Effects of milk cooling: A case study on milk supply chain for a factory in Ethiopia

Working Paper No. 288

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Abstract

Milk has important nutritious values and is therefore can contribute to nutrition security in Africa. The product category is a hotspot for food loss & waste and the associated greenhouse gas emissions in African countries. Therefore, adequate design of milk collection chains and choice of technology options is essential to make the food product available with minimum climate impact.

In this study the effects of different scenarios for introducing a cold milk chain are evaluated based on rejection rates and costs to increase the milk supply of a milk factory near Solulta (Ethiopia). The effect of the scenarios on the milk is calculated with a model that combines temperature, growing rate, lactic-acid production to estimate the quality: chance of rejection on arrival at the factory. Introduction of chilling centres or on-farm cooling system can both make the evening milk delivery possible for the factory. For the first option, the implementation of a collection system will be critical, whereas for on-farm chilling the willingness to extend the power grid and the type of milk containers are essential. On-farm off-grid cooling systems seem not economically feasible in the studied area.

Keywords

Milk supply; milk rejection; chilling centres; on-farm cooling

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Contents

1. Introduction

The analysis by Guo et al. [17] shows that milk is a hotspot for food loss & waste and the associated greenhouse gas emissions in African countries. Moreover, milk has important nutritious values to African people. These features make milk a highly relevant food product for climate change and food security that needs in-depth studies.

Specific to the African country Ethiopia, 98% of the milk in Ethiopia is produced by small farm holders. Part of this production is collected and transported to milk factories where the milk is pasteurized or processed to yogurt, butter or cheese for the upper-class consumers in the large cities.

One of these factories is the Zagol Factory. The factory is located at Sululta, one-hour drive from the north of Addis Abeba, the capital of Ethiopia. The factory has a maximum processing capacity of 1000 litres per hour but it currently only processes 2000-3000 litres a day.

The market in Addis is big enough to sell more milk products than the current production. The challenge for the Zagol Milk Factory is therefore to increase their milk supply, as it is currently a limiting factor for their business scalability. The factory has an own farm with approximately 100 cows and also purchase the milk from the neighbour farms on a daily base. The produced amount from their own and neighbour farms is about half of the total supply. The other half, about 1000 litres, is the collected morning milk from small farms in the area between Chancho and Derba.

The storage at the farm, the collection of the milk as well as the transport to the factory is commonly done at ambient temperature. As a result, a part of the milk arriving at the factory is not suitable for production and rejected by the factory due to the bad quality. The rejected milk is not thrown away but used for the production of fermented local milk products like Ayib, butter and whey [1].

The small farm holders generate incomes by selling their raw milk or their fermented products which they don't consume themselves. This is done locally to collectors or the milk factory. A complicating factor in Ethiopia is the regular fasting period where consumption of milk is not allowed for majority of the population. In these periods the demand for milk products is very low in the local market, resulting in an oversupply. Especially in these periods it would be beneficial if not only the morning milk but also the evening milk could be delivered to the factory. When there is an efficient supply chain for the milk to the factory, the large price drops during a fasting period can be potentially avoided. In august 2018 the milk prices were about 50 $cent/litre during the none fasting period, and 33 $cent/litre in the fasting period. Also fermented products such as ayib suffer about the same price reduction [2].

Without expanding the sourcing area collecting the evening milk from the small farm holders is the easiest way to increase the milk supply for the milk factory.

In this study different scenarios are evaluated on the capability of reducing the rejection rates to an acceptable level to create a more efficient milk supply chain. Moreover, the additional costs per litre milk for the new collection methods are calculated.

The different scenarios are based on the introduction of a cooling step of the milk before it is delivered to the milk factory. On-site cooling storage and chilling centres are evaluated which have already been introduced in Ethiopia. In this study, the expected effectiveness and costs of these interventions are studied.

2. Methods

The scenarios

The cows are milked twice a day, at 18:00 in the evening and 6:00 in the morning. The current situation is scenario A (Figure 1). In this scenario only the morning milk is brought to the collection point since the chance for evening milk to be rejected is high. At the collection point every bottle of milk is tested with a 70% ethanol solution. The milk passes this test when the pH of the milk is above 6.4. At the collection point the milk is gathered in milk cans of 25 litres and loaded on an open truck. After all the milk is collected the truck drives back to the milk factory where the milk is tested for a second time before it is chilled or processed.

