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Review

Cattle crossbreeding for sustainable milk production in the tropics

Richard Osei-Amponsah*, Ebenezer Kwaku Asem and Frederick Yeboah Obese

Department of Animal Science, School of Agriculture, College of Basic and Applied Sciences, University of Ghana, Legon, Ghana.

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Crossbreeding has been used to improve milk production performance of local cattle in the tropics. Crossbreeding exploits additive and non-additive allele gene effects leading to improvements in lactation length, decrease in calving interval, higher milk yields and early age of calving of cows and potentially increasing producer incomes. Varying levels of success have been reported for various crossbreeding programmes and the objective of the current review was to document the key challenges, best practices, lessons learnt and to propose sustainable interventions for future initiatives. Although crossbreeding has had some impacts on smallholder dairy production in the tropics, a number of bottlenecks affect its smooth implementation including inadequate funding, inappropriate policies, low participation of farmers and genotype and environment mismatches. The availability of large base of adapted local cattle genetic resources, innovative state of the art breeding technologies and goodwill of governments to make favourable policies and increase budgetary allocations for the livestock sector offer some prospects for crossbreeding for a sustainable dairy industry. Provision of the required infrastructure for improved management of crossbred dairy cattle including feeding and health care, access to markets, training of stakeholders, a well-trained and motivated local extension service personnel are recommended to help achieve this objective.

Key words: Artificial insemination, genotype-environment interaction, local breeds.

INTRODUCTION

The African Union Inter Bureau for Animal Resources (AUIBAR) in its Livestock Development Strategy for Africa (LiDeSA) 2015-2030 projects that per capita annual consumption of livestock products in Africa will increase 2 to 8-fold in the next two decades (AUIBAR, 2016). Already, total consumption of milk in developing countries has been projected to increase from 164 million metric tons in 1993 to 391 million metric tons this year (2020): a 138% increase while the expected increase in per capita consumption will be from 38 to 62 kg/person due to population increase, income growth and urbanization (Delgado, 2005; FAO, 2015; FAO, 2012; AUIBAR, 2019). Milk and dairy foods provide important nutrients such as calcium, magnesium and vitamin D that are beneficial to human life (Givens, 2018). With an expected increase in human population estimated at 100% for Africa by 2050 (UNDP, 2015), food insecurity will be a major problem unless food production is increased (Garcia et al., 2020). The local milk industry has the potential to help alleviate malnutrition among

*Corresponding author. E-mail: ROsei-Amponsah@ug.edu.gh. Tel: +233208637575.

vulnerable groups through optimized production, processing and marketing channels (Parry-Hanson Kunadu et al., 2019). Low milk production in most tropical countries is due mainly to the use of local cattle breeds (FAO, 2010) which have not been selected for high milk production. There is a ten times difference in milk output per cow, from approximately 500 kg per annum in Africa and India to over 5000 kg in North America and Europe. Consequently, production to a higher level to meet the increasing demand of livestock products is limited using local cattle breeds motivating smallholder farmers to keep larger herds of cattle to produce higher amounts of milk (Thornton, 2010; FAO, 2010). At the same time, there is the major challenge of pasture unavailability to feed such large herds (FAO, 2013).

Although tropical cattle breeds are not genetically advantaged in terms of milk production, there is ample evidence of their adaptation and resistance to most endemic diseases and harsh climatic conditions. Therefore, to ensure an improvement in their sustainable productivity and also improving fitness characteristics to cope with the production environment strategic crossbreeding has been undertaken (Aboagye, 2014; Kebede et al., 2018) in many parts of sub-Saharan Africa. Crossbreeding exploits additive and non-additive allele gene effects leading to improvements in lactation length, decrease in calving interval, higher milk yield and early age of calving of cows and thus increase producer income. Crossbreeding has thus been employed as a tool for increased milk production in many countries in the tropics to produce crossbreds which are both adaptive to the environment and more productive than local breeds (Aboagye, 2014; Ojango et al., 2017; Kebede et al., 2018). Daily milk production has on the average been reported to be about 1.9 L in an indigenous tropical cow and 5.9 L in crossbred cows with income level from milk yields of crossbred cows is 3.2 times higher than the indigenous cows (Quddus, 2017). Increase in milk yield also improves family nutrition and provides extra income to farmers (Manirakiza et al., 2017) thereby improving livelihoods. After many years of utilizing crossbreeding in this manner, it is important to review its impact on dairy cattle crossbreeding in the tropics. This will enable an objective assessment of its impact on milk production, dilution of local cattle genetic resources, available infrastructure and also indicate the role of stakeholders in helping to improve on dairy cattle production. The objective of this review therefore was to document the experiences, challenges, key lessons learnt and the best practices of smallholder dairy cattle crossbreeding as a tool for sustainable milk production and make appropriate recommendations to improve on future initiatives.

