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Review Article
Adaptive Potential and Breeding Paradoxes of Sanga and Zebu Cattle

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Abstract
Beef farmers are faced with multiple production-related challenges which are complex. Although, Sanga and Zebu beef cattle are used in crossbreeding programs, deliberate efforts to improve polygenic traits are still limiting and, this is threatening their existence. Their potential to survive harsh conditions has not been genetically tested and proven, in the same vein, their meat characteristics are unknown. There is also a need to determine the relationship between farmers' and consumer preferences for Sanga and Zebu beef. To solve such production-associated problems, there is a need to incorporate all factors which affect beef production when defining a beef breeding plan. There is thus, a need for research in areas such as feed resource utilization, maternal behaviour, greenhouse gas emission and thereof incorporate such information into breeding objectives. The balance between adaptive traits and economic traits in these animals is also unknown. Approaches such as the use of genomics to identify the expression of specific genes for particular diseases, behaviour attributes and other complex traits can be explored to produce beef with the required meat quality. Generally, Sanga and Zebu cattle have traits that compare favourably with other beef breeds, however, there is a need to synchronize selection and definition of breeding objectives to meet beef consumer demands on the market. Deliberate conservation of cattle genetic resources as well as improving productivity is germane. Consumer preference for these meaty breeds should predominate breeding objectives. Breeding goals and the development of a selection index for these breeds are germane.

Key words: Genomics, greenhouse gas, maternal behaviour, meat quality

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INTRODUCTION

Human beings have been tussling with nature for a long period to acquire goods and services essential for their survival. In particular, the world is facing a myriad of food-related problems which are complex to discern and solve. These include climate change, the need to conserve plant and animal biodiversity[1], ever-increasing human population, encroachment of human beings into agricultural land[2], consumer demands for high-quality proteins, lipids and micronutrients from livestock and a call for ethically produced food at the same time[3]. Most of these problems form a puzzle that needs to be untangled. All livestock farmers should, therefore, rear animals tolerant and efficient to the existing environmental conditions to meet the consumer's need for quality and sufficient quantities of food on the table[3].

Land reserved for livestock production has been worst hit by bush encroachment[4], prolonged dry periods[5] and proliferation of vectors of different diseases among other problems[6]. Farmers are therefore expected to formulate breeding objectives, selection of future breeds and anticipate the ultimate performance of cattle breeds to be in sync with their respective environments. Generally, the consensus among beef farmers is to produce animals with high growth rates which thereon attain quality carcass yields at slaughter[7]. Any beef quality attribute is achievable if breed characteristics become compatible with the environment. With a variety of genetic materials from various beef breeds, there is, therefore, a need to synchronise the breeding and selection criteria to meet the consumer's expectations of beef[8,9]. However, there seem to be considerable conundrums between farmers who rear Sanga and Zebu breeds and the beef consumers. At the onset, they face competition from fellow farmers who rear other beef breeds and secondly, they are currently operating in an environment where consumers seem to doubt livestock science, expect the same quality of beef irrespective of breed origin and are ultimately more concerned about food security[10,11].

Beef cattle have a long history that is intertwined with humankind. Sanga and Zebu cattle form part of the beef breeds found among the Sub-Saharan African rangelands. Sanga cattle (*Bos taurus africanus*) include breeds not limited to the Afrikaner, Ankole, Nguni, Mashona and Tuli, while the most prominent humped Zebu breeds (*Bos indicus*) are the Brahman and the Boran[9,12-14]. Generally, both breed groups have consistently evolved to tolerate environmental challenges including tsetse flies, tick and tick-borne diseases and droughts among other factors[15,16]. Such traits have evolved through natural selection in different harsh geographical and ecological environments[16]. Moreover, with the current climate change problems, both the Sanga and Zebu cattle are vaunted to be ideal for extensive environments because of their adaptive potential[17]. However, given the fact that consumer expectations are now inclined towards lean and tender beef[18-20] and healthy imparting or associated fatty acids[9,21,22], the paradox attached to Sanga and Zebu breeds is on foregoing a certain level of their adaptive traits to meet the expected meat quality attributes required by the market[23]. Furthermore, the genetic improvement of low-input cattle production systems is intertwined with their cultural way of life, hence adaptation to local environments is critical besides presumed economic benefits[24]. Unfortunately, the adaptive attributes and genetic characteristics of these breeds are either entirely lacking or incomplete[25].

Adaptation is a homeostatic condition where an organism or animal changes its physiological, biochemical and behavioural attributes to suit the demands of its immediate environment[26,27]. This phenomenon is more linked to a state of sacrifice for survival rather than a luxury one and can form part of functional traits in a breeding objective[16]. Adaptation encompasses several aspects which include maternal attributes, physiological, behavioural, genetic and biochemical processes essential for survival[27]. In extensive Sub-Saharan African environments where there are high production risks from inconsistent rainfall patterns, overgrazed rangelands, exposure to heat stress and varied vegetation types[15], precludes farmers to rear animals that require the least resource requirements. As is the case with any business enterprise, farmers should design breeding objectives and selection criteria that are in direct response to the consumer demands[28], although attainment of such goals may take time. The breeding goals are achieved by identifying traits that are of economic importance and then subsequently translating their contribution to the selection index[23]. Currently, this kind of information can be utilised through the use of average phenotypic variances of traits in combination with a genomic estimation of breeding values[29]. Adaptation to prolonged heat stress in these breeds may have led to production losses[30] nonetheless, animals have acclimatised and survived these harsh conditions for a very long time. However, little information is available on how multiple trait selections of Sanga and Zebu cattle can meet trade-offs between productivity, adaptation and ultimately the meat quality and quantity required by the market. There is also a lack of extensive information on these breeds stand out in the beef market and their subsequent acceptability by consumers in Sub-Saharan countries. In addition, there is a lack of deliberate efforts to evaluate their adaptive traits in a proper breeding program, to ensure there is a balance between adaptation and productivity. This paper highlights the paradoxes associated with breeding objectives and adaptive characteristics of the Sanga and Zebu cattle. Consequently, it also illustrates how production should meet the expected meat quality attributes required by the present-day consumer.