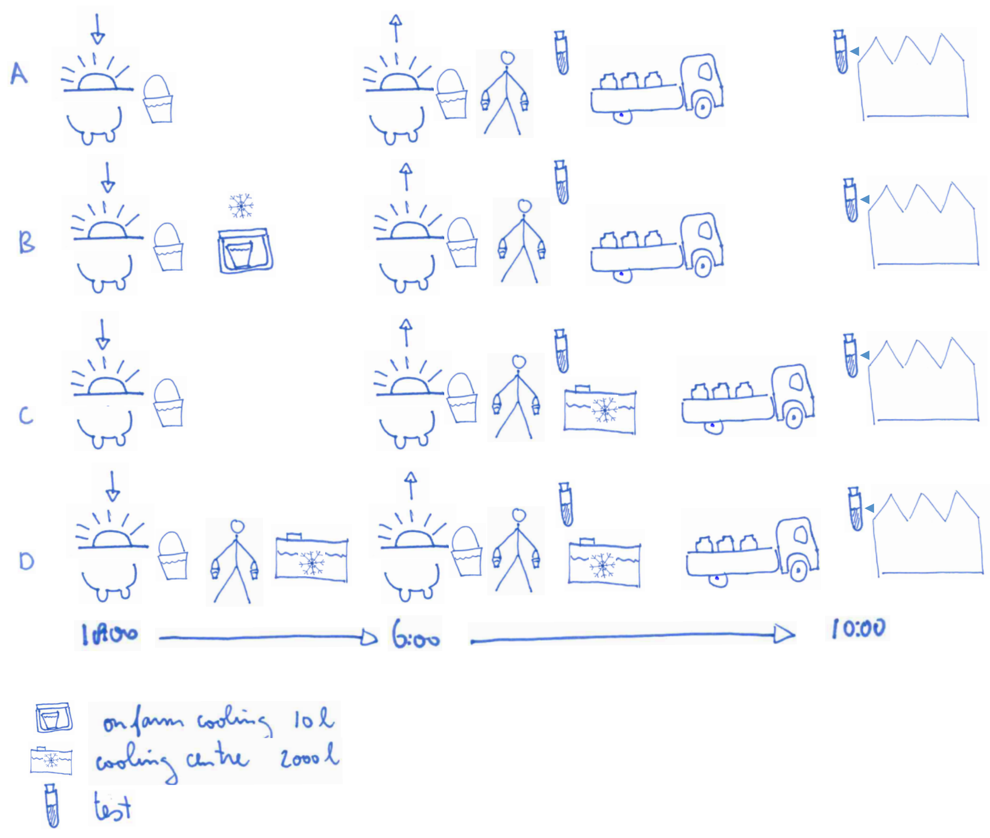

Figure 1. Scenarios to improve raw milk quality at factory delivery

Figure 2. A current situation: collection of morning milk on the road between Derba and Sululta where the milk factory is situated. The milk factory, Zagol, delivered their processed milk to Addis Abeba. Photos: Bert Dijkink

In scenario B an on-farm cooling unit for 10-20 litres of milk is used to cool the evening milk. The cooling unit can run on either solar power or biogas (Figure 2). Solar power has the disadvantage that the energy is only available during the day time but it is also needed in the night. Therefore, the cooling case in figure 3 has a second box inside the isolation box. During the day ice is formed between walls of these two boxes [3]. Biogas can locally be made from e.g. cow-dong and used whenever the gas is needed for cooking or cooling [4].

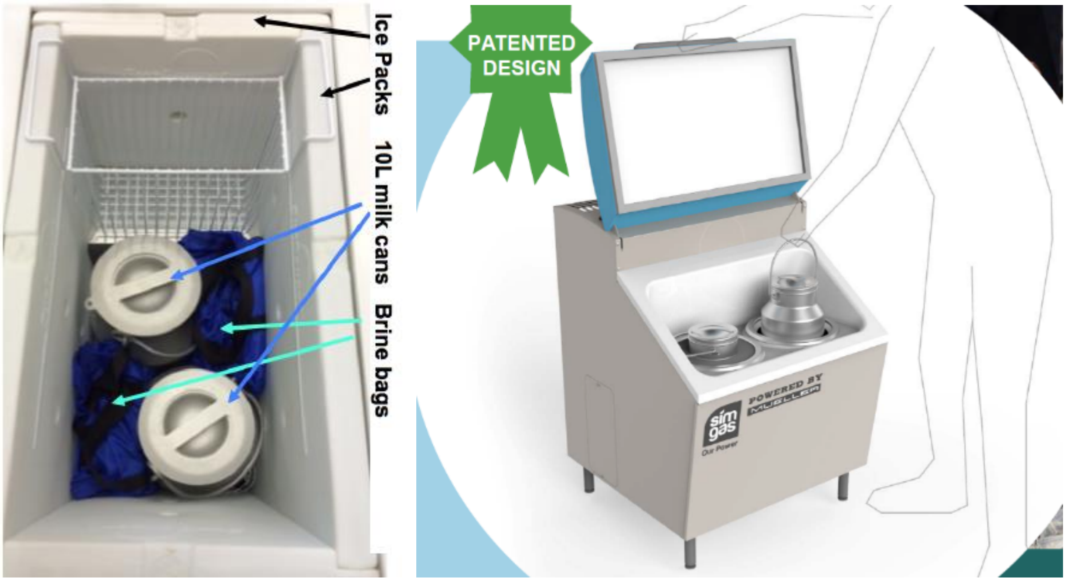

Figure 3. On farm milk coolers for evening milk. Left solar powered cooling case [3], right biogas chiller of Sim Gas [4].

Scenario C and D use a chilling centre located on a strategic place where the farmer has to deliver the milk once (scenario C) or twice (scenario D) a day. The chilling centre (Figure 4) is equipped with two separated tanks to realize separated storage of the evening and morning milk. It has a double wall for cooling and an inside mixer to reach high cooling rates [5]. Whereas in scenario B the morning milk cannot be cooled before transport to the factory, this is possible in scenario C. Furthermore, the collection, in the chilling centre, does not require the presence of the truck. Therefore, although a cooling time of 2 hours for the morning milk is required, the truck can arrive at the factory gate at approximately the same time as when the cooling procedure is absent.