EXPERIENCES FROM DAIRY CATTLE CROSSBREEDING

Tropical dairy cattle are descendants of the Zebu cattle and well adapted to the tropics and tolerant to high temperatures and heat stress, partial resistance to diseases and pests such as ticks as well as their low nutritional requirements (Cunningham and Syrstad, 1987; Thornton, 2010; Aboagye, 2014; Osei-Amponsah et al., 2019). However, their genetic potential for high milk production is poorly developed (FAO, 2010) usually not letting down milk unless stimulated by sucking of the calf (FAO, 2013). On the other hand, exotic breeds of the temperate region have higher genetic potential for milk production. This provides the basis of crossbreeding to improve upon the tropical indigenous dairy cattle breeds for more milk yield. Crossbreeding combines the complimentary genetic and phenotypic characteristics of the adaptive potential of both *Bos indicus* of tropical regions and *Bos taurus* cattle breeds of temperate regions and increases heterozygosity and genetic variation (Aboagye, 2014). Many benefits such as increase in milk production, long lactation interval, and early calving age have all been some of the positive outcomes of crossbreeding. Furthermore, crossbreeding encourages involvement of NGOs in breeding programs to provide AI services, governments willingness in drafting policies that aids breeding programs and increase in diversity genetic resources of national population.

Consequently the low productivity of tropical cattle has made crossbreeding a viable option to improving their productivity to ensure profit (Aboagye, 2014; Roschinsky et al., 2015; Ojango et al., 2017). Crossbred cows are more economical and provide higher yield than the indigenous cows, and inclusion of a few crossbred cows can increase the income of a dairy entrepreneur and provide gainful employment of its family labour (Islam et al., 2008; Kebede et al., 2018). Consequently, crossbreeding has made many impacts on farmers and changed their management of pure-bred dairy cows. In many countries including India, crossbreeding of non-descript zebu cows with semen of exotic dairy cattle breeds has resulted in enhancing milk production by 5 to 8 times to that of non-descript cows, reducing age at first calving and shortening calving intervals in first generation crossbred progenies (Singh, 2016). Compared with milk production in the local cattle breeds of Ghana, milk yields increased dramatically in the F_1 crosses with Jersey and Friesian cattle with age at first calving and calving interval decreasing as the level of exotic breeding increased in the crossbreds (Aboagye, 2014). Galunkande et al. (2013) reported relative performance of indigenous breeds compared with different grades of crossbreds in terms of milk yield per lactation, age at first calving, services per conception, lifetime milk yield and total number of lactations completed. The findings indicated that at 50% *Bos taurus* blood, lactation milk yields were 2.6, 2.4 and 2.2 times higher than those of local cattle in the highland, tropical wet and dry, and semi-arid climatic zones, respectively; with superior lactation lengths and

Table 1. Reasons for success or failure of some cattle crossbreeding programs.

Crossbreeding type and breed of cattle	Country	Success	Reason
Rotational Crossing			
Holstein/Gir	Brazil	Yes	Increased profit
Synthetic Breed			
Mpawpaw	Tanzania	No	Lack of interest from local farmers
Breed Substitution			
Holstein	Kenya	Yes	Zero or semi zero-grazing systems; High potential agroecological area; Market linkage
Holstein	Ghana	No	Increased mortality due to low adaptation

Source: Leroy et al. (2016).

lower calving interval and age at first calving. The effect of indiscriminate crossbreeding in African countries are well known and sometimes visible as indicated in the gradual reduction of the population sizes of pure indigenous breeds with dilution of local adaptive germplasm (AUIBAR, 2019). Additionally, crossbreeding in most parts of the developing world has not always met the desired objectives. Table 1 gives an indication of the mixed results of cattle crossbreeding in selected countries.

