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Review

Analysis of Food Safety and Security Challenges in Emerging African Food Producing Areas through a One Health Lens: The Dairy Chains in Mali

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ABSTRACT

Challenges posed by changes in livestock production in emerging food producing areas and demographic development and climate change require new approaches and responsibilities in the management of food chains. The increasingly recognized role of primary food producers requires the support of the scientific community to instruct effective approaches based on scientific data, tools, and expertise. Mali is an emerging food producing area, and this review covers (i) the dairy farming scenario and its environment, (ii) the role of dairy production in food security, including the greatly different animal rearing systems in the Sahel and tropical regions, (iii) risk management pillars as modern infrastructures, effective farmer organizations, and institutional systems to guarantee animal health and safety of products, and (iv) feasible interventions based on good practices and risk assessment at the farm level (e.g., sustainable use of fertilizers, feeds, veterinary drugs, and pesticides) to protect consumers from food safety hazards. Social innovation based on the empowerment of the primary food producers emerges as crucial for sustainable and safe food production. Sustainable policies should be supported by the mobilization of stakeholders of One Health, which is a science-based approach to linking human health and nutrition with the health and management of food producing animals and environmental safety. In the context of the complex, multifaceted scenario of Mali dairy production, this article presents how a cost-effective animal health and food safety scheme could be established in the dairy production chain. Because milk is a major commodity in this country, benefits could be derived in food security, public health, the resilience of the farming system, animal husbandry, and international trade.

Key words: Contaminants; Family farming; Nutrition security; Primary production; Risk assessment; Risk management

THE MALIAN SCENARIO

Mali is a large northern African (Sahel) country, with no access to sea. It has a population of 16.3 million in an area of 1.25 million km^2, with a density of 13.04 people per km^2. The annual average percentage increase in population is about 3% *(11)*. In 2006, the capital, Bamako, was estimated to be the fastest growing city with an urban community of 1.63 million people in Africa and the sixth fastest growing city in the world. About 80% of the labor force is engaged in agricultural activities, which include producing commodities, keeping livestock, and freshwater fishing. These activities provide 33% of gross domestic product ($2.97 billion of the estimated $9 billion in 2010) *(71)*. In particular, livestock production represents both a traditional resource and an economic sector that could be further developed for the growing domestic market and for export *(1)*. Mali borders seven countries (Algeria, Mauritania, Niger, Burkina Faso, Senegal, Guinea, and Cote d'Ivoire) and is a cross-road between the desert-like Sahel in the north (Sahara) and the tropical humid region in the south (central Africa); the Niger River marks the border between the two areas. Thus, Mali has a remarkable environmental and cultural diversity that has promoted exchange and conflict from historical times to the present.

The Malian agricultural system is vulnerable to drought, especially in the north, but is overall able to ensure food and nutrition security to the whole country. The main staples are cereals (millet, rice, sorghum, and maize), which are complemented by dairy products and to a lesser extent by pulses (cowpeas), starchy roots (sweet potatoes, yams, and cassava), fruits, and vegetables *(32)*. Mali has a low human development index (0.344, ranking 182 of 187 of the world's countries), a high gender inequality index (0.649), and a very low living standard or gross national income per capita ($853 as expressed in constant 2005 international dollars converted using purchasing power parity rates) *(65, 66)*. Only 67% of people in Mali have access to clean drinking water *(66, 67)*; however, considerable efforts have been devoted to natural systems for collecting and treating rain water to obtain potable water *(59)* and irrigation water.

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Ongoing global climate change is expected to result in widespread and unpredictable alterations of environmental conditions.

The purpose of this review is to describe and analyze the Malian dairy sector, to discuss requirements and suggestions for gradual modernization and innovation of the livestock sector, and to consider the role of primary food producers as key actors at the interface between environmental, animal, and human health.

Current international understanding of how the food and nutrition security challenge, including sustainable food safety awareness for protecting future generations *(42),* is embodied in the One Health perspective *(62)*. The One Health framework entrains a collaborative effort of multiple disciplines working locally, nationally, and globally to establish food production and consumption schemes based on concomitant protection of the environment, farm animals and plants, and humans. For proper implementation, the One Health approach must include the definition and transfer of risk management measures, such as the targeted, safe, and sustainable use of substances (fertilizers, feeds, veterinary drugs, and pesticides) based on risk assessment.

Dairy products: food and nutrition security factors. According to a widely used definition *(34),* food security is transnational and "exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." The food security pillars (availability, access, utilization, and stability) are analyzed in the following sections, recognizing that nutrition security exists when "food security is combined with sanitary environment, adequate health services, and proper care and feeding practices to ensure a healthy life for all household members" *(68)*.

Mali's livestock system: the north and the south. Livestock is an important source of income for Mali. The population of farm animals involved in milk production in Mali in 2007 was estimated at 13.593 million goats, 9.761 million sheep, 8.141 million cattle, 0.852 million camels, 30 million poultry, 0.8 million donkeys, 0.35 million horses, and 0.071 million pigs *(54)*.