General characteristics of Zebu and Sanga cattle: While we recognise that the breed characteristics of these two types of cattle are different, the circumstances befalling them in Sub-Saharan Africa are similar. Both Sanga and certain types of Zebu cattle have a common history that is strongly associated with African people, although half of the population of Zebu cattle is found in Asia[31]. It is reported that all cattle breeds originated from common ancestors called aurochs and were domesticated approximately 10,000 years ago[32]. Beef cattle breeds are classified into three categories which are namely *Bos primigenius, Bos primigenius opisthonomous* and *Bos primigenius nomadicus*[33]. These categories can be traced back to Zebu (from Southwest-Asian), Sanga (origin less clear) and taurines (from Europe)[34]. Moreover, beef cattle reared in the present day and age were selected mainly for their outstanding skeletal frame and muscles, which thereof are turned into meat upon slaughter[10].

Zebu and Sanga cattle are well adapted, thrive and survive among beef animals which range from smaller sizes like the Dexter breed to the double-muscled Belgian Blue. Such variation in frame size evolved through consistent and careful selection of parents in populations while matching their performance with the environment over a relatively long period[35,36]. Moreover, different sizes and features from other competing breeds serve as clues for setting out breeding goals and attaining the desired beef quality required by the market. On the other hand, there is also a concern for animal genetic resources conservation of cattle breeds in Sub-Saharan Africa[14]. This is against a background where most of the Zebu and Sanga cattle are reared by smallholder farmers who have no defined breeding objectives but rather solely rely on natural selection for the survival of their animals.

Sanga and Zebu cattle are generally resistant to heat stress[9,16,37], due to their short hair length, large dewlaps, prominent sweat glands and their ability to modulate temperature changes through shedding and replacements of hair depending on the season[12,16,38]. This attribute is ascribed to the metabolic capacity of these animals in different seasons. These animals adapt to challenging environments through low metabolic rates and body mass which subsequently minimise their water requirements and maintenance levels[16,39]. Sanga and Zebu cattle have lower energy requirements per unit mass of animal[12,35,36] and as a result of this phenomenon, it is probably the reason why they can maintain their weight loss at a minimum in different seasons. However, low maintenance and metabolic rates result in lower growth and maturity rates in Zebu[16,38] and Sanga cattle[40]. Lower growth rates are detrimental to farmers as they subsequently result in lower off-take rates of animal products, low-profit margins and animals that are finished at old age having lower carcasses grades and acceptability on the market.

Sanga and Zebu cattle are also believed to have high fertility (Mashona, Nguni and Tuli), longevity (Afrikaner and Boran) and longer reproductive lifespan[12]. This is attributable to the highlighted low maintenance requirements, bulky and non-selective grazing behaviour and their ability to recycle rumen ammonia for microbial protein synthesis during the dry periods where active growth of forage material is low[41,42]. However, the adoption of the longevity trait into breeding objectives is debatable, the argument is that it is reasonable to keep animals that optimally perform and produce over a short period for as long as the break-even point is attainable. Longevity is a trait that is prominent in most Sanga and Zebu cattle, however, it has not been proven whether this trait outsmarts the general performance levels of *B. taurus* breeds when all scales of the economy have been considered. Certain farmers however suggest that it makes business sense to keep animals that are relatively young and cull them when they have just surpassed their peak performance levels. A recent report[43] clamour for a need to characterise communal owned beef cattle populations, to understand the existing clamour diversity hence facilitate the development of sustainable rational conservation strategies. In light of such an exercise, breeding objectives should be tailored towards the enumeration of adaptive traits since these animals have survived the harshest conditions. Genomic selection, including mapping of genes controlling economically important and adaptive traits, is needed and possible for these breeds.

Maternal characteristics of Zebu and Sanga cattle: Generally, the genetic potential of any animal is determined by its ability to impart additive genetic characteristics for a particular trait to its progeny[44]. Maternal characteristics are the cornerstone and determining factor in any cow/calf enterprise. Precisely, how the cow overcomes environmental challenges between one lactation period and the next is of prime importance to any herd performance. It has been reported that the dam's nutritional status, the changes in the neuroendocrine system and the magnitude of stress have long-term implications on the behavioural and physiological performance of its offspring[45,46]. Each production stage during such a period is judged and its resulting contribution towards the economic returns (beef quality included) is weighed within the breeding objectives of the enterprise. Moreover, it is of great value if such attributes are heritable and passed on from the dam to its calves. Therefore, the inclusion of maternal traits into a breeding objective has a direct ripple effect on the performance of finisher beef cattle[47]. It is the humble belief that animal breeders promote these traits in Sanga and Zebu breeds to suit market demands for high-quality beef, rather than exploit these characteristics and improve the adaptation of exotic breeds to tropical environments. Breeding objectives should target economic implications emanating from lack of adaptation which includes production losses, mortalities (parasitic endemic diseases), treatment costs and marketing issues.

Genetic associations between growth and body composition attributes and, between growth and reproductive traits have been reported[48]. These associations can still be used in Sanga and Zebu cattle in developing breeding programs. Traits that are moderate to highly heritable can be improved by selection in tropically adapted cattle while lowly heritable traits show antagonistic correlations to adaptation. The extent to which traits are measured in Sanga and Zebu breeds remains a constraint for meaningful breeding programmes. The paucity of information on genetic parameters for adaptive traits in indigenous Sub-Saharan African breeds is unknown but we believe deliberate efforts to incorporate selection for adaptation are germane.

The fact that nearly all adaptive traits are moderate to highly heritable[12,48] is compelling and should be used as the basis for selection in breeding programs. The downside is that current genetic evaluation systems fail to incorporate adaptive traits because it is believed they are difficult to measure. However, there is ample evidence that these traits are positively correlated, such that selection to improve resistance to any one stressor is likely to increase resistance to other stressor[48]. The difficulty and cost of measuring economically important productive and adaptive traits, required to achieve a balanced breeding objective in tropical environments remain a challenge. Nevertheless, correlated responses and genomic selection are key to further investigations.

