Technologies for enhancing value addition, quality and safety of milk produced by smallholder farmers in Africa

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Abstract

FAO 2003 data indicate that Africa imported 5.6 million tonnes liquid milk equivalent worth about US $1.8 billion or 29% of world dairy import trade. Part of this demand-supply gap for value added dairy products could be filled by processed dairy products from within the African region. While Africa produces about 28.7 million tonnes of milk annually (26.7 kg/per capita), in most countries more than 85% is sold as raw milk thus raising quality and food safety concerns. The paper reviews and discusses technologies that have been developed to address these problems including improvement of milk handling by informal milk traders, traditional fermentations, butter and cheese processing, milk preservation using lactoperoxidase (LPS) and in-pouch pasteurisation of liquid milk. It is concluded that Africa's dairy industry needs to grow from an industry dominated by informal actors to small and medium enterprises answering the needs of the changing socio-economic landscape of African countries.

Introduction

Among the major regions in the world, Africa's dairy industry is the least developed in terms of productivity per cow, milk supply per capita and proportion of industrially processed milk and dairy products. A large proportion of the 28.7 million tonnes of milk produced annually is by traditional cattle keepers and smallholder dairy farmers of whom more than 80% are concentrated in Eastern and Southern Africa (Tambi et al. 2001). FAO data show that in 2003 Africa as a whole imported 5.633 million tonnes liquid milk equivalent worth US $1.766 billion or 29% of world dairy import trade worth US$ 6 billion. The imports are necessary to fill the ever-growing gap between supply and demand for milk and dairy products and to compensate for the low internal capacity to collect and process domestically produced milk into preserved dairy products. The challenge for Africans is to apply appropriate technologies and economies of scale to fill the gap from domestic and regional supply chains.

From the mid-1990s in most African countries, the state-owned dairy parastatals have given way to private sector operated milk marketing and processing ventures. In Kenya, Tanzania and Uganda, the number of dairy plants increased from less than 10 in each country to more than 30 small- and medium-scale dairies in each country. In spite of this, more than 80%, 95% and 85% of the milk produced is marketed as raw milk, respectively in Kenya, Tanzania and Uganda (Lore et al. 2005). Reasons why informal milk marketing dominates the dairy industry of most sub-Saharan African countries are weak infrastructure for milk collection and processing and the fact that most poor urban consumers cannot afford the added cost of processing and packaging of pasteurised milk (Staal and Omore 2003). Recent studies in Kenya and Tanzania have shown that a significant proportion of informally traded milk does not meet microbiological and composition specifications set forth by national bureaus of standards and adulterations are quite common (Omore et al. 2004). Post-harvest losses due to milk spoilage and spillages have been estimated at 2.7%, 5.6% and 3.0% in the entire marketing chain in Uganda, Tanzania and Kenya (Lore et al. 2005). Reasons for high microbial loads in raw milk and spoilages include poor hygienic practices and the lack of cooling facilities at the farm level and in the entire marketing chain. To address some of these problems affecting smallholder dairy farmers and informal milk traders, various milk preservation and processing technologies have been investigated or promoted in various countries in Africa. The objective of this review is to present appropriate technologies and discuss their implications for dairy marketing and processing industry development in Africa.

Milk preservation at the farm level

Most smallholder farmers and milk traders operate in rural areas without access to electricity. Milk marketing chains are in most cases short involving direct sales of raw milk to consumers or milk vendors (itinerant milk traders) who act as intermediaries between producers and consumers in some cases. Due to the high perishability of milk, these warm milk market chains are limited to the sale of morning milk within 2–3 hours travel distance from the farm. Beyond these time and spatial limits, some form of preservation has to take place. Cooling is the technology of choice where electricity is available; the use of generators can be justified by the quantities of milk that can be bulked at a milk-cooling centre. While bulk coolers are common and the preferred mode of chilling milk, the use of locally fabricated ice banks can enable small quantities of milk to be cooled in 30–50 litre milk cans. In Tanzania, the Sokoine University of Agriculture has in the past several years promoted the fabrication and use of this technology by some smallholder farmer groups with considerable success (Figure 1). Using this technology milk can be preserved for up to 24 hours and the ice block formed can still keep the milk below 10°C for at least 12 hours following breakdown of electricity. Due to technical and economic limitations attempts to use solar refrigeration in milk preservation has not been commercially applied anywhere in Africa.

