ILRI Review Report: Opportunities to Quantify Resilience of Dairy Cattle to Environmental Stressors in Sub-Saharan Africa

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Abstract

Dairy production contributes significantly to food and nutritional security and employment in sub-Saharan Africa (SSA). However, production is negatively affected by environmental challenges such as high temperatures and heat stress, diseases and parasites, unreliable rainfall patterns, and shortages of feed crops and forages. Thus, the resilience capacity of dairy animals must be fostered to enable them to withstand climatic adversities without compromising their production levels. This can only be achieved if reliable and practical methods that can quantify and analyze resilience in SSA have been described and tested. By appreciating existing technological innovations and body of knowledge on resilience, this review presents the significance of resilience of dairy animals to environmental perturbations, proposed resilience indicators from the literature, and phenotypic data needed for characterizing resilience of dairy cattle in SSA. Resilience of dairy cattle is important in the fight against poverty and helps to improve animal welfare and prepare them for future unseen consequences of climate change. Indicators of resilience include variance of deviation, root mean square of deviation, autocorrelation of deviation, slope of the reaction norm, and the absolute value of the reaction norm. Genetic variation and favorable correlations with health, fitness and fertility traits have been previously reported for these indicators, however their potential remains to be tested in SSA. Phenotypic data needed for resilience should be labor- and cost-effective and easy to collect using available tools. Such phenotypic data include longitudinal data on milk production traits, body fat related traits and activity patterns. These data are however not usually available in volumes that would allow characterization of resilience of dairy animals in SSA using the proposed indicators. African Dairy Genetic Gains Project of the International Livestock Research Institute is collating data from large and small scales dairy farms that could be used to test the potential of these indicators in SSA.

Key words: resilience, dairy cattle, longitudinal data, sub-Saharan Africa

1. Introduction

Sub-Saharan Africa experiences numerous environmental challenges such as severe droughts that are accompanied by high ambient temperatures and heat stress; diseases and parasites, and shortages of feeds and forages, all of which negatively affect dairy production. Therefore, improved management practices as well as improved genetic potential for both production and resilience are needed to cope with the above challenges. Genetic improvement that confers resilience to the physical environmental, disease and parasitic challenges offer more pragmatic and long-term solutions.

The environmental disturbance is a change in conditions that negatively affect the normal functioning of a biological system (Capucchio *et al*., 2019). Disturbances in the environment are classified as either macroenvironmental or microenvironmental (Falconer and Mackay 1996). Macroenvironmental disturbances are characteristics of the environment such as heat stress and disease pressure that affect the whole population. Microenvironment disturbances occur within the macro-environment and affect only a few individuals within that environment (e.g., disease).

An animal's degree of resilience to a disturbance is its capacity to be minimally affected by the perturbation or rapidly return to the state pertained before exposure to the disturbance (Berghof, Poppe, and Mulder 2019). These disturbances are normally situation-specific, episodic, or sporadic and not permanent attributes of the environment (Colditz and Hine 2016). Degree of resilience therefore compares the differences in the magnitudes of phenotypes associated with resilience among individuals after exposure to the environmental challenges (Rutter 2012) and is a measure of better adaptability or lower sensitivity to a challenging state of affairs. This means that, when exposed to a disturbance, the performance of a resilient animal need not be the same as when it is under no disturbance, but rather, the negative change in its performance would be relatively lower compared to less resilient individuals that are exposed to similar disturbances.

Although 80% of cow milk in sub-Saharan Africa is produced from smallholder systems (Ojango *et al*., 2017), the breeding goals are not defined clearly to respond to the prevailing challenges. Even where attempts have been at defining such goals, resilience components are usually missing.

Recent technological advancement has enabled the invention and innovative use of tools and software such as activity meters, and thermal imaging cameras to collect data on resilience related phenotypes in livestock. However, the potential and utility of such innovations is yet to be realized in SSA's dairy industry. Besides, methods of deriving indicators to measure the general resilience of cattle using longitudinal data have been proposed and adopted for high-performing exotic cattle in temperate countries (Poppe *et al.,* 2020; Berghof *et al.,* 2019; Elgersma *et al*., 2018; Sánchez-Molano *et al.,* 2019). Nonetheless, the potential of using such indicators to quantify general resilience are yet to be fully tested in SSA.

The conclusions and recommendations made on livestock resilience from temperate countries might not apply in the SSA case for several reasons. The majority of commercial dairy cattle in SSA are crossbreds of different proportions of zebu and taurine breeds, which are quite different from the cattle breeds in temperate countries in terms of body conformation and size, performance, and feed requirement. Additionally, the environmental perturbations that affect dairy cattle and the level of animal husbandry in SSA are quite different from those in the temperate world. The level of resilience of SSA's livestock should therefore be quantified based on the cattle genotypes as well as the set of disturbances to which they are exposed. This report reviews the significance of the resilience of dairy cattle in SSA, how such resilience can be quantified and the set of phenotypic data that is needed to adequately assess resilience.