The livestock systems and activities are very different between north and south Mali *(32)*. As reported by the Malian Ministere de l'Elevage et de La Peche *(54),* pasturing practices in the north are variable. Nomadic stock rearing (i.e., free movements of animals to find feed) occurs only in the Sahel regions (Tombouctou, Kidal, and Goa). Transhumant stock rearing (i.e., movement of people and herds from one grazing land to another during seasonal changes between fixed winter and summer pastures *(5)*) occurs in most of the country, including the Sahel, based on rainfall during the flooding season in the internal delta of the Niger River. During the rainy season, animals are divided into (i) *garti,* large transhumant herds controlled by a chief herdsman, (ii) *benti,* herds of milking cattle and young calves making a small transhumance close to the villages *(5),* and (iii) *dumti,* small dairy herds assuring a food supply to elderly, women, and children remaining in the village *(54)*. The livestock-dominated food supply system typical of most of northern Mali is found where irregular rainfall does not ensure good crop production but provides enough forage for animals. However, in most cases herds are not cared for properly, and their economic role is usually to provide meat and milk for domestic use and to serve as an investment. The self-sustained pasturing that occurs in the Sahel and bordering regions has been historically important but currently is becoming difficult because of the poor control of animal health and vulnerability to constant seasonal droughts or floods. The Sahelian subdesert area is considered vulnerable to food deficit crises because of natural resource degradation and desertification, which makes pasturing even more difficult. Thus, the previously sustainable practice of nomadic pastoralism is now part of a social, environmental, and economic crisis to which the solution is difficult to determine *(12, 25, 47, 48, 60)*.

A quite different situation occurs in the south of Mali, where farming systems prevail, with a more organized way of livestock management, marketing, and exploitation of meat and milk production. Here, the crop-dominated subsystem pivots on agriculture; some former herd owners have settled down to become farmers and practice a brief, short-distance transhumance. In most cases, livestock is purchased with the earnings from the crops and used as a support (work oxen) for production of cash crops (mainly cotton as a domestic and export commodity). The animals are given constant care and shelter and provide energy (dung) and food (milk); they are also sold for cash. Commercial production systems are specialized for producing milk and fattening stock. Farmers select the best dairy animals in their herd and improve their feed with cultivated forage, cotton cakes, molasses, treated straw, cotton seeds, and cotton concentrates. On some farms producing cotton, the improvement in feed can result in 3 to 5 liters of daily milk during the dry season when otherwise milk production would be almost zero. The milk is usually sold to small dairies in urban centers. Milk production becomes the dominant activity in urban and periurban livestock keeping, which helps to improve the livestock breeds. Peak daily milk production in the periurban area of Bamako is 20 liters *(32)*. In urban and periurban areas, large ruminants can be kept either in the household or in an open space near homes where different households can take care of the animals in turn or together.

Meat production is not as developed as milk production. The U.S. Agency for International Development *(69)* found that livestock fattening enterprises buy cattle or sheep from the north and feed them intensely to achieve weight gain so that animals can be resold at a higher price. Fattening is practiced in both periurban and rural areas.

The annual production of milk in Mali is estimated at 500,000,000 liters for all dairy species (cattle, sheep, goat, and camel) combined, corresponding to an average availability per capita per year of approximately 30.7 liters *(54)*. However, existing infrastructure and practices are inadequate to respond to the challenges of demographic pressure and socioeconomic development. In 1985, the Malian

government adopted a policy aimed at promoting the local milk sector, increasing the production and consumption of local milk, and reducing the milk and dairy product imports with technical support from the Food and Agriculture Organization of the United Nations (FAO). However, despite this policy, milk production is still not sufficient to meet the nation's demand, according to the 2008 estimate by the Malian Ministere de L'Elevage et de La Peche *(54)*. Mali imports milk powder to make reconstituted milk, spending around 10 to 15 billion CFA francs (approximately US$1.9 to US$2.8 million) each year or approximately US$0.15 per person *(31)*. The overall food imports in Mali were 15% in 2000 and 14% in 2012. Food export was estimated 4% in 2000, after which the situation improved significantly, reaching 20% in 2012. This increase is associated with the increase in domestic food production; the food production index increased from 72.41 in 2000 to a more than double 153.77 in 2013, according to world development indicators.

Milk is consumed daily in small amounts both as a drink and as an ingredient of local dishes *(45)*. The average figure of 50 liters per year per person provides a mean daily intake of 0.135 liter. Major variations are expected to occur among the diverse sectors of Malian society, e.g., higher figures are expected in the Sahel. However, no regional data on milk consumption are available.

In 2008 the Ministere de L'Elevage et de La Peche *(54)* reported that 98% of domestic milk production was provided by traditional (family) farms; the remaining 2% was provided by semi-intensive periurban farms. In rural areas, raw milk collected at the family farm can be used several ways: (i) the surplus can be sold directly in markets and collection centers, (ii) milk can be curdled and then sold in markets, and (iii) milk can be boiled and sold in urban areas, and ghee can be made from the curdled milk. Several typical Malian dairy products can be found. Natural curdled milk is a thick milk curd with an acidic taste. It differs from yogurt because it is a product of spontaneous curdling without specific cultures or pasteurization (wild ferment). Ghee is liquid butter, *féné* is a mixture of cream and fermented whole milk, and *takkamart* is a very dry cheese made by curdling cow's or goat's milk with a fragment of dried goat stomach. In general, within the traditional family farm women prepare feed, clean sheds, look after the small ruminants such as sheep and goats, and prepare dairy products while men collect fodder and supervise grazing and milking of larger animals *(18)*.