The ice bank is double walled, galvanised milk steel tank measuring 86 cm wide x 218 cm long x 82 cm deep (1.45 m^3) insulated with styropol sheeting (5 cm) in between the two walls. Two 0.75 hp single phase compressors are installed on one side of the box (Figure 1). Copper pipes (3/8’’ diameter) from each compressor are lined 9 cm apart along the tank walls and bottom surface to function as the evaporator that absorbs heat from the water. The tank can accommodate 10 milk cans each holding up to 50 litres of milk (Figure 1). Alternatively, the tank can be constructed out of smooth finished concrete or fire bricks insulated with styropol held in place by chicken wire on the outer wall and finished by a smooth layer of cement plaster.

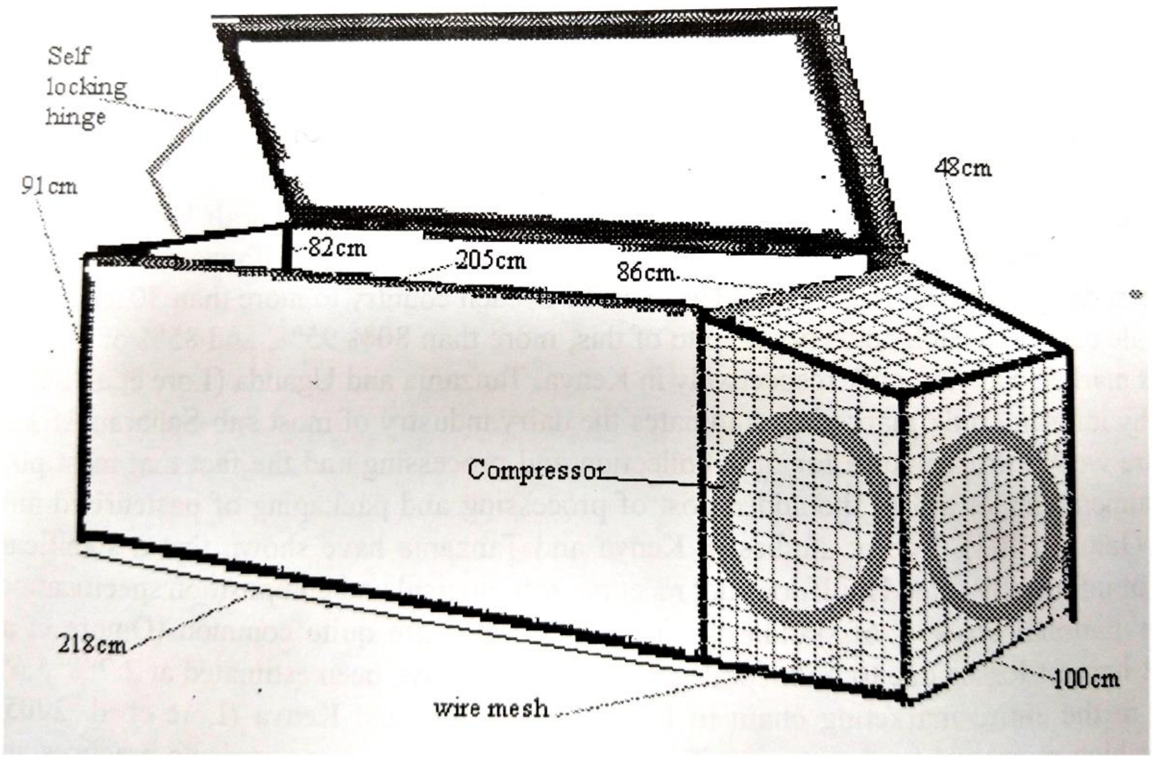

Figure 1. Simple design of a 500 litre ice bank milk cooler.