Sanga and Zebu cows have some of the exceptional maternal traits shown in Table 1.

Such traits include birth weights, weaning weights, calving intervals, age at puberty and first calving[49]. In a study carried out by Das *et al.*[50], they found out that Zebu cows were producing less milk during milking but were rather holding it and only releasing it to their calves during the suckling period. Such an attribute could be one of the reasons why most Zebu cows wean heavy calves with a mean weight which ranges between 50-60% of their mature weight (Johnson, personal communication). Moreover, mammals have been found to show plasticity in the form of their behavioural and physiological changes and this is more evident when the dam and offspring bond is disrupted[45].

The strong caring characteristics of the Sanga and Zebu cows seem to be a trait that is dominant and transmitted from one generation to the next. The ability of the dam to care for its young one is reported to be transferred from the mother to its daughters and thereon passed to the female offspring down the line, subsequently, this affects steroid receptor genes which cumulatively alter its resulting behaviour[46].

There is a need to investigate and document the maternal behaviour of cows in different parities, age groups, locations and seasons for specific breeds. Such information is crucial to draw valid conclusions on what influences and how cows raise their young ones. Currently, there is little information available on behavioural studies on cow-calf interaction in both Sanga and Zebu breeds. However, Nogueira[53] has shown that routine human handling and contact promote poor reproductive performance in cows. Additional associated maternal behaviour is yet to be tested in extensively raised cows and valid conclusions drawn from such experiments. Sanga and Zebu cattle have also been reported to have a strong social structure and cohesive behaviour when raised under extensive conditions[54]. Finger *et al.*[55] showed that Zebu cattle had a bond with related animals which were raised in the same herd even after 5 years. Apart from positive attributes such as herd cohesion, it is also worth noting that

Table 1: Cow productivity indices for some Sanga and Zebu cattle

	Breed	Birth weight (kg)	Weaning weight (kg)	Inter-calving period (days)	Age at first calving (months)	Source(s)
Sanga	Nguni	25	155-162	404	31	Scholtz *et al.*[17], Malusi *et al.*[78]
	Tuli	31	188	421	35	Scholtz *et al.*[17]
	Ankole	16	154-179	387	32.5	Gregory[51], Kugonza *et al.*[52]
	Afrikaner	32	191-197	448	37	Scholtz *et al.*[17]
Zebu	Boran	29	187-200	469	36	Gregory[51], Scholtz *et al.*[17]
	Brahman	31.6	200	455	36	Scholtz *et al.*[17]

negative behaviour such as aggression can be beneficial for extensively reared cows. Aggressive animals can deter predators from attacking vulnerable young ones in the herd. However, there is a need to determine and link all behavioural and physiological dynamics between the dam and its calf from the period when it is born until the time it's weaned. It is reported that maternal behaviour such as nursing, suckling, social interactions and aggression can be linked with heart rate, temperature and physiological biomarkers like oxytocin, cortisol and prolactin[56,57].

Sanga and Zebu cows have comparably good reproductive characteristics compared to *B. taurus* cattle[31,53]. For example, in a review by Manzi *et al.*[49], it is highlighted that Sanga cattle reared under on-station conditions had fertility indicators which compared favourably with *B. taurus* breeds. Moreover, Zebu cattle have been reported to possess high heritability characteristics for age at puberty for heifers[53]. Therefore, if breeders are to select for such a trait, while also incorporating functional traits associated with adaptation, then the ultimate goal of improving the efficiency of a cow/calf suckler replacement system will be realised. This phenomenon will then affect other associated traits that are directly linked with cow productivity. Indirectly this will affect weaner production and age at entry into a feedlot. However, adapted breeds are characterised by lower calf output[58] and poorer meat-quality attributes[59]. This has inevitably led to the development of tropical composite breeds as a fall-back strategy to improve overall herd productivity.

Regrettably, genetic links between beef quality and components of herd profitability in Sanga or Zebu animals have not been done, yet these animals have been used to develop some of the most prominent composite breeds including Bonsmara Charbray and many others. Strongly recommend such genetic analysis for these breeds to determine herd profitability components for productive, adaptive and reproductive traits. It is factual that the selection of animals over the past decades for high levels of production has exposed animal vulnerability and susceptibility to environmental and climatic challenges. All this was done to achieve optimum levels of animal production but, now we know that it is not necessarily the most economical, even under controlled environmental conditions[8].

Feeding and nutrition-related attributes: There is a paradox associated with animal performance and the genetic merit of a breed in a feedlot. This enigma emanates from the fact that most feedlot animals are usually those individuals with a selection index below the threshold level. Under normal circumstances, a farmer retains the best animals as future parents while removing the least performing animals for sale or finishing in the feedlot. Currently, there is scanty information on Zebu and Sanga feed efficiency measures and their application in the formulation of breeding objectives for individual animals or breeds[60].

Information on residual feed intake (RFI) and residual daily gain (RDG) is becoming increasingly crucial in this era where feed resources and land availability are scarce[61]. The RFI is defined as the difference between actual and predicted intake for a known rate of gain[60,62] while RDG is the actual growth rate, based on the animal's actual feed intake[63]. These two aspects have the potential to promote a reduction in feed costs while indirectly improving feed efficiency[63]. This is against a background where there seems to be a problem with other Sanga cattle that have been reported to have low feed efficiencies in the feedlots. Therefore, such information can only save farmers rearing such breeds from incurring losses by adopting the use of genomics through calculations of estimated breeding values (EBVs) for feed intake and incorporating them into an economic selection index[63]. It is however costly to come up with such information since it is difficult to measure the feed efficiency of individual animals as well as compute enough genomic data from a representative and known sample of cattle breeds.