In urban areas, households transform imported milk powder into liquid milk because fresh milk is difficult to obtain from distant production centers. Simple equipment is used to pasteurize and ferment the liquid milk with minimum packaging. Mini dairy plants with capacities of 1,000 liters per day are located in the cities such as Koutiala, Fana, Sikasso, San, and Niono. They use local milk to make sweetened curds, yoghurts, curdled milk, and double cream. Industrial milk processing plants are used to reconstitute imported milk powder into milk for drinking with a capacity of approximately 20,000 liters per day. However, very little locally produced raw milk makes its way to the industrialized plants *(54)*.

ACTORS OF RISK MANAGEMENT MEASURES

Malian agriculture is mostly based on traditional, small family-operated farms, which may not be able to cope with increasing demand due to demographic pressure, environmental challenges, or the requirements for making products suitable for export. Because of a recent persistent drought situation and the resulting scarcity of feed, water, and grazing land, Mali is struggling to keep its livestock for domestic use alive; resources are too scare to raise livestock for export *(44)*. Because of significant rural poverty, Malian households continue to face food difficulties while the country has experienced rapid urbanization in recent years *(50)*.

In 2008 the Malian Ministere de L'Elevage et de La Peche *(54)* reported that Malian farmer organizations were very diverse and insufficient to democratically represent farmer interests in consultations with the government and its agency for the improvement and development in water and land management (Office du Niger) *(27)*.

The National Federation of Milk Producers of Mali (FENALAIT) is the major producer of milk and organizes the dairy industry. The Billital Maroobe Network (BMN) is the official voice for pastoralists in the area including Sahel and the regions around the Niger River. This network brings together associations from various countries (Benin, Burkina Faso, Mali, Mauritania, Niger, northern Nigeria, and Senegal) and has over 180,000 members (herd owners and agropastoralist groups). The Malian BMN membership is made up of the Amadane/Tassaght with 4,600 pastoralist members. The BMN enables pastoralist groups to share knowledge, experiences, and up-to-date information and informs them about their rights. It also advocates on the behalf of pastoralists to ensure that their needs are taken into account in national and regional policy-making. This advocacy is a major long-term step in tackling the lack of organization and limited political influence that currently keep pastoral communities in poverty; it also might provide guidance to nomadic communities *(44)*. Formalized and well-functioning farmers' organizations, such as those in Cinzana and the wider Ségou region in Mali, are a recent phenomenon stimulated by the need for strong collective organizations to deal with harsh price offers from traders *(21)*.

Other successful approaches to representation of smallholders' interests are (i) the Conseil National de Concertation et de Coopération des Ruraux (CNCR) in Senegal and Mali, (ii) Via Campesina 120, which represents the interests of landless people and is active in 69 countries from Asia, Africa, Europe, and the Americas, and (iii) Réseau des Organisations Paysannes et de Producteurs Agricoles (ROPPA) in West Africa *(72)*. Nevertheless, Doumbia et al. *(27)* criticized the initiatives started by many organizations, including the Agricultural Chambers, ROPPA, and the World Bank Programme d'Appui aux Services Agricoles et aux Organisations Paysannes, because these initiatives appear to have little effect on establishment of farmer-friendly market arrangements. Currently, the Sahelian networks pay little or no attention to possible and badly

needed actions to improve the quality and safety of dairy activities.

Although small and medium-size farm enterprises are attracting attention in Mali and Europe *(56),* land grabbing in Mali is threatening small farmers unable to own the land they work on *(58)*; instead, land is sold to foreign investors, and local people end up working for these industrial agriculture producers *(46)*. Land grabbing is a special hazard for the development of family farming. Land tenure represents a social and economic problem in Mali and a food security issue with far-reaching implications *(58),* because family farms are increasingly recognized as crucial for achieving sustainable food and nutrition security *(33)*. Social class can be a barrier to obtaining land; aspirations of young households and landless individuals for land ownership also cause disputes, leading to disruption of the traditional extended family and fragmentation of holdings, and new forms of basal social organization develop slowly *(19)*. Because people lack security about their land tenure, long-term domestic investment is difficult. People usually use the land for subsistence farming or production for immediate returns, and little surplus is available from most very small farms. Although they might also increase capital flow, large foreign land acquisitions are expected to negatively impact Mali's food security and the survival of small-scale farming *(58)*.

National food safety policies: top-down food safety. The establishment in 2004 of a ministry specifically devoted to subsectors of livestock and fishing *(54)* is an example of the political will to protect and augment these two subsectors. The guidelines of the National Policy of Livestock Development are issued to assist efforts to increase production and marketing while preserving natural resources.

In 2002, Mali adopted a Food Safety National Policy and Institutional Framework. A National Food Safety Agency, the Agence Nationale pour la Sécurité Sanitaire des Aliments (ANSSA), was established on December 2003 with the task of coordinating all food safety actions in Mali. A National Food Safety Council was also created on March 2004 *(17)*.

