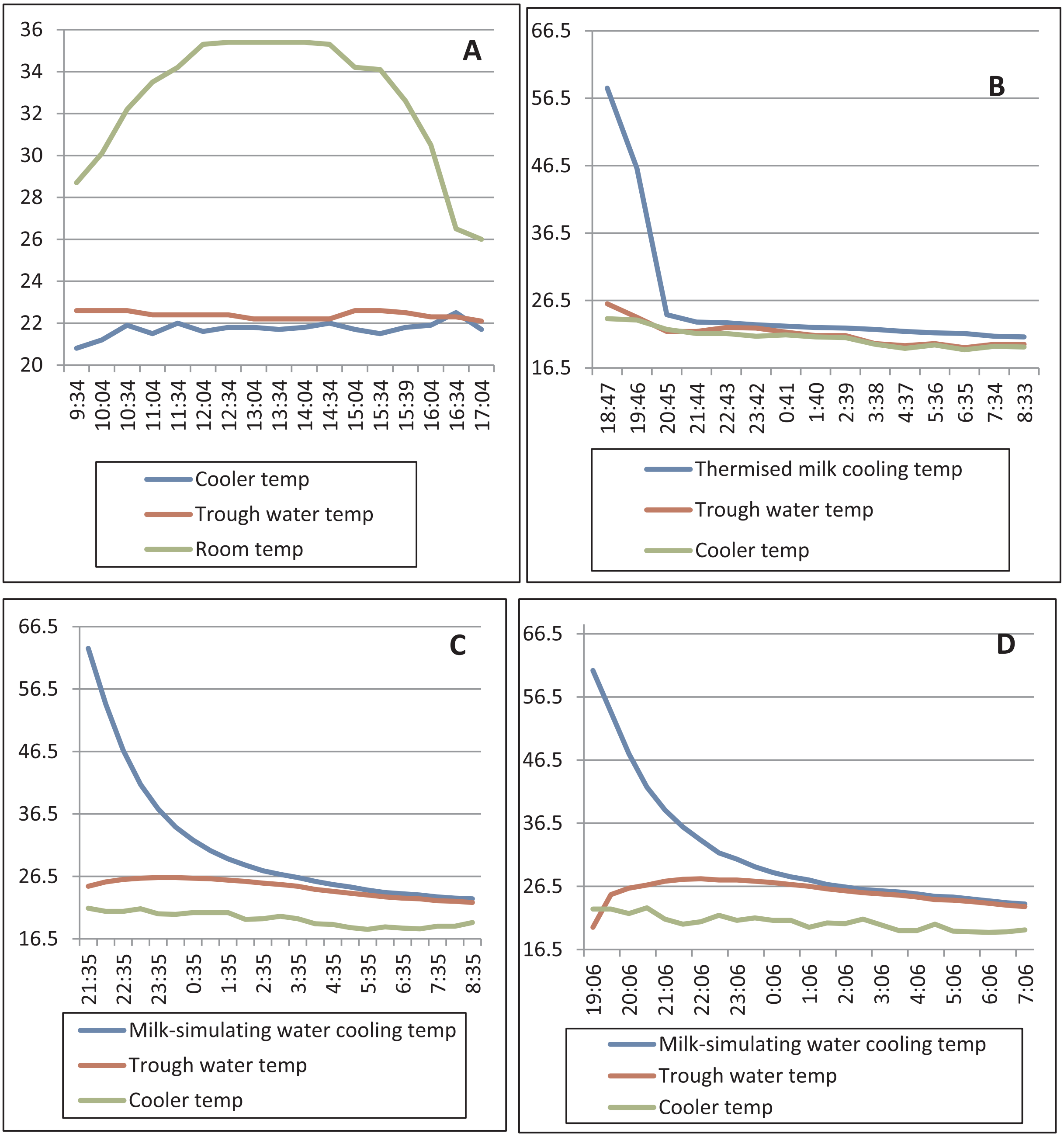

Fig. 4. Evaporative cooling time-temperature profiles: A) Air temperature inside the evaporative cooler (cooler temperature) in comparison to outside or room temperature, conducted during day, without load or warm milk/milk-simulation water to cool; B) Ten-liter thermized milk or warm milk load cooled during night; C) Twenty-liter thermized milk-simulating water load cooled during night; and D) Forty-liter thermized milk-simulating load cooled during night.