The utilisation of feed is increasingly becoming popular given the global concerns about Greenhouse Gas (GHG) emissions from ruminant animals like cattle. There is a section of the global population which is calling for the banishment of animal agriculture because they say it is causing damage to the environment through the emission of GHGs. Residual feed intake and RDG will therefore promote efficient use of feed and thus results in low GHG emissions. Likewise, breeds such as the Sanga and Zebu cattle have not been extensively investigated on the issue of GHG and such a trait has also not been incorporated into breeding objectives or goals. Emission of GHG like methane has been heavily linked with energy loss, therefore it is envisaged that if the issues of RFI and RDG are fully understood, Sanga and Zebu cattle would be more efficient feeders and will lose less energy of per unit feed consumed.

Despite the proposed breakthrough which one obtains from all the information on RFI and RDG, its application or adoption in animals which are extensively reared or finished off-veld remains a challenge since Sanga and Zebu breeds are well adapted to extensive rangelands set-ups. Furthermore, it has also been reported that forage-fed or forage-finished beef has healthy benefiting fatty acid profiles such as conjugated linoleic acid and omega-3 fatty acids[64,65]. This information has led to a niche market for such kinds of meat products.

Nevertheless, there is no conclusive information on how the feed intake of grazing animals in such systems can be determined although there are certain indirect approaches which have been created. Indirect approaches to determining herbage intake such as the use of n-alkanes can however be employed[66]. However, the limitations of this procedure are that it is complicated and sometimes results in variations of herbage intake estimates[67]. Such restrictions will therefore directly limit the estimation of parameters such as RFI and RDG from extensively raised Sanga and Zebu cattle. Consequently, it, therefore, means that the inclusion of RFI and RDG into breeding goals for animals that are intended to be finished in extensive rangelands will remain a challenge and therefore it should be applied with extreme caution. There is however no information on how the Sanga and Zebu cattle acquire forage resources in different seasons under the extensive rangelands. Such information is essential to gain an understanding of how these animals utilise their feed in different seasons and stages of plant growth.

Disease resistance: The environment and its interaction with the expression of genes are the main factors that influence the ultimate performance of animals. All breeds' present characteristics are traced back to their places of origin. For example, temperate or exotic cattle breeds in Sub-Saharan Africa originated from extreme cold environments which then define or influence how they can cope with the disease outbreaks in such places. Likewise, Sanga and Zebu cattle have evolved in environments which are conducive to the proliferation of tsetse flies or tick and tick-borne diseases hence are either tolerant or resistant to the former[12]. However, despite having such a general understanding and background knowledge of different cattle breeds, incorporation of production and functional traits into a selection index has not been fully utilized in most cattle breeds[33]. For example, MacArthur and Reinemeyer[68] stated that most beef producers hardly monitor faecal egg counts or weight changes for their animals. Moreover, they further reported that less than 1% of farmers administered dewormers based on the faecal egg counts. Similarly, there is also evidence to show that the climatic conditions have changed and as a result are going to have a direct knock-on effect on animals which survive on the land, cattle included. Of particular concern is the fact that changes in environmental conditions like temperature, moisture, solar radiation and humidity among others have a direct influence on promoting mediums for disease outbreaks[2]. Sanga and Zebu cattle are therefore no exception to such a scenario. It is then a priority to incorporate functional traits such as disease resistance/tolerance, host-pathogen interaction and knowledge of the mode of infection into breeding objectives[33]. The evidence available so far only shows that these animals are tolerant to disease and worms but this has not been tested at the gene level, nor has any breeding evaluations done for such adaptive characteristics[12,48,69,70]. However, care should be taken by ensuring that the production potential is not compromised.

There is evidence that suggested that Sanga and Zebu cattle are resistant to parasites and diseases. For example, Nguni cattle in South Africa were reported to be tolerant to tick and tick-borne diseases[69,70], while N'Dama cattle are resistant to tsetse fly-induced trypanosomiasis[71]. Such adaptive attributes towards diseases need to be incorporated into breeding objectives for each specific breed. Moreover, with the emergence of technical aspects such as genomics, one can genotype and then identify animals which do not possess genes responsible for disease resistance early in life[72]. Genomics is a tool which has not been fully exploited in many Sanga and Zebu cattle herds. The reason for its limited use is because lack of cooperation by individual farmers to aggregately genotype their animals into a combined system and the lack of funding to finance the exercise[72]. It is, therefore, a priority for different governments who have specific strategic plans to help finance such programmes, ultimately contribute towards animal genetic resource programmes (AnGR) and meet goals for food security.

Meat quality and consumer demands: The selection of animals is reflective of market preferences of the product market in the case of commercial enterprises or farmer preferences in the case of subsistence production. To achieve this, breeding management is structured such that genetic evaluation, selection and mating patterns reduce generation intervals[73]. Economic benefits are precluded by production and profitability maximisation, however, scarcity of resources within most small-scale production systems has negated the objective and concept of maximisation, hence commercial and smallholder production systems are premised on the concept of optimisation (efficiency). The discussion around consumer or farmer choice in breeding objectives has been ongoing, nonetheless, Rewe[74] aver that the valuation of non-market traits for indigenous animal genetic resources in sub-Saharan tropics was done using conjoint analysis but we can infer that even up to now very little is known about these characteristics and their possible interactions within a multiple trait selection schemes Furthermore, only a few chosen experiments were used for these studies and animals came from controlled studies rather than communal and extensive systems where most of these breeds are found.