Figure 4. 2m³ cooling tank in a chilling centre near Derba, Ethiopia. Photo: Bert Dijkink

Estimation on the rejection rate by the factory quality control

The reject rates for the four scenarios are evaluated with a model. The model predicts the pH of the milk, and thus whether it will pass the alcohol test or not. When the pH is 6.4 or lower the milk will fail the alcohol test and be rejected by the factory.

The model describes three processes: the growth of the lactic acid producing bacteria, the production of lactic acid by increase of that biomass and maintenance, and effect of the amount of produced Lactic acid to the pH of the milk.

Growth model

For given storage conditions, the growth rate is mainly dependent on the temperature according to the Arrhenius equation. Only at high concentration of micro-organisms (expressed in colony forming units per gram (CFU/g)) the growth rate decreases because of diminishing resources. When contaminating a product, before the growth becomes manifesting there is a period of none or retarded growth, which is known as the lag phase. This is because the naturally present micro-organisms are not yet adapted (or suited) to fit the conditions during storage [6]. However, in this study the lag phase does not apply since the bacteria are already adapted to the milk medium.

The model parameters that describe the growth rate like max grow rate at 20°C, minimum grow temperature, and maximum number of bacteria depend on the type of bacteria in the milk. The majority of the bacteria in the milk will be Lacto bacteria. As the exact strain of Lacto bacteria causing the acidulation is not known and will differ, the growth model assumes a standard commercial culture of Christian Hansen (Hørsholm, Denmark) Fresco culture DVS 1010 consisting of Lactococcus lactis subsp. lactis, L. lactis subsp. cremoris and Streptococcus thermophilus [7].

For the initial contamination levels (t=0) the data from Tegegne are used [10]. Tegegne measured the contamination levels of the milk directly after milking in the Gondar region of Ethiopia.

Lactic acid model

A model that predicts the production of lactic acid depending on the growth and maintenance was developed by Leudiken and Piret [8]. Their model is based on two parameters: α (growth associated production) and β (non-growth production), which are quantified through Optical Density (OD) measurements. However, for milk this determination cannot be done with OD, as milk is not transparent. Therefore the values given by Leudiken are recalculated to: α: g lactic acid/g biomass production and β: g lactic acid/g biomass/h, with a conversion factor 1 OD = 450.106 c.f.u./ml and 1,1.10-9 mg/c.f.u. [9].

Economics

Improving the milk supply will need investments, labour and the use of utilities. The amount will depend on the scenario and how it is implemented. The economic impact is calculated for the following 3 situations:

1. a chilling centre located between Derba and Chancho at tarred road side;
2. on-farm milk off-grid chillers;
3. chillers with power supply to all households.

To estimate typical transportation distances and costs for these scenarios about, the situation in 20% of the current morning milk collecting area is analysed. In figure 5 and table 1 the current supply area from the small farmer holders, studied area and the locations and distances to the factory are given. The maximum walking distance to the road in the studied area is 6.4 km.