followed with night cooling of 10 L of thermized evening milk with the results presented in Fig. 4B; the temperature of the thermized milk equilibrated with the trough water temperature in a little less than 2 hr. At such temperatures, after thermization, the activity of surviving spoilage microorganisms is substantially decreased [22]. More time-temperature profiles were generated with 20-liters (Fig. 4C) and 40-liters (Fig. 4D) of thermized milk-simulating water. The quantity of water in the inside trough was not adjusted in relation to the load, yielding the expected result of increasing equilibrium temperatures, measured the next day, with increasing milk load, of 20.3 ± 0.2, 22.5 ± 0.1 and 23.3 ± 0.1 °C for 10-, 20-, and 40-liters' loads, respectively. Overall the performance of the evaporative cooler is consistent with previous designs [10,23]. Factors to consider in improving the performance of the evaporative cooler are: thickness of the charcoal pad in relation to its water retention capacity [24]; the effectiveness of the air suction fan in relation to the resulting pressure difference [25] – this pressure difference drives the inflow of cold air through the porous charcoal pad; and alternative pad materials.

"Evakuuled" evening milk quality

The question that needed answering was whether the evakuuled evening milk is suitable for entry into the cold chain the next day, based on the standard Resazurin assay used in Uganda for this purpose. The before and after evakuuling assay results are presented in Fig. 5. Milk from our neighboring farm (S1 and S2) and our farm (S3 – S5) were used. All samples were morning milk, kept at 2 °C in a solar-powered fridge for approximately eight hours and then evakuuled as evening milk overnight. The Resazurin test was performed soon after receipt, just before and after evakuuling. Milk is accepted for entry into the cold

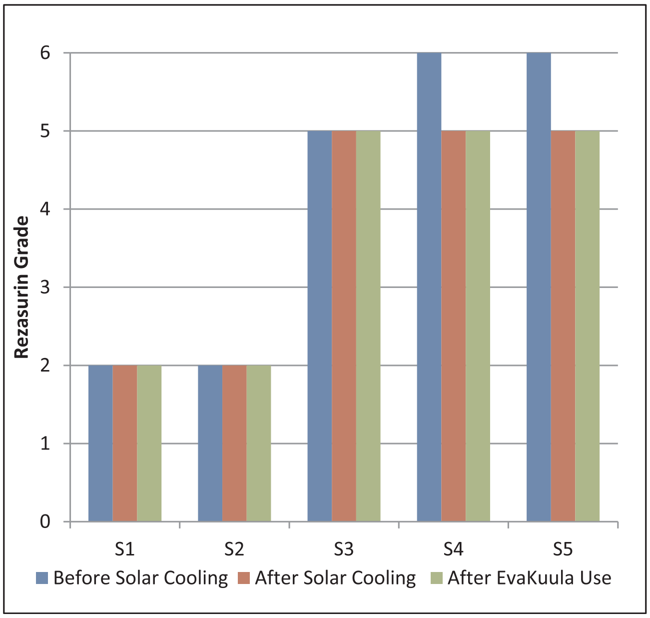

Fig. 5. Evakuuled milk quality assessed with the Resazurin assay. Five-liter milk samples were collected from morning milk and chilled to 2 °C in a solar-powered fridge till evakuuling overnight as evening milk. Fresh five liters of evening milk ware added to the chilled morning milk and the total was evakuuled. Sample S1 and S2 obtained from a neighboring farm were of poor quality to start with, scoring 2, which is unacceptable. Samples S3 to S5, from our farm, scored at or above 5. According to international dairy standards, milk within the range of 5 and 6 is regarded as fresh and acceptable for entry into the cold chain.