The Malian food safety system is based on food legislations (Projet de Loi portant Regolementation de controle de la qualite et du conditionnement, Decret d'application de la meme loi 2002) *(17)*. The Office du Niger is a semiautonomous Malian government agency whose tasks, defined in 1994 and 1996, are the improvement and development in water and land management in the Central Delta of the Niger River. Although regulations exist, resources are not sufficient to enforce them or to support education of farmers and consumers. This problem is made more difficult by the low level of education among the general population, especially women. Overall, the existing laws are not very effective for improving food, including milk, safety in Mali.

Veterinary services: bottom-up food safety. The general lack and poor quality of veterinary services may be a significant problem in developing countries. The FAO *(31)* determined that the livestock sector is constrained by poor support from veterinary services due to insufficient human and physical resources; this issue contributes to low milk quality as a consequence of the poor health of milk-producing animals.

The ANSSA has audited various dairy units in Mali and found a lack of hygiene in milk processing, potential risks related to the presence of residues of veterinary drugs in milk, and poor quality of cattle feed *(15)*. Overall, the audit revealed that primary production is as critical to improving milk quality and safety in Mali as are the later phases of milk storage and processing. Implementation of veterinary public health education *(64)* and actions *(53)* in Mali could be achieved with technology. The networking capabilities of communication technologies (e.g., mobile phones and satellites) could support the development and organization of veterinary services in large and underpopulated areas. For instance, satellite-supported geomapping of farming areas could help farmers select grazing areas, reducing the impact of drought, and alert farmers to contaminated sites that should be avoided by cattle herds. In a country such as Mali, an important and often overlooked issue is the nutritional quality and safety of pastures and feedstuffs. Feed and food safety regulations must be enforced, but a more updated and cost-effective management framework is also needed that, in addition to regulations and official control of marketed products, gives due attention to safe primary production systems centered on the modern perspective of One Health *(53)*.

INTERVENTIONS TO SUPPORT FOOD SECURITY AND THE BENEFIT-TO-RISK RATIO

Food safety is part of the concept of food and nutrition security. Thus actions to achieve sufficient, safe, and nutritious food have to be integrated. The scientific benefit-to-risk assessment aims at the comprehensive and balanced comparative assessment of beneficial and adverse effects on health caused by the same food (or food production process) for subsequent action by the decision makers, who will also consider economic, societal, and ethical aspects.

For instance, a nutrition-rich food such as milk is highly likely to contain contaminants and must be protected; however, interventions to mitigate hazards must be assessed for their possible undesirable effects, e.g., toxicologically relevant residues. For example, the mass use of antibiotics to combat or prevent mastitis could lead to antibiotic residues in milk and, more important, to the environmental spread of antibiotic-resistant bacterial strains *(73)*.

On more advanced dairy farms using composite feeds, appropriate feed storage (temperature, relative humidity, and pH) is paramount to prevent fungal growth *(20)* and related contamination by mycotoxins, including aflatoxin. Some widespread feed materials derived from grains and nuts are particularly susceptible to fungal growth and mycotoxin production. Ruminants are generally less vulnerable to mycotoxic effects than are monogastric mammals, but a few highly toxic mycotoxins such as aflatoxin M_1 (a metabolite of aflatoxin B_1 that is a potent carcinogen and hepatotox-

icant) and the nephrotoxicant ochratoxin A may be transferred to milk. The treatment of contaminated feeds with mycotoxin-binding agents may be useful to protect animal health and avoid milk contamination by the carcinogenic aflatoxin M_1 metabolite. However, mycotoxin binders may impact animal health, e.g., by interfering with the absorption of nutrients or medications *(10)*.

Feeds may also be supplemented with nutrients (vitamins and/or minerals) to protect animal health and the quality of animal products; however, some nutrients are toxic in high concentrations, and when added at excess concentrations to feeds, their presence in milk may raise concerns for consumer safety, as noted for excess iodine supplementation *(29)*.

The use of biocides to clean and disinfect milking machines also may lead to unwanted residues in milk *(22)*.

All the above practices are justified by the need to solve immediate problems related to animal disease or poor hygiene conditions. However, the use of these practices should be knowledgeable and targeted, otherwise serious problems may arise such as antibiotic resistance or the unsuitability of products for consumption and export due to residues. Possible undesirable effects should be recognized and their occurrence should be prevented or minimized. Most important, no single action can replace good animal husbandry by informed and responsible farmers.

The FAO *(35)* has investigated ways to improve the availability of milk in Mali by adding appropriate amounts of thiocyanate and hydrogen peroxide to reactivate lactoperoxidase in raw milk and thus inhibit bacterial growth. This treatment allows milk to be kept at ambient temperature without spoiling, which means that milk can be transported to collection centers to be processed without major spoilage losses. However, concerns exist about chemical breakdown products such as cyanide, which is harmful when ingested in high doses over a short period of time, and a safe long-term consumption level has not been defined. At the 31st session of the Joint FAO/WHO Food Standards Programme Conference organized in 2008 by the Codex Alimentarius Commission *(16),* the authors stated that milk treated with the lactoperoxidase system should not be traded in international markets. This statement suggests that this approach is a possible solution where food and nutrition security problems exist but may be inadequate for complying with international food safety standards. Both the factsheet of International Dairy Federation *(49)* and the Codex Alimentarius Commission stressed that the lactoperoxidase system should not be used as an alternative to refrigeration but only in situations where cooling of the milk is not possible.