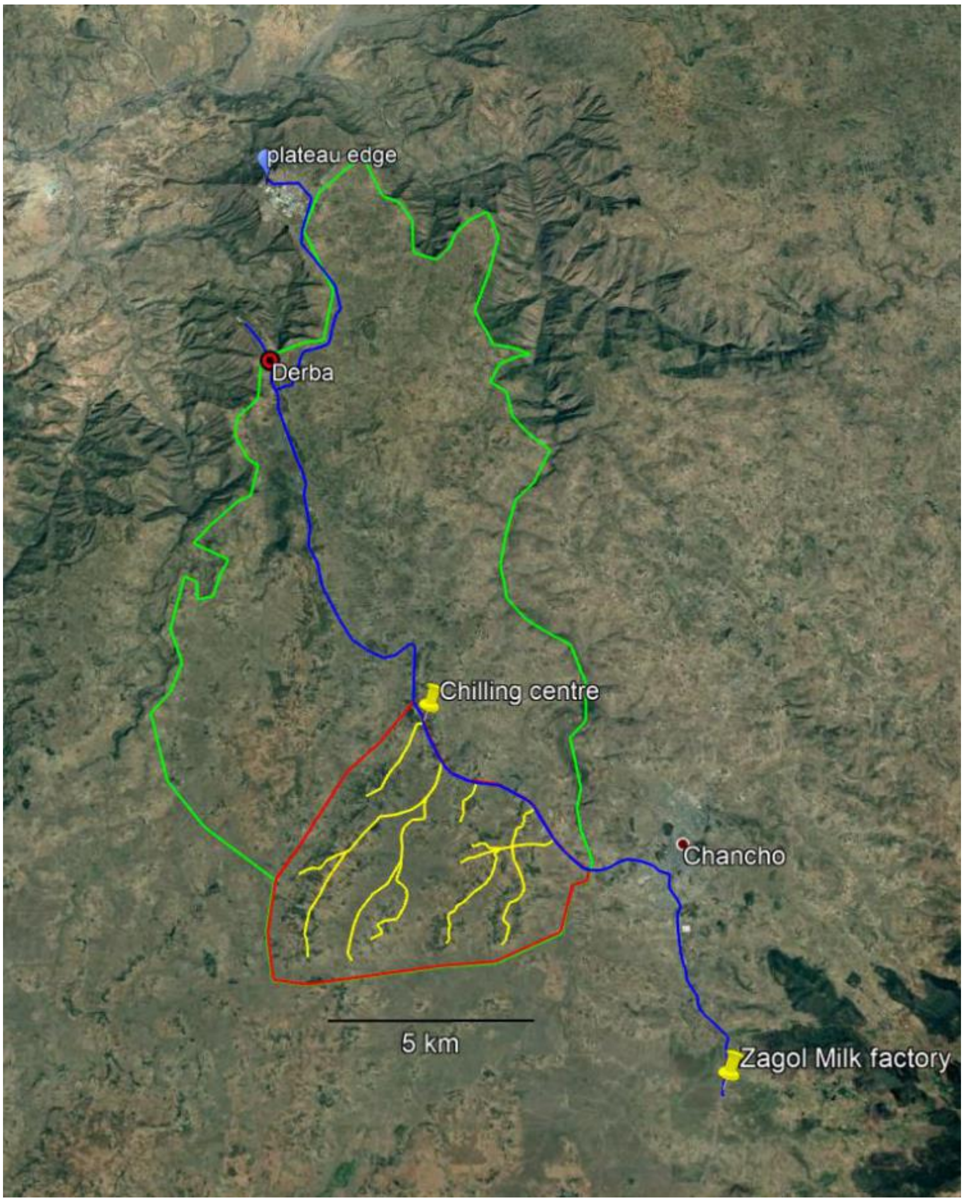

Figure 5. Situation of the milk supply area of the Zagol Milk factory. Red studied area, green total supply area, blue tarred roads, yellow main walking tracks to tarred road.

Underlying image from Google Maps.

Table 1. Locations and distances of the Zagol factory

location		
Zagol milk factory	9°15'19.66"N	38°45'45.75"O
chilling center	9°20'7.14"N	38°41'44.33"O
distances tarred roads		
factory-chilling center	13.9	km
factory-Derba	27.7	km
Derba-edge plateau	8.8	km
Areas		
Studied area (red)	34	km^2
Total area (green)	165	km^2

Chilling centre

For the use of a chilling centre a solution must be found to get the milk from the farmer to the chilling centre in the evening. In the current situation there is no interest for the 2nd walk to the chilling centre in the evening. In this scenario the evening milk is therefore collected at the farm by a scooter. It collects milk between 18:00 and 21:00 directly from the farmers.

In the selected area, collection rounds are constructed to cover the whole studied area. Only the likely paths were chosen by studying the satellite images. They are namely the pathways on which a scooter with 100 litres of milk is able to drive. To avoid too long driving distances, the scooter will not always drive up to the courtyard. The farmers who want to sell their milk will have to walk to a main path, maximumly 400 meters. The round can be circular or one-way.

From every round the total driving distance and number of courtyards at the route is determined. The courtyard can cover more than one house or building. It is assumed that a courtyard has farming activities. In the rest of this study one courtyard is referred as one household. From these rounds an average round distance with an average amount of households is determined to be able to calculate the total driving distance and number of collectors needed to fulfil the pre-set collection goal within the time frame that is available.

There are some uncertainties in the parameters in this scenario for calculating the number of scooters needed to collect the required milk. First it is not known how many of the farmers on the route will sell their evening milk. Furthermore, the time needed to collect the milk at the farm and how fast a scooter can drive on the single tracks are also uncertain.

Therefore, an optimistic and a conservative (max, min) estimation is made to calculate the number of scooters needed (table 2). For the optimistic estimation the character of the round is a one-way route. So, the scooter has the same way from and to the farmers. It has a little advantage to a circular route if the number of farmers per km is the same. At a one-way route the scooter can start at the end of the route ensuring a minimal amount of driving at the round to collect the milk. After 100 litres is collected the scooter has to drive back to the chilling centre and can start collecting again at the point closer to the road. Therefore, the collector drives half of the distance of all the trips in a round with an empty scooter, this will decrease the average driving time. For a circular route, if the middle point is known, one needs always to drive two times to the furthest place on the route. In the calculations, however, it is assumed that this collection middle point is not exactly known. Therefore, the distances are calculated for circular rounds. The collector starts collecting on the tarred road and drive back until 100 litres is collected. For the next trip the collector starts again where he left off until the collector passes half of the total driving distance. In that case the scooter will not drive back but complete the round as that is the shortest way. For the next trip the collector will drive up to the starting point from the shortest route following the same strategy as the one of the one-way route.

On-farm milk, off-grid milk chillers

When on farm milk chillers are implemented all the farmers must be equipped with these coolers. There are off-grid cooling systems developed to cool milk at remote areas, either with solar power or biogas. Foster is at all developed a solar power installation for 5-40 litres of Milk. Solar power has the disadvantage that the energy is only available during the day time but the energy is also needed in the night. The solar chiller of Foster has no battery to store energy, instead it has an inside cold storage. Between the outer isolation box and an inner box ice is made during the day which can melt again in the evening [3]. The gas for the biogas chiller can be locally made with a biogas digester and used when the energy is needed. Simgas build coolers on biogas to cool 2.5-10 litres of evening milk [4]. However, these chillers are not on the market anymore after bankruptcy of the company [13]. The farmers have to bring the milk to the roadside themselves in the morning where the milk is being collected. Except for the off-grid chiller no additional costs to the evening milk will occur.

On-farm milk chillers with power grid connection

The amount of cables needed to connect all farmhouses to the power supply was determined in the studied area. Currently the farmers are not connected to the power grid. Power lines are only available at the tarred road. From there the amount of power cables is determined by an optimal connection between all courtyards. In contrary to the chilling centre scenario are that the cables are not necessary to follow the current tracks to minimize the amount of cables needed. Required line capacity is based on 5kW (ca 22A). To calculate the investment of the power cable the total required capacity is rounded up to the first MW.