chain with Resazurin scores between 5 and 6, 6 being the best. We were surprised by the poor quality of the milk from the neighboring farm (well below acceptable levels), speaking to the need to educate smallholder dairy farmers on good dairying practices. The freshness of the evakuuled milk from our farm was maintained to acceptable levels for entry into the cold chain as shown in Fig. 5 (Samples S3–S5). This finding should not be surprising - when milk is chilled soon after milking, psychotropic bacteria tend to grow, which causes spoilage under refrigeration. This explains why the milk still reduces in quality even when chilled. Thermization process performed using the EvaKuula mainly eliminates the psychotrophs [26]. This explains why milk from the evaporative cooler does not continue to deteriorate in quality after going through the preservation process. With these positive laboratory results, two EvaKuula units were fabricated and placed in the hands of farmers to assess if the laboratory results were replicable on smallholder farms.

EvaKuula in the hands of target users

Two EvaKuula kits were distributed to two "star" smallholder farmers, considered to be innovators, to confirm that the technology can preserve the evening milk for entry into the cold chain the next day in the hands of these target users. In addition to innovators attributes, other factors for selection were: 1) capacity to harvest at least 10 L of evening milk, 2) in possession of a domestic biogas plant, and 3) regularly supplies milk to a collection center, where quality for acceptance is assessed with the Resazurin assay. The two smallholder farmers identified were female. They were trained on how to use the kit. At the time of writing, it has been over 20 months and the farmers' evakuuled milk has never been rejected by the collection centers. Thus the milk preserved using the EvaKuula unit with two farmers was able to enter the cold chain as "fresh". These farmers are excited about the evening

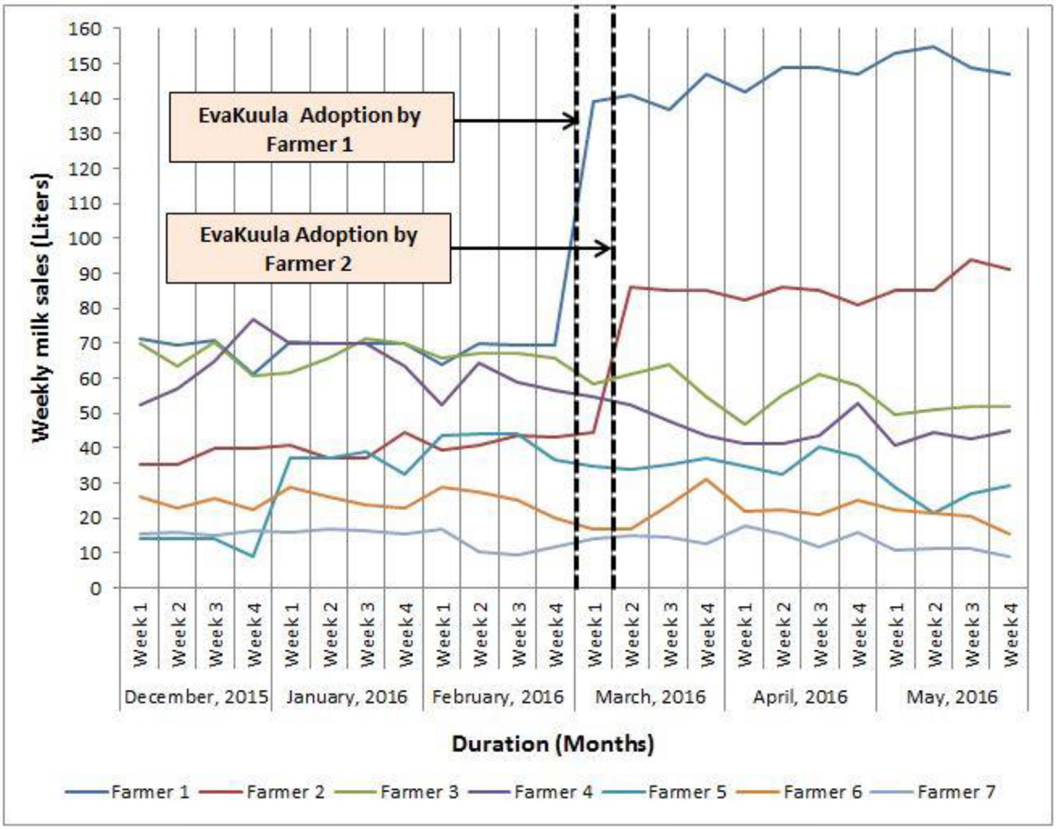

Fig. 6. Weekly sold milk before and after adoption of EvaKuula (Farmers #1 and #2), with control Farmers #3 to #7 (no EvaKuula adoption). The flat results from control farmers provide evidence in support of attributing the increase among Farmers #1 and #2 to EvaKuula adoption.