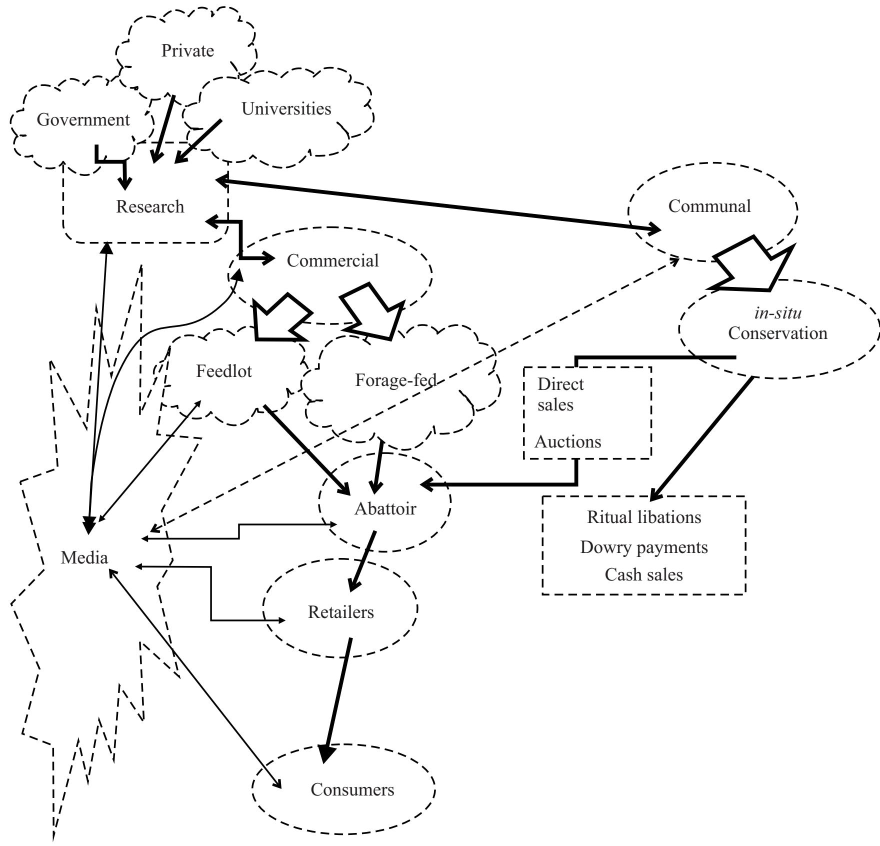

Fig. 1: Relationship between farmers, associated beef production chain partners and consumers

Zebu cattle have the adaptive potential to cope in harsh and challenging environments. For this reason, meat from breeds like the Brahman is reported to be less tender because of higher proportions of calpastatin: μ-calpain ratio. Muchenje *et al.*[75] reported that increased calpastatin and a reduced calpain activity results in low proteolysis and translates into faster growth rates due to heavily built muscle. However, high levels of calpastatin have been reported to be responsible for the inhibition of myofibril proteolysis during the post-mortem aging of carcasses which then translates to less tender meat[75-77]. Therefore, farmers who rear Zebu cattle must select for low calpastatin levels to produce tenderer beef while also ensuring not to compromise the growth rates of well-adapted cattle on the rangelands. There is however no convincing report on whether Sanga cattle have higher calpastatin but there have been reports which suggest that they have lower growth rates in the feedlot as compared to pure *B. taurus* breeds[17]. The problem of low meat tenderness in *B. indicus* breeds can be improved by crossbreeding with taurine cattle.

Farmer and consumer relationship: Zebu and Sanga cattle exist in both commercial and communal farming systems. The immediate appeal of beef quality attributes from such animals to the consumers is dependent on the breeding objectives implemented by the farmer. For example, beef animals are a source of complex functions to the communal farmers. Beef cattle satisfy several needs of the communal farmers[40], among these needs include a source of libation, manure, draught power, meat and milk, dowry payment and sales to raise cash when the need arises in Fig. 1.

The existence of pure Zebu and Sanga genetic material in the communal rangelands is also through admixture with other bloodlines from other breeds because of no defined breeding objectives and selection of parents in a herd. Government initiatives such as *in-situ* conservation of indigenous resources in the communal farming set-ups will therefore be a platform offering valid evaluation for meat quality by consumers. Such a set-up includes programs like the Nguni cattle project which involves rearing the Sanga-derived Nguni in communal areas of South Africa[77].

Under such a program breeding objectives can be formulated and direct measurement of consumer preferences for such kind of beef thereon easily be assessed. It is now commonly accepted to say that beef consumers have a huge stake in influencing the way farmers produce their animals. Of prime importance is the fact that if there are any rumours of malpractice in one or more of the production protocols, consumers have the power to boycott buying such a product from the shelf. There are clear indications that food production is shifting from farmer to consumer-driven[33]. In this information age era, consumers have a myriad of connections and knowledge bases about animal husbandry practices and their relation to meat safety. Beef farmers on the other hand receive the same information but their relationship with consumers is quite complex. Farmers are expected to grow an animal that is adapted to the environment, achieve the target weight within the shortest possible time, attain a good carcass grade when slaughtered and ultimately receive better retains for them to remain viable in the business. This value chain is an indirect contact between the beef producer and the consumer. Given a background where farmers have no direct or immediate contact with what the consumers prefer, it is therefore quite complex to establish and quell any misunderstanding between the two parties who are interdependent on each other.

Moreover, it is not easy to achieve the desired breeding goals which are tailored specifically to meet the consumers' preferences. Breeding goals are attained through a consistent selection of superior animals across different generations. However, this can be made easier through the use of genomics although normal animal growth and physiological phases have to be met to get the desired beef quality on the table. Currently, there is a lack of information on how consumers perceive beef produced from Sanga and Zebu farmers and vice-versa. Such information will formulate the basis from which both parties can hinge their relationship and ultimately define how this can be achieved. Developed an 8-point breeding strategy for adaptive traits, also proffer these strategies for Sanga and Zebu cattle breeders within the tropics.

CONCLUSION

Sanga and Zebu cattle have exceptional adaptation characteristics due to the long period of existence in challenging environments. The cows have good maternal characteristics which compare favourably with other *B. taurus* breeds. There is however a need to include functional traits within the breeding objectives such that farmers can meet consumers' demands for quality beef. This can be achieved while maximising productivity at the same time. The use of genomics to determine factors like RFI and RDG, genes for disease resistance and maternal and behavioural attributes are also needed in the future. Research on the farmer and consumer relationship is also required in the future.