Milk preservation without electricity

Preservation of raw milk without electricity has proved to be of considerable technological and ethical challenge. In 1956, FAO approved the use of hydrogen peroxide for preservation of milk in warm developing countries where refrigeration was not possible. It has not been widely applied commercially due to a number of drawbacks including presence of impurities such as trace amounts of iron, copper and arsenic acid, the need to remove excess H_2O_2 by catalase treatment and oxidation of proteins, aldehydes, ketones and vitamins A and C and more seriously, the splitting of a minor component of the casein complex which affects the ability of rennet to coagulate milk during cheese making (Scott 1981). Moreover, this method cannot be regarded as a safe method in respect of pathogens in milk such as *Mycobacterium tuberculosis* that can survive H_2O_2 treated milk for longer than 24 hrs. For these reasons, the use of H_2O_2 for the preservation of raw milk has now been replaced by the activation of the naturally occurring lactoperoxidase system (LPS) (IDF 1981, Claesson 1995; FAO 1999).

The activation of LPS in the milk is achieved through addition of 14 mg of sodium thiocyanate (NaSCN) and 30 mg of sodium percarbonate ($2Na_2CO_3.3H_2O_2$) to give an initial concentration of about 15 ppm of thiocyanate (SCN^-) and 8.5 ppm (H_2O_2) respectively in the milk. This treatment, when done within 2 hours of milking and to milk of good hygienic quality, prolongs the bacteriostatic effect of the natural antibacterial systems for a further 6–24 hours depending on the (ambient) temperature of the milk thereby enabling milk to be marketed for longer distances and time interval after milking (Table 1).

Table 1. Effect of temperature on efficacy of the lactoperoxidase system

Temperature (°C)	Shelf life (time, h)
30	7–8
25	11–12
20	16–18
15	24–26

Source: FAO (1999)

The technical and economic efficacy of the LPS system has been a subject of considerable interest and investigations in recent years. Field trials conducted in Ethiopia showed that the lactoperoxidase preserved the milk for 3 hours longer than the untreated control, but failed to do so after 7 hours (Tolemariam et al. 2000). Under tropical environments in Africa, it appears that the usefulness of the LPS system to preserve the quality of milk is limited to 6–7 hours (IDF 1988) but it is still cheaper than conventional cooling is (Wanyoike et al. 2004).

High ambient temperature and initial quality of raw milk are important factors to consider where it is desirable to use LPS to prolong the shelf life of evening milk (Kurwijila and Mwaikambo 2003). An added advantage of the LPS treatment is the extension of shelf life of pasteurised milk which has been preserved by LPS (Kamau et al. 1999; Nicholete et al. 1999; Mwaikambo et al., 2005). The results of a recent study (Mwaikambo et al. 2005) showed a clear advantage in shelf life extension of LPS activation over the control sample for milk pasteurised within 3–6 hours following activation and storage at ambient temperature (24–25°C) (Figure 2). All pasteurised milk samples were subsequently stored in a refrigerator maintained at 5–8°C. This has positive implications for marketing of pasteurised milk by small-scale milk traders and retailers as it would reduce losses due to spoilages. To date the major drawback to commercial application of the LPS treatment is a clause in the guidelines which requires such milk not to enter international trade (IDF 1981).