Table 1
EvaKuula kit fabrication costs.

Item	Quantity	Unit cost (UGX)[a]	Total Cost (UGX)
Evaporative cooler			
1″/2.5 mm Hollow section	4 pcs	55,000	220,000
Plastic water trough	1 pc	125,000	125,000
Welding Rods-3.2	1 pkt	35,000	35,000
Cutting disk-Rhodius Big	1 pc	15,000	15,000
Grinding disk-Rhodius small	1 pc	8000	10,000
Plastic mesh	10 m	15,000	150,000
Paint-4 L	1 tin	35,000	35,000
Car filler	5 kgs	10,000	50,000
PVC pipe-3/4′	2 pc	30,000	60,000
Elbows	4 pcs	5000	20,000
T-junction	1 pc	8000	8000
Union	1 pc	7000	7000
Flexible transparent pipe-3/4′	1 m	7000	7000
Water tank with a valve/ tap	1 pc	50,000	50,000
Rivets	30 pcs	1000	30,000
Wind suction fan	1 pc	350,000	350,000
cooler-lock	1 pc	6000	6000
Labor		200,000	200,000
Thermization unit			
Nile Plywood-2 mm	1 pc	35,000	35,000
Cotton waste	15 kg	3000	45,000
Wood glue-Fevicol	3 tubes	50,000	150,000
Wood for base board	1 pcs	60,000	60,000
Wood for top board	1 pcs	70,000	70,000
Reinforcing wood pieces	1 pcs	30,000	30,000
Screws-11/2′	1 pkt	15,000	15,000
Nails 11/2′	1 kg	6000	6000
Nails 1′-China	1 kg	8000	8000
Machine work			90,000
Labor			150,000
Saucepan-2 mm (#33)	2 pcs	65,000	130,000
Welding 2 pans into 1 deep pan			270,000
20-liter milk can	1 pc	210,000	210,000
Total			2,647,000 (790 US $)

[a] 1.00 US$ equals 3350 Uganda Shillings (UGX).

milk preservation technology. For example, Farmer #2 said that, "*I have been sending my granddaughter to sell our evening milk, door- to-door, after she comes back from school. Most of the time she would manage to sell one to two liters per day, out of the 10 or so liters we harvest in the evening. We consume some of the unsold milk and the rest given freely to the neighbors and/or workers on the farm. Sometimes all the milk just gets spoilt when my granddaughter gets home late and I can't send her out in the dark. Where has this technology been all these years!!!?*"

Reflecting on thermization energy options

As in our earlier solution to the evening milk problem [11], we have been narrowly focusing on biogas. However, with the EvaKuula, other energy sources are possible. For example, woody biomass, charcoal, kerosene, and butane can easily be used to raise the thermization water temperature. In discussions with future users who currently do not have a domestic biogas plant, it became apparent that having to install a biogas digester and at the same time acquiring the kit presents a huge barrier to technology acquisition in terms of the size of investment. It may be possible to start the famers interested in the kit with one of the most sustainable of the energy source with the promise of transitioning to biogas in the future, after paying for the cooler system.

The target smallholder farmers are mainly rural and the most common energy source used in these settings is woody biomass [27]. The unsustainable use of this energy resource and its charcoal cousin has led to depletion of forests [28,29]. Kerosene and butane fuels are fossil fuels with limited supply. Besides these fossil fuel options are high-cost and only affordable by a small percentage of urban dwellers. Because of farmers whose decision process to acquire the EvaKuula is burdened by the thought of concomitant acquisition of a domestic biogas plant, we have conducted a comparative study of possible energy sources [30]. We have included devices like woody biomass-saving stoves, following approaches similar to those presented by Wilson et al. [31], and recommend powering EvaKuula with firewood combusted in efficient stoves such as the Rocket Lorena type, as famers consider acquisition of the technology and transitioning to biogas in the near future, when financially ready.