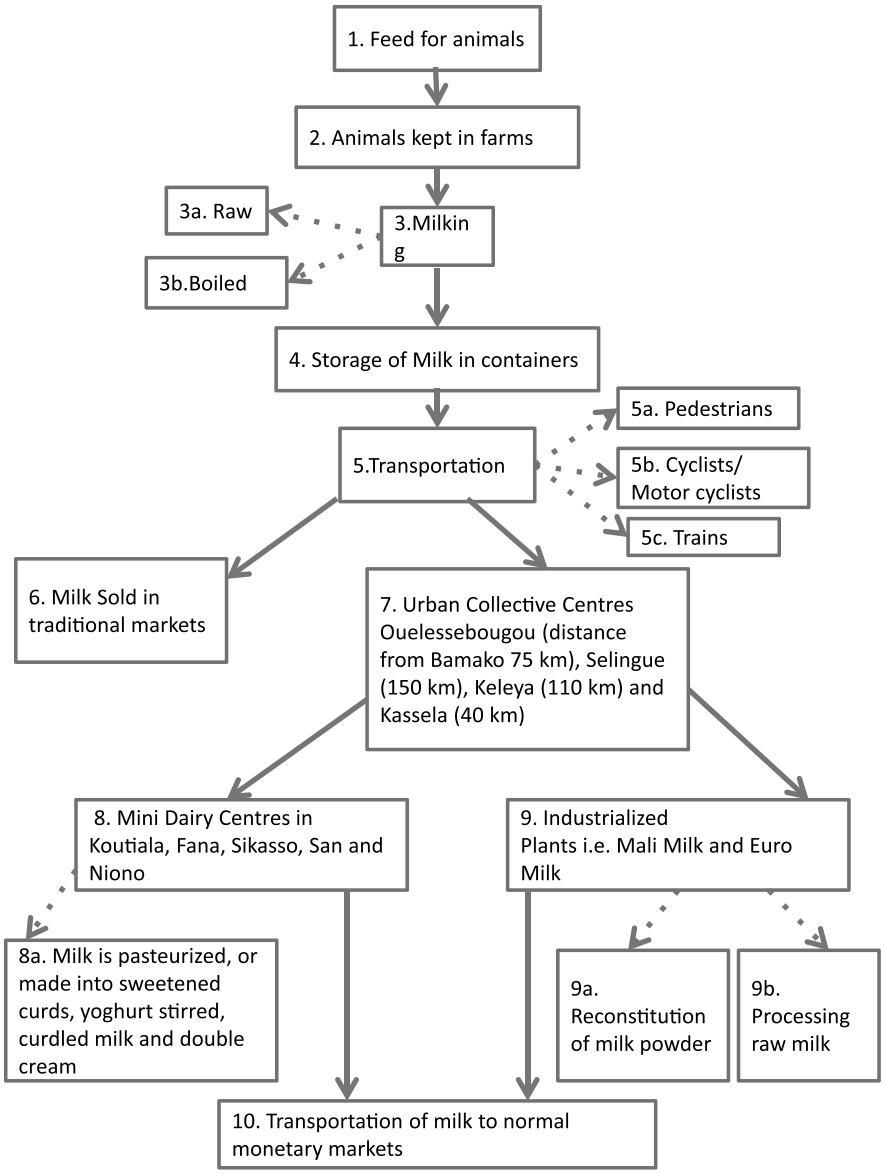
Other risk-benefit issues may involve the indirect impact on the food chain, including the dairy chain. African countries prevent the transmission of malaria by indoor spraying of DDT *(61)*. However, the persistent lipophilic DDT bioaccumulates in the lipid fraction of animal tissues and can be substantially excreted in milk. DDT and its metabolites are persistent pollutants, and these hormonally active substances can harm people, especially pregnant women, fetuses, and small children *(9)*. Thus, DDT spraying procedures and formulations must be modulated (e.g., by removal of the *o,p*-DDT part of the DDT mixture, which is persistent but devoid of insecticidal properties) to achieve a better risk-benefit balance *(61)*.

The use of genetically modified (GM) crops as animal feeds may seem to be an attractive solution for developing countries in terms of higher production rates per hectare, reduced need for mechanical soil treatments, and better resistance to the effects of climate change, all resulting in less dependence on agricultural imports. The safety of GM organisms (GMOs) is a controversial and complex issue that must be tackled with specific instruments. The absence of evidence of higher risks of GM technologies versus conventional breeding technologies has been argued in the scientific community *(28),* but a more sound requirement of clear (proven) absence of evidence of risk is definitely required. A general approval or condemnation of GMOs would be scientifically unacceptable. Evaluation criteria must be specific to each GMO under specific use conditions and scenarios. When evaluating GMOs as feed ingredients rather than as risks for consumers, priority should be given to possible impacts on the agricultural environment (e.g., GM crops might require higher amounts of pesticides over the long term *(4)*) and the agricultural system (e.g., in terms of farm management self-monitoring). Thus, according to some criticisms, a diffusion of GM feed crops in developing countries, far from being a solution, might reduce food security in the long run *(13)*.