Table 2 parameters used for the calculation of the cost for the different scenario's. With minimum and max value for: amount of selling farmers, collection time at farmer and driving speed.

	max	min	
amount of milk to collect	1000	1000	l/day
amount of evening milk a farmer can sell	6	6	l/farmer
fraction farmers on the route want to sell	0.6	0.3	[-]
collection time at farmers place	3	5	min
average speed scooter on single track	20	10	km/h
max liter milk per scooter	100	100	l milk
max collection window	3	3	h
character of round	one way	circular	

For the different scenarios the additional costs per collected litre milk are calculated with the prices for hardware and utilities and labours from table 3. The cooling centre has electricity, but diesel usage is included in the investment price to secure cooling capacity during power failures. For the energy calculation, however, only the energy from electricity is assumed. The scooter can drive 30 km on 1 litre gasoline. The home refrigerators, in the power grid extension situation, are expected to run the whole day at an average power consumption of 30W. Maintenance and financing are not taken into account and depreciation time is 10 years.

Table 3. Cost of hardware, utilities and labour used for the economic analyses.

hardware			
low voltage power cable	1491-6636	$/MW.km [14]	
cooling center	31000	$ 2000l	VCRS-diesel [15]
solar chiller	1850	$ 5-40 l	Solar FMC [16]
home refrigerator	256	$ 20 l/110W	https://www.qefira.com/fridges-freezers
Scooter with 4 milk cans	2000	$	
utilities			
electricity cost	0.018	$/kWh	https://allafrica.com/stories/201808150215.html
gasoline	0.73	$/l	https://www.globalpetrolprices.com/Ethiopia/gasoline_prices/
labour cost rankX level8	0.26	$/h	https://wageindicator.org/salary/minimum-wage/ethiopia/2287-middle-level-professionals

3. Results and discussion

Effects of the different chilling scenarios on the rejection rate by the factory

Based on the the relation between pH and the amount of lactic acid in the milk, figure 6, a second order polynomial is fitted: pH=0.0693[LA]^2-0.6753[LA]+6.705 with [LA]= lactic acid concentration in g/l. Correlation coëfficient of the fit between pH 5.3 and 6.7 was r^2=0,9993.

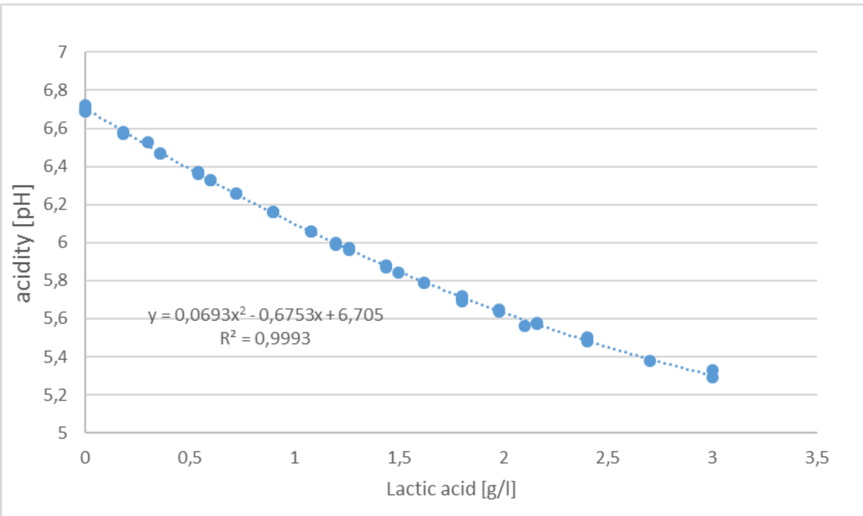

Figure 6 Fit of titration of milk with lactic acid 4 replica's combined.