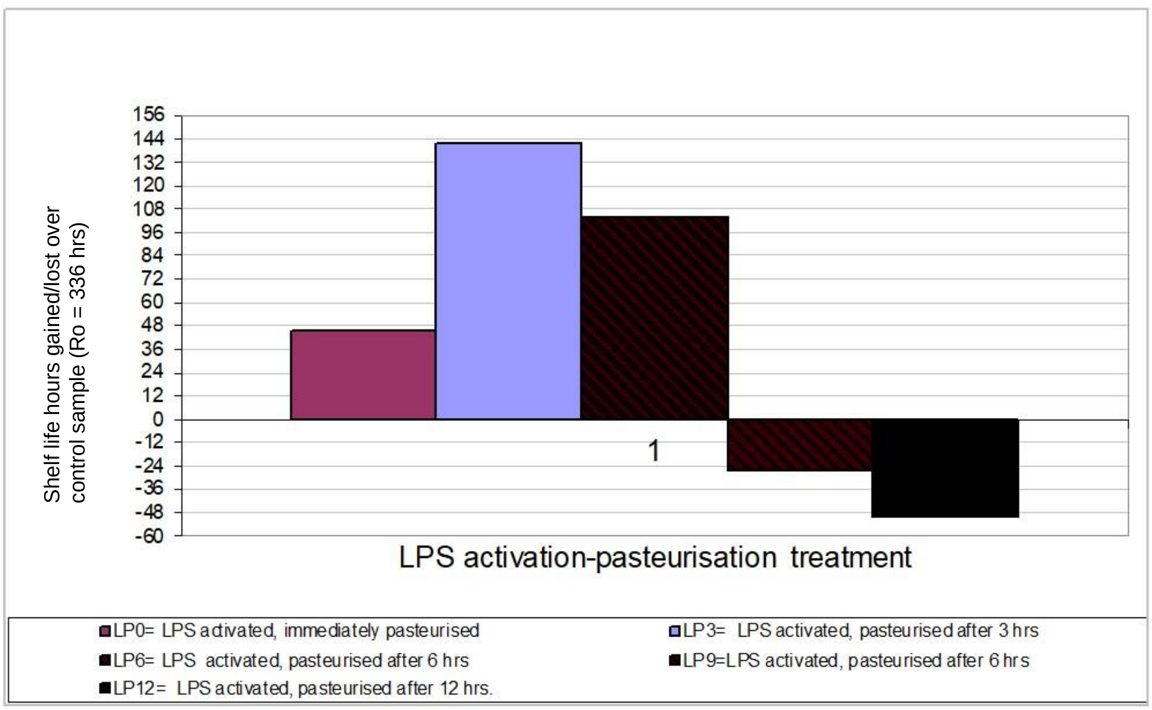

Figure 2. Effect of storage period after LPS activation on extension of shelf life (pH=6.4) of in-pouch pasteurised milk stored at 5–8°C.

Milk fermentation

Throughout Africa, naturally fermented milk is the most common milk food. Various societies have evolved fermentation processes that produce products with specific flavours and taste. The end products of spontaneous fermentations have a tart acid flavour while Zimbabwean *amasi* also has a malty flavour which is preferred by the local population (Narhvus et al. 1998). The fermentation is effected by naturally occurring lactic acid bacteria present in the milk and in the pores of older vessels. Occasionally addition of previously fermented milk—'back slopping'—is practised (Gonfa et al. 2001). Work done on traditional fermented milks in Africa over the last two decades shows that both thermophilic and mesophilic lactic acid bacteria take part in the fermentation depending on the environmental temperature and other factors. Yeasts also play a role in the later stages of the fermentation, contributing to the flavour of the end products (Gonfa et al. 2001). The vessels used differ from community to community. Clay pots, calabashes and gourds, wooden and woven vessels and smoking of these vessels are common (Shallo and Hansen 1973; FAO 1990; Bekele and Kassaye 1987; O'Mahony and Peters 1987; Shallo 1987; Coppock et al. 1992; Gonfa et al. 2001; Abdelgadir et al. 2002). Wood of different species is used including *Olea africana*, *Acacia busia*, *Acacia nilotica, Cordia gharaf*, *Cordia ovalis*, *Combretum molle, Balanities aegyptica* in Ethiopia (Bekele and Kassaye 1987; FAO 1990; Gonfa et al. 2001) and *Combretum* spp.*, Diplorhynchus condylaccarpon* and *Olea africana* in Tanzania (FAO 1990). The application of smoke slows down the fermentation process, improves flavour and slows down the growth of coliforms (Ashenafi 1996) thereby contributing towards safety and extended shelf life of the fermented products.

Amongst most pastoralist communities who have to walk long distances in search of pastures and water for their livestock, the shelf life of the milk products is of paramount importance for food security. Hence, over hundreds of years, these communities have evolved processes to make concentrated dairy products with long shelf life. Products such as *ititu* prepared by Borana pastoralists in Ethiopia and *biruni* made by the people of Nuba mountains of western Sudan have been reported to have a shelf life of 90 days (Coppock et al. 1991) and up to one year (Abdelgadir et al. 2002) respectively. Another product, *mish*, related to *biruni*, is made by the people of Darfur State (western Sudan) and the nomadic tribes in northern Sudan and the Dinder Region (Ethiopian border). This product is reported to undergo fermentation for 1 month. This has to be compared with commercial, western type yoghurt or cultured milk which, without the benefit of refrigeration, has a shelf life of less than five days and not more than 20 days with refrigeration (Tamine and Robinson 1988).