Sustainable safety in productions: the One Health key. Stress factors among farm animals, such as poor husbandry (e.g., inadequate housing, bedding, living space, equipment, nutrition, feed storage and transport), can lead to increased susceptibility to disease and can therefore affect food security and food safety by increasing exposure to biological hazards (e.g., *Salmonella* infection), which are mainly short-term health risks, and chemical contaminants, which may pose long-term health risks *(37)*. A biomonitoring study of people from Western and Central African countries revealed that people from low-income African countries had significantly higher levels of persistent organochlorine compounds, such as DDT-like pesticides and polychlorinated biphenyls, than those from high-income countries *(52)*. Diet is by far the main source of such pollutants, with milk and dairy products featuring prominently. These pollutants may be transferred from the mother's body burden to the fetus and the suckling newborn. Therefore, milk is a main issue of the sustainable food safety concept, where the food is especially considered for its impact (favorable or adverse) on the health of the next generation *(42)*.

Predictive farm management factors impacting food safety have already been assessed with regard to zoonotic hazards *(51)*. Changes in temperature and humidity may predict higher risk of migration of zoonosis, e.g., parasitic insects from other regions. For farmers willing to intensify their livestock operations, the increased density of animals may lead to more rapid dissemination of pathogens and to horizontal transfer of virulence and antimicrobial resistance. An increase in disease pressure can also lead to increased

FIGURE 1. *Milk chain in urban/periurban Malian areas (south) (7, 54, 70).*



use of antibiotics. Wildlife habitat reduction increases wildlife contact with domestic animals, such as free-ranging grazing ruminants and, consequently, the potential carryover of zoonoses in agricultural areas and an increased exposure to pathogen vectors. If animal trade increases without measures in place to ensure sufficient hygienic conditions, contact between live animals of various species from various places may facilitate transfer of disease, as observed for avian influenza.

The following section includes a discussion of possible approaches for identifying and managing exposure to toxicants in dairy products from an emerging African food producing area, such as Mali.

Points of particular attention for exposure to toxicants from farm dairy production. Figure 1 depicts how farmers and herders manage milk production in the urban and periurban areas of southern Mali. Points of particular attention for urban and periurban farmers are water sources, feed, animal stress, milking, storage, and transport. The environment where animals are kept is critical, e.g., to reduce the incidence of udder infections or the carryover of persistent environmental pollutants through watering and grazing. The farm environment itself may be a source of contaminants. Possible interventions for dealing with microbiological hazards in water sources includes treatment with sodium hypochlorite *(30),* and chemical hazards can be monitored by checking the proximity of pastures to chemical emissions (e.g., waste incineration sites, traffic areas, and crop fields sprayed with pesticides) *(23)*. Major insecticide classes such organophosphates, carbamates, and pyrethroids do not accumulate in the body like DDT and other organochlorines but may nevertheless be excreted via the milk. All of these compounds are neurotoxic, and even when feed residues are low they may affect animal health through contaminated pastures and farm environment. For instance, an increase of residues in milk or of biomarkers of exposure or effect in animals (e.g., reduced acetylcholinesterase in red blood cells caused by exposure to organophosphates and carbamates *(40)*) would be related to excessive or improperly managed treatments of outdoor fields or of the farm animals themselves (e.g., by spraying or

dipping for parasites). Many pesticides that have been banned or severely restricted in industrialized countries are still marketed and used in developing countries, especially in Africa, that have weak import controls, have inadequate methods of pesticide storage and stock management, and lack of proper training in pesticide use.

Periurban pastures are more likely to be affected by human-caused air pollution. Particularly important pollutants are the dioxins, which are by-products from incineration of wastes and have bioaccumulation potential and high chronic toxicity. Dioxins are among the milk pollutants of top concern also because of their recognized ability for cumulative effects through the common mechanism of interaction with the aryl hydrocarbon receptor *(2)*. The fallout of polluted air particulates on periurban farms and pastures may expose ruminants to lead, another major chronic toxin. Lead is stored in the skeleton, where it can be mobilized and excreted in milk *(43, 63)*. Toxic metals from the leaching of old paints, building materials, barns, and fences made of unsafe material, from material stored indoors (e.g., car waste materials used as containers), and from airborne contaminants from vehicular traffic should also be considered. These toxic metals include cadmium, lead, and mixtures of other less known chemical elements such as those in the platinum group *(41)*.

The generation of electronic waste and its inappropriate management are a more recent source of persistent pollutants, such as dioxins, in several African countries *(40)*. Currently, problems with this kind of waste have not been reported in Mali, but the rapidly growing Bamako metropolitan area is likely to be affected by electronic waste production and pollution in the near future.

A reasonably clean and well-kept farm environment minimizes the presence of such pollutants as dioxins, polychlorinated biphenyls, pesticides, and metals. The proximity of the farm and/or pastures to sites where combustion of electronic waste occurs is an important factor in exposure to fat-soluble contaminants such as dioxins *(40)*. Fires containing plastic waste give off dioxins and dioxin-like compounds and should not be burned in the farm area.