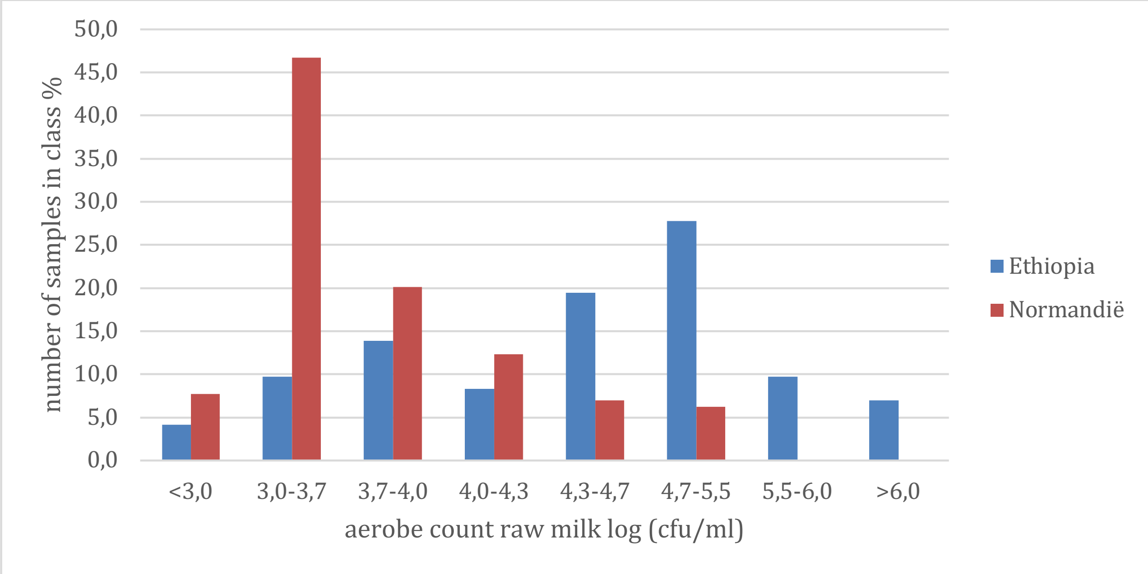

Figure 7. Contamination of raw milk as total bacterial count (log c.f.u./ml) collected directly from teat and milking buckets in and around Gondar, Ethiopia [10], compared with data from on farm cooling tanks (2-4°C) in Basse-Normandie, France [12].

The initial contamination levels (t=0) from Tegegne [10] are presented in figure 7 as a histogram and compared with a study in Normandie, France. Tegegne found an average increase of a half log between sample directly from the teat and from the bucket. The initial contamination of the raw milk in Ethiopia is significantly higher as found in Normandië.

With the pH-Lactic acid fit and the initial contamination the rejection rates of the different scenarios are estimated and presented in table 4. The rejection rates are calculated for the different scenarios to pass the alcohol test at 8:00 and 10:00, assuming that all the aerobe counts are lacto bacillus and there is no lag phase. Hence, it could be expected that the calculated pH will be on the lower end. Ashenafi found that 60% of the bacteria on the meso-arobic plates where lactobacillus in milk used for ergot production [11].

As expected, the collection of the current evening milk without any cooling is not feasible. For the morning milk the predicted rejection rates are similar to the real rejection rates at the Zagol milk factory (table 5) which was in 10% of the milk coming from small farm holders. Whereas in the same period none of their own farms and the farms of the neighbours had to be rejected. Those farms have +100 cows and have no significant travel time between milking and the delivery to the factory.

The high rejection rate of the evening milk cannot be solved by improving the milking hygiene alone. Using the contamination data from Normandie of which the milk is significantly lower contaminated, does not help the rejection rates a lot. Even then 92% of the evening milk will be rejected at the factory gate if no cooling is applied.

Table 4 Estimation of milk sample not passing the alcohol test at 8:00 (collection on road side) and 10:00 (arrival at factory gate) in the morning for the field data from Tegegne at the different scenario's.

		rejection of milk samples %	
Scenario		8:00 collection road	10:00 factory gate
A	Current evening	96%	97%
A	Current morning	0%	8%
B	Cooling Farm evening plastic*	21%	26%
B	Cooling Farm evening metal**	0%	3%
B	Cooling Farm morning	Same as A morning	
C	chilling centre 1 del evening	96%	96%
C	chilling centre 1 del morning	0%	0%
D	chilling centre 2 del evening	6%	6%
D	chilling centre 2 del morning	Same as C morning	

*Scenario B evening milk calculated with two different heat transfer coefficient 0,23/h 5l plastic jar and 5l metal jar in Simgas milk chiller 0,6/h.

Table 5 Rejected milk at the factory gate at the Zagol Milk factory of morning milk from different sources in the beginning of 2019.

source	delivered	rejected	% rejected
Own farm	8967	0	0%
Neighbour farm	18537	0	0%
Small farm holders	50608	5160	10%

When the cooling of the milk already starts on the farm the milk can be delivered to the milk factory with low rejection rates even though only when metal cans are used. Using the 5 litre plastic jars the heat transfer is quite low. Therefore, it takes a long time to reach a milk temperature where the growing rate is low enough to avoid reduction in the pH. Metal cans have much higher heat transfer coefficients. The former producer of milk chillers, Sim Gas, reached a cooling rate of 0,6 1/hr in their gas-powered chillers as is chosen for a metal jar in combination with close wall to wall contact. This results in lower milk temperatures during the night and thereby lower growing rates, which reduces the rejection rate at the factory gate from 26% to 3%.

As in scenario C the evening milk is already spoiled before it can reach the chilling centre as calculated in the current situation, this scenario has no positive effect on the usability of the evening milk. For the morning milk the quality will be improved, whereby the rejection at the factory will be reduced to zero.

Quality-wise scenario D is preferred, as beside the evening milk also the morning milk being cooled before transport to the factory improves its quality. For the evening milk, the use of on farm cooling can give the same quality of milk as the cooling centre. However, this happens only when metal jars with good heat transfer are used. The largest disadvantage of a cooling centre is that the farmers need to offer their milk twice a day.

From the scenarios tested the best improvement can be expected from the cooling centre is when the farmers are willing to offer their milk twice a day. Although this will increase the farmers' incomes, it is not for sure if they want to do so. Beside the extra trip to the cooling centre in the evening there will be nothing left for their own consumption or production of traditional fermentation products. From this perspective scenario B is probably a better choice. The farmers have then a choice on what to do with their milk and also the possibility to improve the self-life of the traditional fermented products. Attention has only to be paid to the type of jars in use. In case of the plastic 5-litre cans being put in a refrigerator, still about 26% of the milk will be rejected at the factory gate.