In recent years, great interest has therefore been directed at isolation and characterisation of lactic cultures from traditional African fermented milk products. Nearly all commercially known lactic acid starter bacteria have been isolated from traditional African fermented milk products (Feresu and Muzondo 1990; Isono et al. 1994; Abdelgadir et al. 2001; Savadogo et al. 2004). A number of species of lactic microflora have been isolated from a variety of traditional African fermented milk products (Table 2). These microbial species represent a vast range of biodiversity that remains to be exploited in the formulation of starter cultures that could be formulated to suit the special flavours and tastes that have been the cornerstone of many a traditional fermented milk of various communities on the African continent. The challenge that remains is the commercial development of fermented milk products that simulate the characteristics of traditional African products in the same way yoghurt and *kefir*—traditional products in the Balkan states—were developed 100 years ago.

Table 2. Isolates of lactic acid bacteria from traditional fermented milks in Africa

Species	Products from which isolated	Author
L. lactis ssp. *lactis; L. lactis* ssp. *lactis* biovar *diacetylactis; Lb. confus; Lb. delbrueckii; Lb. plantarum; Leu. citreum; Leu. lactis*	Burkina Faso fermented milk	Savadogo et al. (2004)
L. lactis; Lb. fermentum; Lb. acidophilus; *Streptococcus salivarius; Saccharomyces cerevisiae* and *Candida kefyr*	Sudanese fermented milk *rob*	Abdelgadir et al. (2001)
L. lactis ssp. *lactis; Lb. acidophilus*; *L. lactis* ssp. *lactis* biovar *diacetylactis* strain INF-DMI	Naturally fermented milk (*amasi*) in Zimbabwe with malty flavour	Mutukumira (1996); Narvhus et al. (1998)
L. lactis/lactis; biovar *diacetylactis*; *maltigenes*; *lactis/cremoris*; *Lc. mesenteroidesmes* spp. *cremoris;* ssp. *dextranicum; lactis* *Lb. plantarum; curvatus; brevis; casei; Enterococcus* spp.	Isolates from Ethiopian fermented milks	Beyene (1994)
S. cerevesiae	*Nono*, a Nigerian fermented milk; *mbanik,* Senegalese cultured milk	Okagbue and Bankole (1992); Gningue et al. (1991)
S. thermophilus	*Iria ri matti*, a fermented milk from Kenya	Kimonye and Robinson (1991)
Lb. plantarum; *Lb. curvatus; L. lactis* ssp. *lactis; Leu. mesenteroides* ssp. *mesenteroides*	*Maziwa lala*, a traditional fermented milk from Kenya	Miyamoto et al. (1989)
Lactobacillus spp.; *Leuconostoc* spp.*; Streptococcus* spp. + yeasts	*Ergo* and *ititu,* fermented milk from Ethiopia	Ashenafi et al. (1996)
L. lactis; *Streptococcus thermophilus*; *Lb. bulgaricus*; *Lb. helveticus*; *Lb. fermentum*; Yeasts: *Saccharomyces globus; S. exigus; Kluyveromyces bulgaricus* and *K. lactis*	Sudanese *Rob* collected from the market	El Mardi (1988)
L lactis ssp. *lactis* biovar. *diacetylactis*. *Leu. lactis, Leu. mesenteroides* ssp. *cremoris; Leu. dextranicum*	*Laban*, a Moroccan fermented milk	Hamama (1992)

Traditional butter making

In Ethiopia, fermented milk is often churned to produce butter and the buttermilk is filtered off and used as a drink or eaten with other foods (Bekele and Kassaye 1987; Gonfa et al. 2001). Scientists from the International Livestock Research Institute in Ethiopia developed an agitator mechanism for clay pot churns that greatly reduces the churning time and improves efficiency of fat recovery. Hundreds of the improved churns are now widely used in Ethiopia. Similar improvements can be applied to traditional gourds used widely in churning of sour milk to produce butter. The results obtained by O'Mahony and Bekele (1985) working with the improved clay pot butter churn in Ethiopia are summarised in Table 3.