SIGNIFICANCE STATEMENT

Sanga and Zebu beef cattle in Sub-Saharan Africa are the least studied animals in terms of their nutritional and genetic parameters. Both farmer and consumer preferences vary widely among Sanga and Zebu breeds. Fortunately, these breeds have traits which compare favourably with other beef breeds, otherwise, they would have been extinct by now. Unfortunately, there is a lack of deliberate selection and breeding objectives to meet the general and specific consumer demands for beef on the market. Incorporation of adaptive traits in a breeding program for these breeds is germane as this will further boost their productivity.

REFERENCES

1. Tscharntke, T., Y. Clough, T.C. Wanger, L. Jackson and I. Motzke *et al*., 2012. Global food security, biodiversity conservation and the future of agricultural intensification. Biol. Conserv., 151: 53-59.
2. Thornton, P.K., J. van de Steeg, A. Notenbaert and M. Herrero, 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agric. Syst., 101: 113-127.
3. Hayes, B.J., H.A. Lewin and M.E. Goddard, 2013. The future of livestock breeding: Genomic selection for efficiency, reduced emissions intensity and adaptation. Trends Genet., 29: 206-214.
4. O'Connor, T.G., J.R. Puttick and M.T. Hoffman, 2014. Bush encroachment in Southern Africa: Changes and causes. Afr. J. Range Forage Sci., 31: 67-88.
5. Washaya, S., P.D. Muchaurawa and D.D. Washaya, 2022. Drought coping strategies by smallholder cattle farmers in Zimbabwe. Trop. Subtrop. Agroecosyst., Vol. 25. 10.56369/tsaes.3789.
6. Brites-Neto, J., K.M.R. Duarte and T.F. Martins, 2015. Tick-borne infections in human and animal population worldwide. Vet. World, 8: 301-315.
7. Hozáková, K., K. Vavrišínová, P. Neirurerová and J. Bujko, 2020. Growth of beef cattle as prediction for meat production: A review. Acta Fytotechnica Zootechnica, 23: 58-69.
8. Gaughan, J.B., V. Sejian, T.L. Mader and F.R. Dunshea, 2019. Adaptation strategies: Ruminants. Anim. Front., 9: 47-53.
9. Mapiye, C., O.C. Chikwanha, M. Chimonyo and K. Dzama, 2019. Strategies for sustainable use of indigenous cattle genetic resources in Southern Africa. Diversity, Vol. 11. 10.3390/d11110214.

10. Garnier, J.P., R. Klont and G. Plastow, 2003. The potential impact of current animal research on the meat industry and consumer attitudes towards meat. Meat Sci., 63: 79-88.
11. Grunert, K.G., 2005. Food quality and safety: Consumer perception and demand. Eur. Rev. Agric. Econ., 32: 369-391.
12. Mwai, O., O. Hanotte, K. Young-Jun and S. Cho, 2015. African indigenous cattle: Unique genetic resources in a rapidly changing world. Asian-Australas. J. Anim. Sci., 28: 911-921.
13. Makina, S.O., L.K. Whitacre, J.E. Decker, J.F. Taylor and M.D. MacNeil *et al*., 2016. Insight into the genetic composition of South African Sanga cattle using SNP data from cattle breeds worldwide. Genet. Sel. Evol., Vol. 48. 10.1186/s12711-016-0266-1.
14. Nyamushamba, G.B., C. Mapiye, O. Tada, T.E. Halimani and V. Muchenje, 2017. Conservation of indigenous cattle genetic resources in Southern Africa's smallholder areas: Turning threats into opportunities-A review. Asian-Australas. J. Anim. Sci., 30: 603-621.
15. Strydom, P.E., 2008. Do indigenous Southern African cattle breeds have the right genetics for commercial production of quality meat? Meat Sci., 80: 86-93.
16. Berman, A., 2011. Are adaptations present to support dairy cattle productivity in warm climates? J. Dairy Sci., 94: 2147-2158.
17. Scholtz, M.M., C. McManus, A.M. Okeyo and A. Theunissen, 2011. Opportunities for beef production in developing countries of the southern hemisphere. Livest. Sci., 142: 195-202.
18. Strydom, P.E., R.T. Naude, M.F. Smith, M.M. Scholtz and J.B. van Wyk, 2000. Characterisation of indigenous African cattle breeds in relation to meat quality traits. Meat Sci., 55: 79-88.
19. Troy, D.J. and J.P. Kerry, 2010. Consumer perception and the role of science in the meat industry. Meat Sci., 86: 214-226.
20. Makweya, F.L. and I.B. Oluwatayo, 2019. Consumers' preference and willingness to pay for graded beef in Polokwane municipality, South Africa. Ital. J. Food Saf., Vol. 8. 10.4081/ijfs.2019.7654.
21. Daley, C.A., A. Abbott, P.S. Doyle, G.A. Nader and S. Larson, 2010. A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. Nutr. J., Vol. 9. 10.1186/1475-2891-9-10.
22. Liu, J., M.P. Ellies-Oury, T. Stoyanchev and J.F. Hocquette, 2022. Consumer perception of beef quality and how to control, improve and predict it? Focus on eating quality. Foods, Vol. 11. 10.3390/foods11121732.
23. Gizaw, S., H. Komen and J.A.M. van Arendonk, 2010. Participatory definition of breeding objectives and selection indexes for sheep breeding in traditional systems. Livest. Sci., 128: 67-74.
24. Laske, C.H., B.B.M. Teixeira, N.J.L. Dionello and F.F. Cardoso, 2012. Breeding objectives and economic values for traits of low input family-based beef cattle production system in the State of Rio Grande do Sul. Rev. Bras. Zootecnia, 41: 298-305.
25. Washaya, S., W. Bvirwa and G.B. Nyamushamba, 2022. Herd dynamics, phenotypic characteristics of indigenous beef cattle breeds (*Bos indicus*) in Gokwe North. Trans. R. Soc. South Afr., 77: 27-35.
26. Berihulay, H., A. Abied, X. He, L. Jiang and Y. Ma, 2019. Adaptation mechanisms of small ruminants to environmental heat stress. Animals, Vol. 9. 10.3390/ani9030075.
27. Ahmad, H.I., M.J. Ahmad, F. Jabbir, S. Ahmar, N. Ahmad, A.A. Elokil and J. Chen, 2020. The domestication makeup: Evolution, survival, and challenges. Front. Ecol. Evol., Vol. 8. 10.3389/fevo.2020.00103.
28. Lopes, F.B., A. de los Reyes Borjas, M.C. da Silva, O. Facó, R.N. Lôbo, M.C.S. Fiorvanti and C. McManus, 2012. Breeding goals and selection criteria for intensive and semi-intensive dairy goat system in Brazil. Small Ruminant. Res., 106: 110-117.
29. Quezada, M., I. Aguilar and G. Balmelli, 2022. Genomic breeding values' prediction including populational selfing rate in an open-pollinated *Eucalyptus globulus* breeding population. Tree Genet. Genomes, Vol. 18. 10.1007/s11295-021-01534-7.
30. Rashamol, V.P., V. Sejian, M. Bagath, G. Krishnan, P.R. Archana and R. Bhatta, 2018. Physiological adaptability of livestock to heat stress: An updated review. J. Anim. Behav. Biometeorol., 6: 62-71.
31. Abeygunawardena, H. and C.M.B. Dematawewa, 2004. Pre-pubertal and postpartum anestrus in tropical Zebu cattle. Anim. Reprod. Sci., 82: 373-387.
32. Orlando, L., 2015. The first aurochs genome reveals the breeding history of British and European cattle. Genome Biol., Vol. 16. 10.1186/s13059-015-0793-z.
33. Pitt, D., N. Sevane, E.L. Nicolazzi, D.E. MacHugh and S.D.E. Park *et al*., 2019. Domestication of cattle: Two or three events? Evol. Appl., 12: 123-136.
34. Chan, E.K.F., S.H. Nagaraj and A. Reverter, 2010. The evolution of tropical adaptation: Comparing taurine and zebu cattle. Anim. Genet., 41: 467-477.
35. Kongphitee, K., K. Sommart, T. Phonbumrung, T. Gunha and T. Suzuki, 2018. Feed intake, digestibility and energy partitioning in beef cattle fed diets with cassava pulp instead of rice straw. Asian-Australas. J. Anim. Sci., 31: 1431-1441.
36. Cabezas-Garcia, E.H., D. Lowe and F. Lively, 2021. Energy requirements of beef cattle: Current energy systems and factors influencing energy requirements for maintenance. Animals, Vol. 11. 10.3390/ani11061642.
37. Gororo, E., S.M. Makuza, F.P. Chatiza, F. Chidzwondo and T.W. Sanyika, 2018. Genetic diversity in Zimbabwean Sanga cattle breeds using microsatellite markers. South Afr. J. Anim. Sci., Vol. 48. 48: 128-141.