Unit economics

Smallholder farmers typically lack liquidity and are hesitant to take loans with long pay-back periods [32]. Other things being equal, adoption of technology is made easier if pay-back periods are short. To establish sustainable pricing and a representative payback period, we focused on Farmer #1. Unlike Farmer #2, this farmer is an "aggregator" as well; she cools her own milk and milk from neighboring farmers. Her own milk is not enough to support payments for the EvaKuula – she charges a small fee for her cooling service. Farmer #2 only cools her own milk. In Fig. 6, we present increase in milk-sold for both Farmers #1 and #2. Also, sold-milk from five "control" Farmers #5–#7 is included in the same Fig. As shown, two of the control Farmers' sold-milk was in the same range as Farmer#1 and the other three were in the same range or lower that sold-milk by Farmer #2. The increase in sold-milk from Farmers #1 and #2, is confidently attributable to the adoption of EvaKuula because the control sold-milk remains flat throughout the six months study period.

Farmer #1 average sold-milk before and after EvaKuula adoption come to 68.5 and 146.3 L, respectively. The difference attributable to EvaKuula adoption comes to 77.8 L. Of this 77.8, 30% (23.3 L) comes from Farmer #1 farm and the balance (54.5 L) from neighboring farms. Additional expenses as a result of preserving and selling the evening milk includes daily labor associated with energy at UGX 500. The milk collection center or buyer pays Famer #1 UGX 900 per liter and Farmer #1 charges UGX 300 per liter she cools for the neighbors. Therefore, the weekly extra income from the evening sold-milk comes to UGX 33,970 [(54.5 L × UGX 300) + (23.3 L × UGX 900) – (7 days × UGX 500)]. Assuming 52 weeks in a year and one US$ conversion rate of UGX 3350, the extra income available to finance EvaKuula comes to US$ 527.29 [(52 weeks per year × UGX 33,970)/3350 UGX per US$]. Production of each of the two EvaKuula units that were distributed to Farmers #1 and #2 came to 842.00 US$, as shown in Table 1. A 20% decrease in production cost is being realized with a batch of 50 units and a further 15% decrease in production cost is expected with a 500-unit batch to US$ 572.56 per unit. If the extra income from Farmer #1 for a period of 18 months (US$ 790.94) is used to finance EvaKuula, the difference of US$ 218.38 [790.94 – 572.56] per unit sold is high enough to support a sustainable business.

The EvaKuula capacity is 80 L as previously explained. The average daily evening milk cooled by Farmer#1 is 11.1 L [77.8 L/7days per week], a little over 50% of one 20-liter milk can, only 18.5% of EvaKuula capacity. Higher extra incomes by Farmer #1 can be realized by increasing the quantity of milk cooled, either through more own milking cows or aggregating more milk from neighboring farms. Farmers #1 and #2 were our first early adopters ("star farmers"). At the time of writing, kore than 30 early adopters have are sustainably using the EvaKuula of their smallholder farms. Their incomes are consistent with the analysis provided above.

Concluding remarks

Testing of the EvaKuula with two farmers was considered the first phase, whose purpose was to provide evidence in support of the concept in the target users' hands. The second phase (almost competed) involves 20–50 farmers with the main purpose of engaging a broader cross-section of target users. We have successfully engaged 30 farmers and we are following-up with the third phase, where order of magnitude number of units (e.g., 500–1000 units) will be distributed, the success of which will mark the transition of EvaKuula from a solution to an innovation: an innovation that is poverty-alleviating – increases incomes among those earning 5 Purchasing Power Parity dollars per day; prosperity- and wellness-building – increased quality and quantity of milk is likely to impact the whole dairy industry; and eco-friendly or planet-sustaining – powering with biogas probably represents the lowest carbon footprint in comparison to other energy source options.

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