Table 3. Churning efficiency of traditional clay pot butter churns in Ethiopia

Type of churn	No. of trials	Quantity of milk (litres)	% TA	% BF in WM	Churning temperature (°C)	Time taken (min)	% BF in BM	% fat recovery
Traditional clay pot	25	10	0.88	4.4	18	90	1.00	75
	11	8	0.86	4.9	17	139	0.57	77
	10					134	0.90	
Local wooden butter churn	10	-	-	-	-	56	0.86	-
Imported wooded butter churn	10	-	-	-	-	44	0.90	-
Improved clay pot butter churn	16	16	0.83	4.3	16	61	0.40	90

% TA = titratable acidity; BF = butterfat; WM = whole milk; BM = buttermilk
Source: O'Mahony and Bekele (1985)

Traditional cheese making

Except in Ethiopia, West Africa and North Africa traditional cheese making is not very common on the continent. In Ethiopia, *ayib*, a soft cheese is made from buttermilk which is a by-product of butter making. In West Africa, Fulani pastoralists make a traditional cottage cheese called *wagashie* (*woagashie*) using a coagulant from Sodom apple (*Calotropis procera*) (Awor and Nakai 1986). In Ghana, the processing of *wagashie* is done mainly by women who purchase milk from Fulani herdsmen (Kees 1995; Omore et al. 2004). Due to the high moisture content, the product's shelf life is just 3 days, which artisanal producers attempt to extend by repeatedly dipping the curds in boiling water every day until sold. This gives the cheese a fibrous texture and results in loss of desired flavour (Gilmore et al. 1997; Omore 2004). Although generally not practised in West Africa, recent studies have shown that immersing the cheese in a 10% brine solution for 12 hours will prolong the shelf life and quality of *wagashie* for up to 14 days (Padmore 2001; Sunu-Atta 2001; Omore et al. 2004).

In Egypt and Sudan, pickled cheese is made using rennet as coagulant. It is known as *domiati* in Egypt and *gybna beyda* (white cheese) in Sudan (Osman 1987). Other minor cheeses include dried cheeses such as *aoules,* a sun dried cheese (87–92% dry matter) made by heat coagulation of sour buttermilk protein in Algeria. The curd is subsequently dried to form a flat cylinder, 2 cm thick, and 6–8 cm diameter. *Takammart,* another Algerian sun-dried cheese, is made from goat milk using crude rennet extract from kid stomachs. From Niger, *tchoukou* is a sun-dried cheese made by rennet coagulation (FAO 1990). These traditional products provide valuable avenues for milk preservation and value addition that can be used as stepping stones towards specialised small- and medium-scale milk processing by informal milk traders and women provided they have access to credit and improved technologies. The challenge is how to promote the commercial application of the technologies, identifying the size and growth of potential markets for the traditionally processed products and to what extent they can compete with imports of similar products. This will be a subject of an ASARECA-funded collaborative study between Sokoine University of Agriculture and Animal Diseases Research Institute (ADRI) in Tanzania, ILRI, the Kenya Agricultural Research Institute (KARI) and the Kenya Bureau of Standards in Kenya and the Ethiopian Agricultural Research Organization (EARO) in Ethiopia.

Improvements in milk handling hygiene and food safety

One of the major concerns of public health regulatory authorities regarding informal milk traders and small-scale milk processing is the risk of infection of consumers with zoonoses and other pathogens and the frequency of adulteration of milk with water. Studies done in Kenya and Tanzania show hygiene indicators among raw milk traders vary from acceptable levels to unacceptable levels of coliform counts, presence of *Brucella* antibodies and presence of drug residues and adulteration with added water (Table 4).