Effects of the different chilling scenarios on the collection costs

Chilling centre

Figure 8 shows the path of round 1 where a scooter could drive to collect the evening milk and bring it to the chilling centre. In total 3 different rounds in the studied area are defined, see table 6.

Figure 8 Satellite image of round 1 of the 3 possible milk collection rounds in the studied area to determine the driving distance. The selected route goes over single and double tracks. Rivers and steep slopes are avoided.

Underlying image from CNES/Airbus.

Table 6 Details of the constructed milk collection rounds covering the studied area.

Round	Character of round	total distance (km)	number of households
1	circular	11.3	113
2	one-way	20.1	111
3	circular	18.5	213
average		16.6	146

With the max and minimum data provided in table 2 the number of scooters needed to collect the required milk and the total driving distances are calculated in an optimistic and conservative scenario table 7.

Table 7. The optimistic and conservative calculation of the number of collectors (scooters) needed and the total driving distance in the cooling centre scenario for the collection of 1000 litre of evening milk.

	optimistic	conservative	
number of farmers needed	167	167	farmers
farmers selling in a round	87	44	farmers selling/round
number of rounds required	2	4	
number of full scooters loads per round	5.2	2.6	loads/round
km drive to fill scooter	1.6	6.3	km/fill
km drive per round	52	37	km/round
total km to drive	104	149	km/day
total time driving	5	15	h/day
total time collecting milk	8	14	h/day
number of scooters needed	5	10	

Power grid extension

In total 4 new powers line must be installed to connect as households to the power grid. An example of one of these lines is presented in figure 9. Table 8 show all the data from a four power lines used for the cost calculation.

Figure 9. Satellite image of one of the 4 electrical grid extensions starting from the tarred road. Every dot resembles a household (courtyard) connection.

Underlying image from Google Maps.

Table 8. Measured amount of power cable needed to connect all households to the electrical grid in the studied area. Required line capacity based on 5kW (ca 22A) connection per household.

line	Amount of Power line km	Number of connected households	Average distance km/ household	Required line capacity MW
1	9.3	92	0.10	0.5
2	14	93	0.15	0.5
3	4.7	49	0.10	0.2
4	22	213	0.11	1.1
total	50	447	0.11	2.24

Comparing the collection costs in the different situations

With the calculated number of scooters, collection km, and power line km for the different situations the investment, fixed, variable and total collection costs are calculated in table 9.

Table 9 Required investments for the collection of 1000 litre evening milk per day and an average selling amount of 6 l per farmer in the different scenarios.

	Investment k$			
	transport		chiller(s)	total
cooling center	scooter(s)	9-19	31	40-50
off grid chiller		-	309	309
grid extension all houses	power line	47-416	29	75-445
grid extension selling farmers	power line	28-125	29	57-154

Table 10 Fixed-, variable- and average cost per liter milk for the collection of 1000 litre evening milk per day and an average selling amount of 6 l per farmer for the different scenarios. Depreciation 10 years, variable cost from table 3.

	Fixed costs	**Variable cost k$/year**			**Total collection costs**
	k$/year	elec.	gasoline	labor	$c/l milk
cooling center	4.0-5.0	0.2	0.9-1.3	2.1-4.0	1.9-2.9
off grid chiller	30.9	-	-	-	8.4
grid extension all houses	7.5-44.5	0.9	-	-	2.3-12.4
grid extension selling farmers	5.7-15.4	0.9	-	-	1.8-4.4

For the calculation of the costs of the grid extension two numbers are used in Table 9. In the first, the investment to connect all the households in a round is calculated, whether this household sells their milk or not. In second calculation, only the investment for connection for the selling farmers is taken into account. The latter is fairer for the comparison, even though the total investment needed is higher. Using the second calculation, the power grid extension costs come close to the cooling centre.

An off-grid chiller is not the most economical solution for the collection of 1000 litre extra milk, for an average supply of 6 litre of milk per farmer per day. The main reason of the high costs is that the off-grid chiller, in the calculated situation, has to operate at a low percentage of its max capacity. Figure 10 shows the effect on the collection costs when the amount of milk per farmer increases to the max capacity of 40 litre/day. At a constant collection of 1000 litre/day the off-grid chiller becomes cheaper than a chilling centre when the farmer can sell more than 30 litres/day. It is not likely that an individual farmer can currently reach that goal. As a solution he can team up with his neighbours to cool also their evening milk. For the biogas chiller no data are available, however it is not likely that the collection costs will be cheaper with this chiller. The digester to make the biogas for the chiller was already around 700$ per unit and the maximum cooling capacity is only 10 litres, resulting in collection costs that will probably exceed 5 $cent/litre, when using this chiller.

Either a grid extension or a chilling centre can be used for collection of the evening milk with a minimum of 2 cents/litre extra costs expected in comparison to the morning milk. As an electrical connection to every household will be a desired end situation for the area, the extension of the power grid seems the favourable solution. As there are already power cables available at the road the investment seems reasonable, despite the large spread in the expected investment.

The chilling centre has, on the other hand, also an advantage compared to the power grid extension. The additional costs and required investments can easily be allocated to the evening milk as this milk is separately collected. When the farmers bring the evening milk together with the morning milk you cannot have a price deviation between the two. The Farmers have therefore gives up margins on the evening milk where in the chilling centre scenario the additional costs can directly be paid by the milk factory. Also, the financing of an on-farm chiller will be difficult. It is not likely a farmer can afford to pay for a chiller himself. It probably need to be pre-financed by the milk factory and paid back with the milk deliveries.