Water sources on the farm are crucial for providing water for animals and for milk handling, storage, and transport. Water is required for basic hygiene practices such as hand washing and cleaning and disinfection of containers, utensils, tools, and premises *(6, 7)*. However, efforts to improve hygiene and milk shelf life might lead to excessive use of biocides (e.g., insecticides) and disinfectants (e.g., iodinated compounds, quaternary ammonium salts, and formaldehyde) and thus unwanted residues in milk from use of these chemicals during milking and milk collection, storage, and transportation (e.g., sanitation of trucks).

Milking is a key point in the adoption of good agricultural practices. Because mastitis is the most important hazard for milk production, early identification and management of subclinical mastitis at the end of lactation would help control udder infections in animals. The need to combat the hazards posed by mastitis and to improve milk production may lead farmers to excessive and/or ill-advised use of antibiotics, either as drugs for treatment or as feed additives for prevention. This use can result in unwanted residues of antibiotics or other veterinary drugs in milk, increasing selective pressure for antibiotic-resistant bacterial strains, which is a major problem for human and animals health worldwide. The importance of sound use of antibiotics on the farm should not be overlooked. Good farm practices may reduce the need for therapeutic treatments, which should be performed under the care of a veterinarian to provide accurate doses and determine necessary withdrawal periods to prevent residues from contaminating the milk. Antibiotic residues in animal-derived foods have been reported in many African countries, and World Health Organization maximum residue levels are exceeded in many cases *(24)*. Tetracyclines are the most commonly prescribed antibiotics in Africa; they represent 41% of all antibiotic residues, followed by β-lactams at 18% *(24)*. Critical points include enforcing legislation on the use of antibiotics on the farm and monitoring antibiotic withdrawal periods before the release of milk for human consumption *(24)*.

The time elapsed between milking and milk sale to consumers should be minimal. Prevention of milk spoilage during the shelf life requires proper equipment to ensure adequate cold temperature storage and transport to processing centers or markets. Milk collected in the urban collection centers (Ouelessebougou, Selingue, Keleya, and Kassela) becomes part of the industrial food chain (Fig. 1). The consumption of boiled milk has been considered a major food safety problem in Mali because of poor hand washing hygiene, inadequate container cleaning and disinfection, and the consequent increased risk of foodborne infection *(8, 45)*. Some milk is industrially pasteurized, and some milk is boiled on an open fire in small collection centers or in the home. Both boiled and pasteurized milk sold in open markets is not always handled properly following standard safety procedures, and recontamination often occurs during transportation and storage *(6)*.

Because of the lack of refrigerators in most Malian households, ultrahigh-temperature treatment (UHT) has been suggested. UHT milk can be kept without refrigeration for up to 9 months in sealed containers, thus making milk obtained from animals in the rainy season available to consumers in the dry season *(54)*. Properly applied UHT preserves the water-soluble vitamins in milk much better than does conventional boiling *(3)*. Proper equipment is crucial, because the pasteurization process and the containers used for final delivery of milk to consumers should ensure the safety of the final product.

The changing global climate may have important effects on livestock production *(55)* in terms of the quality of water at animal watering sites and changes in the abundance of geonutrients and their availability in soils. Risks from mycotoxins in feeds, either from raw ingredients in the field or during storage, may increase. Changes in pest populations and associated changes in agricultural practices may increase the exposure of animals to pesticides, mainly insecticides, and fungicides, with possible animal toxicity and residues in milk. Carcinogenic polycyclic aromatic hydrocarbons are combustion by-products, and changes in long-range atmo-

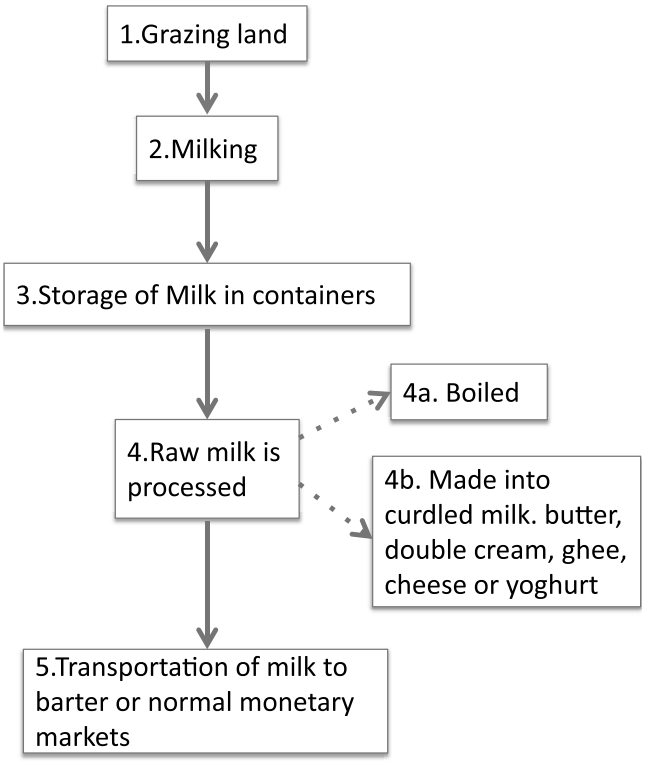


FIGURE 2. *Milk chain in pastured Malian areas (north) (7, 54, 70).*

spheric transport can result in deposition into the environment, including pastures. Herds also may be more vulnerable to mastitis due to the burden of pathogenic bacteria brought by a more frequent exposure to extreme weather conditions.