CHALLENGES OF CROSSBREEDING

Despite the importance of dairy cattle crossbreeding, only few of the programs across Africa and other tropical countries have been successful. The major drawback in improving productivity especially in response to future demands for livestock products in sub-Saharan Africa is the absence of good infrastructure; absence of AI services; poor recording and monitoring systems (Roschinsky, 2013) as well as human and institutional resource constraints. Even though crossbreeding has great potentials and reliable outcomes which are observed in places where it has been in practice, it is not greatly adopted and applied in many parts of the tropics due to several challenges that may limit the advantages of heterosis and breed complementarity and jeopardize the sustainability of the system (Galukande et al., 2013; Roschinsky et al., 2015; Leroy et al., 2016). These include limited or non-involvement of farmers in the planning stages, shortfalls of crossbreeding methods, inadequate funding of crossbreeding programs, mismatches between genotypes and production environment and inappropriate recording and policy systems (Kebede et al., 2018). Limited involvement of farmers when designing crossbreeding programs, shortfalls of crossbreeding programs, inadequate funding of crossbreeding programs, environment and genotype mismatch, trained manpower problem were the major challenges facing smallholder dairy cattle crossbreeding in the tropics (Ojango et al., 2017). Additionally, genetic potential of crossbred cows is not fully exploited due to extreme climatic conditions and variable quantity and quality of feed resources in SSA (Roessler et al., 2019). Therefore, strategies designed to develop the dairy sector should take into account the existing production system and its unique characteristics of the area and should focus on a systematic approach to alleviate the identified constraints by involving all stakeholders in the formulation and implementation of improvement strategies (Moges, 2012; Ojango et al., 2017).

Many management (housing, health and nutrition) requirements of crossbred cattle are too complex and beyond the means of smallholder production systems (Galukande et al., 2013; Ojango et al., 2017). The smallholder sector in the tropics, which constitutes most of the farmers, is at times unable to raise the levels of management and nutrition in line with the requirements of the new genotypes due to resource constraints (Kahi, 2002; Kebede et al., 2018). Most tropical countries do not have adequate infrastructure and the cost involved, such as for transportation and the liquid nitrogen for storage of semen which has led to the failure in carrying out crossbreeding programs even though artificial insemination (AI) has been successful in the developed world (Hailu, 2013; Chebo and Alemayehu, 2012). The failure by smallholder farmers, who lack scientific understanding of crossbreeding, to recognize the unique needs of the different production systems has led to a low success rate of crossbreeding programs in many tropical countries (Galukande et al., 2013). Lack of policies in data collection, documentation and even maintenance of records has been found to be one of the threats to crossbreeding (FAO, 2007). The absence of technical skills and financial resources has been identified as the main obstacles in the establishment of sustainable animal recording systems in many African countries (FAO,

2007). Unlike the local breeds which can be fed through grazing where they walk many kilometres grazing, the crossbreds are kept under cut and carry feeding regime system of where they must be fed with supplements from industrial by-products and concentrates. This requires high labour requirements to feed, clean and manage intensively kept dairy cattle. These requires management skills and equipment such as feeding troughs, lighting system, shelter separation and disease management which are all additional tasks for smallholder farmers (Roschinsky et al., 2015). The crossbreds are also known to be more susceptible to diseases than purebreds and therefore a reliable and affordable veterinary service are required here to manage these diseases (FAO, 2007; Aboagye, 2014).