38. Hansen, P.J., 2004. Physiological and cellular adaptations of Zebu cattle to thermal stress. Anim. Reprod. Sci., 82-83: 349-360.
39. Silanikove, N., 2000. The physiological basis of adaptation in goats to harsh environments. Small Ruminant Res., 35: 181-193.
40. Shabtay, A., 2015. Adaptive traits of indigenous cattle breeds: The mediterranean baladi as a case study. Meat Sci., 109: 27-39.
41. Hartinger, T., N. Gresner and K.H. Südekum, 2018. Does intra-ruminal nitrogen recycling waste valuable resources? A review of major players and their manipulation. J. Anim. Sci. Biotechnol., Vol. 9. 10.1186/s40104-018-0249-x.
42. Mapfumo, L. and V. Muchenje, 2015. Comparative changes in monthly blood urea nitrogen, total protein concentrations, and body condition scores of Nguni cows and heifers raised on sweetveld. South Afr. J. Anim. Sci., 45: 96-103.
43. Mamogobo, M.D., N.O. Mapholi, K.A. Nephawe, T.L. Nedambale, T.J. Mpofu, Y.P. Sanarana and B.J. Mtileni, 2020. Genetic characterisation of non-descript cattle populations in communal areas of South Africa. Anim. Prod. Sci., 61: 84-91.
44. Raphaka, K. and K. Dzama, 2010. Genetic analyses for growth traits of two indigenous beef cattle breeds in Botswana. Livest. Sci., 129: 194-199.
45. Lovic, V. and A.S. Fleming, 2004. Artificially-reared female rats show reduced prepulse inhibition and deficits in the attentional set shifting task-reversal of effects with maternal-like licking stimulation. Behav. Brain Res., 148: 209-219.
46. Champagne, F.A., 2008. Epigenetic mechanisms and the transgenerational effects of maternal care. Front. Neuroendocrinol., 29: 386-397.
47. Twomey, A.J., A.R. Cromie, N. McHugh and D.P. Berry, 2020. Validation of a beef cattle maternal breeding objective based on a cross-sectional analysis of a large national cattle database. J. Anim. Sci. Vol., 98. 10.1093/jas/skaa322.
48. Burrow, H.M., 2012. Importance of adaptation and genotype × environment interactions in tropical beef breeding systems. Animal, 6: 729-740.
49. Manzi, M., L. Rydhmer, M. Ntawubizi, C. Karege and E. Strandberg, 2019. Reproductive performance of ankole cattle and its crossbreds in rwanda. Trop. Anim. Health Prod., 51: 49-54.
50. Das, S.M. I. Redbo and H. Wiktorsson, 2000. Effect of age of calf on suckling behaviour and other behavioural activities of Zebu and crossbred calves during restricted suckling periods. Appl. Anim. Behav. Sci., 67: 47-57.
51. Gregory, N.G., 2010. How climatic changes could affect meat quality. Food Res. Int., 43: 1866-1873.
52. Kugonza, D.R., H. Jianlin, M. Nabasirye, D. Mpairwe, G.H. Kiwuwa, A.M. Okeyo and O. Hanotte, 2011. Genetic diversity and differentiation of ankole cattle populations in Uganda inferred from microsatellite data. Livest. Sci., 135: 140-147.
53. Nogueira, G.P., 2004. Puberty in South American *Bos indicus* (Zebu) cattle. Anim. Reprod. Sci., 82-83: 361-372.
54. Orihuela, A. and C.S. Galina, 2021. The effect of maternal behavior around calving on reproduction and wellbeing of Zebu type cows and calves. Animals, Vol. 11. 10.3390/ani11113164.
55. Finger, A., K.P. Patison, B.M. Heath and D.L. Swain, 2013. Changes in the group associations of free-ranging beef cows at calving. Anim. Prod. Sci., 54: 270-276.
56. Bridges, R.S., 2015. Neuroendocrine regulation of maternal behavior. Front. Neuroendocrinol., 36: 178-196.
57. Geburt, K., M. Friedrich, M. Piechotta, M. Gauly and U.K. van Borstel, 2015. Validity of physiological biomarkers for maternal behavior in cows-A comparison of beef and dairy cattle. Physiol. Behav., 139: 361-368.
58. Prayaga, K.C., N.J. Corbet, D.J. Johnston, M.L. Wolcott, G. Fordyce and H.M. Burrow, 2009. Genetics of adaptive traits in heifers and their relationship to growth, pubertal and carcass traits in two tropical beef cattle genotypes. Anim. Prod. Sci., 49: 413-425.
59. Muchenje, V., K. Dzama, M. Chimonyo, P.E. Strydom and J.G. Raats, 2009. Relationship between pre-slaughter stress responsiveness and beef quality in three cattle breeds. Meat Sci., 81: 653-657.
60. Berry, D.P. and J.J. Crowley, 2013. Cell biology symposium: Genetics of feed efficiency in dairy and beef cattle. J. Anim. Sci., 91: 1594-1613.
61. Elolimy, A.A., M.K. Abdelmegeid, J.C. McCann, D.W. Shike and J.J. Loor, 2018. Residual feed intake in beef cattle and its association with carcass traits, ruminal solid-fraction bacteria, and epithelium gene expression. J. Anim. Sci. Biotechnol., Vol. 9. 10.1186/s40104-018-0283-8.
62. Scholtz, M.M., A. Maiwashe, F.W.C. Neser, A. Theunissen, W.J. Olivier, M.C. Mokolobate and J. Hendriks, 2013. Livestock breeding for sustainability to mitigate global warming, with the emphasis on developing countries. South A. J. Anim. Sci., Vol. 43. 10.4314/sajas.v43i3.4.
63. Herd, R.M., J.A. Archer and P.F. Arthur, 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. J. Anim. Sci., 81: E9-E17.
64. Muchenje, V., A. Hugo, K. Dzama, M. Chimonyo, P.E. Strydom and J.G. Raats, 2009. Cholesterol levels and fatty acid profiles of beef from three cattle breeds raised on natural pasture. J. Food Compos. Anal., 22: 354-358.
65. Mapiye, C., P. Vahmani, V. Mlambo, V. Muchenje, K. Dzama, L.C. Hoffman and M.E.R. Dugan, 2015. The *trans*-octadecenoic fatty acid profile of beef: Implications for global food and nutrition security. Food Res. Int., 76: 992-1000.
66. Reis, S.F., G. Huntington, M. Hopkins, S. Whisnant and P.V.R. Paulino, 2015. Herbage selection, intake and digestibility in grazing beef cattle. Livest. Sci., 174: 39-45.