Attempts to enhance animal productivity may lead to the use of animal feeds that have undesired consequences. The recycling of animal products into animal feeds may allow bioaccumulating chemical contaminants to further accumulate, and infective agents that are not destroyed by processing may multiply through the animal populations being fed these products. For example, recycling of food processing waste into animal feed may result in unintentional concentration of undesirable components such as plant toxins, solvents, and processing by-products (e.g., polycyclic aromatic hydrocarbons) *(51)*.

Mali is a highly diverse area, and the pastoral environment is very different from the closed farm environment. Figure 2 depicts how nomadic herders manage milk production in the pastured areas of northern Mali. Particular points of attention in nomadic rearing of livestock are grazing land (including watering sources and pastures), milking, and milk storage, transport, and processing (including boiling). Pastures in inland areas are generally not expected to have severe chemical contamination problems. Although herders may have practical knowledge of plants that can affect animal health, no systematic toxicological appraisal of plants present in Malian pastures is available for assessment of possible carryover in milk. Whereas good practices should be applied at milking to avoid udder infections, the current, mostly subsistence nature of dairy production makes milk storage, transport, and boiling relatively less important.

DISCUSSION AND CONCLUSIONS

Sustainable development must include social innovation and education. With the Libreville Declaration on Health and Environment in Africa in 2008, African ministers responsible for health and the environment committed to taking the required measures to stimulate the necessary policy, institutional, and investment changes to optimize synergistic approaches to health, environment, and other factors and to implementing previous conventions and declarations related to health and the environment such as the Stockholm Convention, the Bamako Convention on Hazardous Waste, the Millennium Declaration, and the subsequent Millennium Development Goals *(74)*.

The role of primary producers is recognized globally as crucial for meeting food and nutrition security requirements. Empowerment of primary producers is also needed to cope with international food safety standards *(57)* that have been so often viewed in developing countries as trade obstacles and barriers rather than as tools to protect human health. In addition to national and international policy recommendations aimed at improving productivity, the protection of food safety must be incorporated into the sub-Saharan dairy sectors to prevent from adverse long-term health consequences. Risk assessment–oriented sets of priority regulations and resource management objectives require proactive interactions between risk assessors, risk managers, and other interested parties. The International Year of Family Farming *(33)* was launched by the United Nations to raise the profile of family farming and smallholder farming by focusing world attention on its significant role in food security, the agricultural environment, development, and the economy.

In Mali, many studies have been conducted in recent years without producing a consensus strategy for realistic mid- and long-range visions of farming. A discussion of rural development may allow the Malian ministerial department in charge of livestock to interact with stakeholders and technical and financial institutions. This discussion could focus on improving local livestock breeds and ensuring that local products meet international standards through interventions involving public, private, and volunteer sectors (local government and international organizations, national and regional agencies, civil society organizations, legal and insurance companies, and research bodies). The following issues also are critical for strengthening Malian food security.

(i) Professional expertise should be available for training farmer organizations to negotiate with the rest of the value/food chain and for teaching new agricultural techniques. Such expertise should encompass governance, economic modelling, policy impact assessment, and scientific and technological advances. Dogliotti et al. *(26)* reported one example in which by redesigning farm planning and evaluation, 13 of 14 farms experienced a 50% increase in per capita family income and 11 were able

to increase the organic carbon content of their soils, with a 50% reduction in estimated erosion rates in vegetable fields.

(ii) Besides requirements on infrastructures, e.g., facilities for milk treatment equipment and refrigeration, community-based prevention in public health also depends on the empowerment of dairy operators and their use of good practices and animal-based monitoring tools *(40)*. Empowerment could integrate formal training and empirical farmer knowledge, through both town meeting and farmer-to-farmer word of mouth and teaching. Sharing experiences among primary producers encourages community resilience and social relations among breeders. Networking of dairy farmers would also support tracking of wide-scale data and georeferencing of remote areas.

(iii) In the frame of the long-lasting African battle for clean drinking water and safe waste disposal, the farmer network may be exploited as a sentinel for the detection of adverse events in the health of agricultural plants and animals and the safety of new products used in agriculture, including animal farming. From the European experience, a working surveillance system using farmer and/or producer associations implies a set of requirements: the development of unambiguous indicators and adverse event definitions, the implementation of additional data acquisition tools, and the establishment of data management structures *(56)*. Adaptation of such requirements in the African context should be investigated.

The increased presence of scientists in African societies should foster the science-society dialogue. Social media platforms rely on high levels of interaction and user-generated context shared through established and evolving social networks. These networks have modified the way that people access information, including health information *(14)*. The impressive increase in the use of social networks in African societies might be viewed as a novel evolution of the traditional oral transmission of culture. Social tools will help breeders make their voices heard about their present needs and future aspirations. For example, the FAO and the World Association of Community Radio Broadcasters have joined forces to launch an awareness campaign on the contribution of family farming to food security and rural development during the International Year of Family Farming *(33)*. In addition, open knowledge tools *(36, 38)* can support international cooperation among African scientific communities. The growing potential of African science can support the empowerment of the farming system. New prevention challenges in global and local health governance pivot on the role of primary food producers for control of zoonoses, reduction of food losses, and emergency preparedness *(39)*.

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