LESSONS LEARNT AND BEST PRACTICES

Demand for animal products is expected to increase due to human population growth, higher incomes, increased urbanization, and changes in dietary preferences resulting in a need for increased production (Osei-Amponsah et al., 2020). Crossbreeding has often been promoted with the assumption that crossbreds would produce greater outputs as a result of the contribution of the exotic breed to productivity and that of the local breed to environmental adaptation (AUIBAR, 2019). Institutional and human resource capacities, equipment, infrastructure, skilled labour, liquid nitrogen to store imported semen, heat detection, readily available insemination service and reliable means of transport are some of the prerequisites of a successful crossbreeding programme. Under favourable conditions, careful planning and long-term organization, crossbreeding schemes can be considered an effective strategy to reduce poverty among smallholders but it is not recommended for extensive resource-poor production systems. Developing countries often rely on crossbreeding to improve performance of livestock populations, usually because they have not been able to implement proper genetic evaluation and straight breeding programs in locally available breeds has not been considered feasible (Leroy et al., 2016). For instance, the importance of genotype-environment (G x E) interaction requires routine monitoring particularly because of increased global warming (Cheruiyot et al 2019). The failure to develop such breeding programs has been found to be related to poor infrastructure, insufficient capacity for management, lack of long-term commitment of research and investment, governmental and development institutes, and low involvement of smallholders in the implementation of the programs (FAO, 2015). Crossbreeding has been successfully introduced in some favourable areas in the tropics but not in all areas due to lack of long-term breeding strategies or the introduction of breeds that are not adapted to the tropical environments (Philipsson et al., 2011; Aboagye 2014; Kebede et al., 2018). Indiscriminate crossbreeding of indigenous breeds with exotic breeds without enough considerations of environmental conditions of production (Philipsson et al., 2011) should be discouraged. Significantly ex-situ conservation program of the local breeds has been proposed as an accompanying strategy to improve the sustainability of the crossbreeding programs (Manirakiza et al., 2017).

Lack of maintenance and promotion of breed standards and small population sizes limit the selection, multiplication and stabilization of crossbreds to form synthetic breeds (Hailu, 2013; Ojango et al., 2017). In addition, lack of analysis of the different socio-economic and cultural roles that livestock play in each situation usually leading to wrong breeding objectives and neglect for potentials of various indigenous breeds particularly in low input environments (Philipsson et al., 2011; Hailu, 2013) have all led to failure of crossbreeding in the tropics. For any crossbreeding program or initiative to be successfully implemented, the breeding environment or system should be greatly considered (Galukande et al., 2013; Kebede et al., 2018). There is need for better understanding of the genotype by environment interactions to match appropriate genotypes to the production systems (Roessler et al., 2019). Additionally, indiscriminate crossbreeding and breed substitution which are threats to indigenous livestock breeds and can lead to loss of ecologically important traits such as disease tolerance (AUIBAR, 2019) and should be avoided at all costs.

In designing a breeding program, the level of inheritance to be used in the crossbreeds needs to be considered with 50% exotic blood usually recommended (Galukande et al., 2013). Furthermore, stakeholder involvement in smallholder dairy cattle crossbreeding and production should be encouraged. These people are either government or private (non-governmental officials) who play various roles in ensuring a successful breeding program (Rewe et al., 2009) and include breeder's organizations, institutions providing extension services, educational and training institutions, logistical and regulating functions involving credit, storage, transport and marketing facilities as well institutions providing incentives to increase production and productivity. In Brazil, for example, breeding programs for indigenous cattle have been successful because of the cooperation between breed societies, groups of breeders or private firms, universities and research institutions (Rewe et al., 2009). To bring about change in production practices that will lead to improved productivity of dairy systems within the countries, investments are needed: to improve measurement and documentation of animal performance; to build technical capacity at different levels to better design and manage genetic improvement; for research to improve the uptake of genetic technologies in key production systems; and in the infrastructure and

processes that will deliver appropriate technologies to target populations (Ojango et al., 2017).

IMPLICATIONS AND RECOMMENDATIONS

Crossbreeding has led to higher milk production per animal, higher income for the families and provision of high-value food and is thus an important livestock improvement tool in the tropics especially where farmers can provide sufficient management for maintaining animals with higher input requirements and access to the milk market can be secured. This has happened in cases where stakeholders have carefully reviewed the production environment against the demands of crossbred cattle. Policies, market information and access, environmental conditions of the breeding community, characteristics of animal populations and infrastructure available should all be considered when designing crossbreeding programs. Another requirement for successful crossbreeding programmes is skilled human resource. In this regard training of smallholder farmers for instance in nutrition, heat detection, record keeping, AI and veterinary service delivery will be helpful. Additionally, the required infrastructure for improved management of crossbred cattle and access to market should be developed, training of stakeholders including small scale farmers with technical management and improved extension and veterinary service support to farmers. Finally, there is a need for more practical research to improve the implementation of sustainable long-term crossbreeding programs in developing countries. Sustainable use and conservation of local animal genetic resources, commitment of national governments, the farmers, meat and milk processors, retailers and consumers to support crossbreeding will be crucial in securing a robust and environmentally friendly milk industry in the tropics.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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