Table 4. Proportion of unacceptable milk samples from informal milk traders

Quality criteria	Proportion above acceptable limit (%)			Public health implications
	Kenya (SDP 2004)	Tanzania (Omore et al. 2004)	Ghana (Omore et al. 2004)	
Adulteration with added water	10	20–60	37	Farm–market chain critical control point. In conflict with public interest and regulators
Coliform counts	52	55–58	23–27	Inactivated by boiling, pasteurisation; indicates poor hygiene; recontamination of heated ready-to-eat products
Prevalence of antimicrobial drug residues	6	35–40	35	Farm level critical control point. Not removed by pasteurisation
Prevalence of *Brucella* antibodies	5	20–23	22–29	*B. abortus* destroyed by pasteurisation; may survive milk fermentation (pH >4.2)
Prevalence of *Mycobacterium bovis*	0	0	0	Inactivated by pasteurisation/boiling; survive milk fermentation (pH>4.2)
Mycobacteria other than tubercle bacilli	n.r.	10	Not investigated	Inactivated by pasteurisation/boiling, recontamination; pathogenesis in immunocompromised persons
Prevalence of haemorrhagic *E. coli* O157:H7	<1	0.24	<1	Inactivated by pasteurisation/boiling, recontamination

Generally the extent of informally sold milk samples adulterated with water was higher in Tanzania than in either Kenya or Ghana. High levels of antimicrobial residues and *Brucella* antibodies could be attributed to non-observance of withdrawal periods and bulking effect. The proportion of milk samples with unacceptable levels of coliforms is indicative of poor hygienic practices which include the use of plastic containers and non-cooling of milk. Introduction of metal containers and training market agents in better hygiene has been shown in Kenya to improve the proportion of milk meeting the set criteria for good microbiological quality (SDP 2004).

In Kenya, Tanzania and Uganda, small-scale processing has expanded in the last 10 years. Processing adds value to milk by reducing spoilage, increases the variety of products that meet specific consumer demand and enhances the safety aspects of milk and dairy products when good manufacturing practices (GMP) are used. In

Uganda, open pan boiling of milk has given way to batch pasteurisation in water jacketed vats (Balikowa 2003), ensuring both the hygiene and nutritional quality of the heated (pasteurised) milk if adequate measures are taken to avoid recontamination during packaging. Among the technologies that reduce contaminations are in-pouch pasteurisation of milk, which avoids post-pasteurisation contamination, and hot filling of pasteurised milk into plastic sachets. One small-scale dairy in Tanzania has been using these simple technologies and recording a shelf life of at least 10 days under cold storage which is standard for industrially pasteurised milk. The same plant produces fermented milk by inoculation of milk with mesophilic starter cultures followed by immediate filling and sealing in plastic sachets. Incubation takes place in an air conditioned room at 22°C and the resulting product has a shelf life of 20 days, which is comparable to similar products made by large-scale dairies using automatic filling machines (Driessen and Puhan 1988).

Fermentation of milk generally renders such milk safe for consumption, especially when combined with prior heating of the milk. While fermentation *per se* may reduce public health risks by killing off pathogens such as mycobacteria when sufficiently soured for at least 66 hours and attaining pH below 4.2 (Minja 1998), a significant proportion of naturally fermented in milk bars in Nairobi was found to be inadequately fermented to render it safe (Mutave et al. 2004) while 19% of the fermented milk samples had nor undergone any prior pasteurisation or boiling. Such products present risks of consumers being exposed to potential zoonoses and therefore measures need to be taken to educate both milk handlers and consumers on the inherent risks of inadequate fermentation or not boiling milk sufficiently to eliminate potential pathogens. This can be achieved through participatory market chain approaches whereby different chain actors, often with competing interests, can work together to find solutions for each other's problems. This can foster cooperation and co-innovation in the entire market chain for the benefit of all actors. For example, if consumers want better quality dairy products and are willing to pay for the added cost and processors want better quality raw milk and are willing to pay a higher price to producers, then farmers might benefit by investing in technologies that enable the production of better quality milk that satisfies the processors' demand for quality raw milk and consumers' demand for quality dairy products and regulatory authorities will have reasons to feel a *fait accompli*.

Conclusions

The technologies described can easily be adapted by informal milk traders and small-scale milk processors. Mostly lacking to support the adoption of these technologies is enough exposure, training, awareness creation and access to financial resources in the form of credit. Traditional technologies in particular can form the basis for development of products that meet the consumer preferences for flavour and taste, especially of fermented milk products. This should enable a stepwise transformation of the informal dairy sectors into small- and medium-scale enterprises that manufacture nutritious and safe dairy products. This can be achieved through participatory market chain approaches whereby different chain actors, often with competing interests, can work together to find solutions for mutual benefit.

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