Beside this benefit there are also some question marks for the chilling centre scenario. E.g. Can the scooter drive over the single tracks with 100 litres of milk in the dark? Are the tracks still passable in the raining season? Furthermore, all the collectors must have certain skills. Beside the driving they need to test the milk on quality and keep some administration logs.

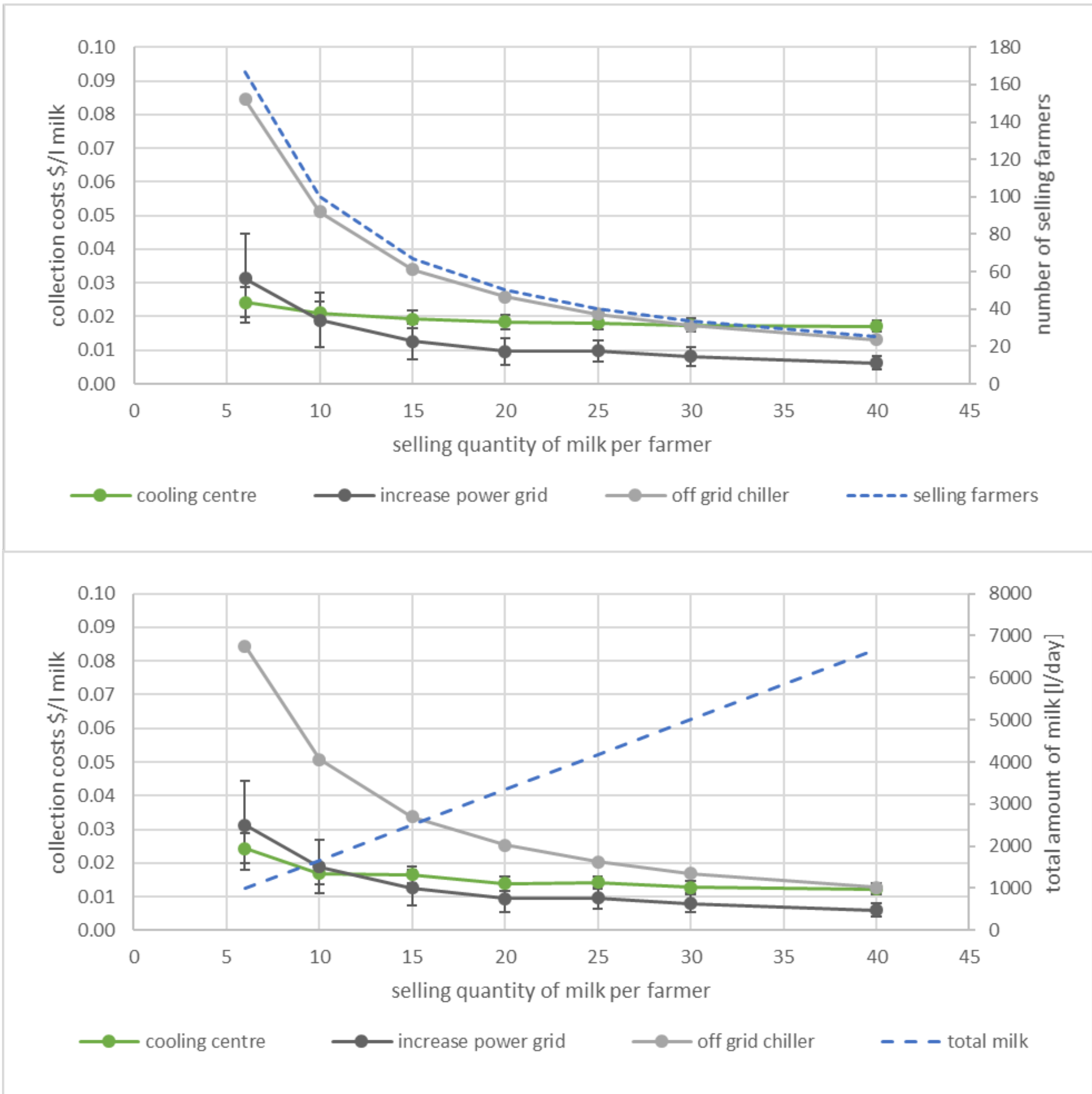

Figure 10. Effect of increasing famer selling quantity on the collection cost of evening milk with different cooling scenario's. A: constant collection 1000 litre milk, B: constant number of 167 selling farmers.

4. Conclusions

The analyses show that cooling is essential for preventing losses in collecting evening milk in the supply area of the Zagol Milk factory. For the morning milk, cooling becomes more essential when the time between collection and arrival at the factory gate increases.

For the cooling of the evening milk, either a cooling centre with an introduction of a collection system or on-farm chiller can be used. The latter only is effective if a metal or comparable vessel with a high heat transfer coefficient is used. Milk in plastic vessel is less suitable as metal vessel, due to the slow cooling rate.

For the collection of the evening milk minimally 2 cents/litre extra costs are estimated compared to the morning milk. Depending on the ambition of the Ethiopian government to connect household in farmland close to an already existing power grid, either increasing the power grid or the chilling centre is the most promising option. Off-grid chillers seem less economical, mainly due to the short distance to an existing power grid and the low average milk production per farm. The success of a chilling centre depends on the success of the collection system.

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