67. Smit, H.J., H.Z. Taweel, B.M. Tas, S. Tamminga and A. Elgersma, 2005. Comparison of techniques for estimating herbage intake of grazing dairy cows. J. Dairy Sci., 88: 1827-1836.
68. McArthur, M.J. and C.R. Reinemeyer, 2014. Herding the U.S. cattle industry toward a paradigm shift in parasite control. Vet. Parasitol., 204: 34-43.
69. Marufu, M.C., L. Qokweni, M. Chimonyo and K. Dzama, 2011. Relationships between tick counts and coat characteristics in Nguni and Bonsmara cattle reared on semiarid rangelands in South Africa. Ticks Tick-borne Dis., 2: 172-177.
70. Mapholi, N.O., M.C. Marufu, A. Maiwashe, C.B. Banga and V. Muchenje *et al*., 2014. Towards a genomics approach to tick (Acari: Ixodidae) control in cattle: A review. Ticks Tick-borne Dis., 5: 475-483.
71. Orenge, C.O., L. Munga, C.N. Kimwele, S. Kemp and A. Korol *et al*., 2012. Trypanotolerance in N'Dama x Boran crosses under natural trypanosome challenge: Effect of test-year environment, gender, and breed composition BMC Genet., Vol. 13. 10.1186%2F1471-2156-13-87.
72. Rolf, M.M., J.E. Decker, S.D. McKay, P.C. Tizioto and K.A. Branham *et al*., 2014. Genomics in the United States beef industry. Livest. Sci., 166: 84-93.
73. Bayssa, M., S. Yigrem, S. Betsha and A. Tolera, 2021. Production, reproduction and some adaptation characteristics of Boran cattle breed under changing climate: A systematic review and meta-analysis. PLoS ONE, Vol. 16. 10.1371/journal.pone.0244836.
74. Pandurangan, M. and I. Hwang, 2012. The role of calpain in skeletal muscle. Anim. Cells Syst., 16: 431-437.
75. Muchenje, V., K. Dzama, M. Chimonyo, P.E. Strydom, A. Hugo and J.G. Raats, 2009. Some biochemical aspects pertaining to beef eating quality and consumer health: A review. Food Chem., 112: 279-289.
76. Geesink, G.H., S. Kuchay, A.H. Chishti and M. Koohmaraie, 2006. μ-Calpain is essential for postmortem proteolysis of muscle proteins. J. Anim. Sci., 84: 2834-2840.
77. Malusi, N., A.B. Falowo and E.M. Idamokoro, 2021. Herd dynamics, production and marketing constraints in the commercialization of cattle across Nguni Cattle Project beneficiaries in Eastern Cape, South Africa. Pastoralism, Vol. 11. 10.1186/s13570-020-00186-x.