2. Significance of Resilience of Dairy cattle in SSA

Breeding for resilience of cattle genotypes in SSA would help increase production efficiency and profitability of dairy production. Resilient animals are generally healthier, more fertile and have longer productive life. Resilient dairy cattle therefore have lower veterinary and disease management costs, produce more from same levels of inputs, and give higher total lifetime returns. A less-resilient herd on the other hand results in high production losses due to high mortality and morbidity rates and lower than optimal production yields. Extra resources are usually used to care for less resilient cows (Berghof *et al*., 2019).

Improving resilience of cattle to environmental stressors contributes to better animal welfare. Dairy cattle in good welfare experience less or no disturbance and thus are likely to perform optimally. Besides benefits related to fertility and production, animals in good welfare attract better prices in the market hence fetching more income to the farmer.

Degree of intrinsic resilience prepares the animals for the future unseen consequences of climate change and ensure future food security for human beings. Global climatic conditions have been predicted to become warmer with the temperature rising by up to 4.8 °C by the next century (Pachauri and Meyer 2015). With the world becoming warmer, shortages of water, forage (feed and fodder) available for dairy cattle as well as the emergence of novel diseases and resistant infectious agents are expected to rise. Continuous improvement of the resilience capacity of animals would ensure that animals are able to survive future adversaries and continue to supply dietary needs to the rising human population.

3. Indicators of Resilience

3.1. Indicators of General Resilience

These are indicators that capture more of resilience to microenvironmental disturbances than macroenvironmental stressors and are based on fluctuations from the normal performance of the animal. They include variance of deviations, root mean square deviations, lag-1 autocorrelation of deviations and skewness of deviations. These indicators have been shown to contain genetic variation (Table 1) that can be utilized to breed for resilience in livestock. They have been shortly described below.

3.1.1. Variance of deviation

Variance of deviation indicates the impact of the disturbance on the performance of an individual animal. It is sometimes known as inherited variability, uniformity, environmental or residual variance (Berghof *et al*., 2019). The biological functioning of resilient animals is less affected by the disturbances in the environment. As such, resilient animals have a smaller range of deviation from their expected performance hence a low variance of deviation, while the performance of less resilient animals tend to be variable because they are more affected by the stressors in their environment. They, therefore, have a higher variance of deviation (Berghof *et al*., 2019). The genetic correlations between variance of deviation (derived from different types of longitudinal data) and fertility and fitness traits are consistently negative but range from weak to moderate (Table 2). This indicates that this indicator could be used to measure general resilience of dairy animals.

3.1.2. Root mean square deviation

Just like variance of deviation, root mean square deviation (RMSD), or root mean square error (RSME) indicates the impact of disturbance on the performance of an individual animal. It is a square root of the raw variance of deviation. A larger RMSD value is expected from a less resilient animal and smaller values for resilient animals. Given the mathematical attribute of this indicator, higher number of records are needed in order to avoid erroneous grouping of animals with fewer records as more resilient (Putz *et al*., 2019). RMSD using feed intake and duration was found to have moderate heritabilities (0.21 and 0.26, respectively) and to be favorably correlated with the number of treatments (0.56 and 0.62) and mortality (0.37 and 0.60) in a health-challenged environment (Putz *et al*., 2019).

3.1.3. Lag-1 autocorrelation of deviation

This statistic shows the duration of the impact of disturbance or the rate of recovery from the disturbance. The biological sense behind Lag-1 autocorrelation (r_{auto}) is that a disturbance would mostly cause animals to deviate from their normal performance and animals would recover from the disturbance at different rates depending on their degree of resilience. Resilient animals are expected to recover faster from disturbances thus tend to have shorter and fewer stretches of negative deviations than less resilient animals. As a result, similarity between subsequent deviations is low. The opposite is the case for less resilient animals. An autocorrelation around one indicates that deviations are because of a similar stressor thus an animal is influenced by the disturbance and has a slower rate of recovery from the disturbance. An autocorrelation around -1 indicates that the deviations are opposite; although an animal is affected by the perturbation, it has a quick and overcompensating response to the perturbation. Past studies have reported low but significant heritabilities for Lag-1 autocorrelation (Table 1) denoting that it contains information on genetic variation among the individuals in the population. Weak and negligible genetic correlations between health traits and r_{auto} have been observed in the past studies (Table 2).

3.1.5. Skewness of deviation

This indicates the direction of the deviation and captures the level of severity of the disturbance experienced by an individual animal. Less resilient animals are more influenced by disturbances and thus have more negative than positive deviations which leads to a negative skewness around -1. Resilient animals have skewness around zero because they have almost equal numbers of negative and positive deviations. 1. An animal that is responding positively to the environmental improvement should show a positive skewness due to positive deviations. Past studies have reported low heritability estimates (Table 1) and unexpected genetic correlations with fitness and health traits for skewness of deviation. Skewness around zero was expected to show good resilience, however in a study by Poppe *et al.,* (2020) , it was observed that skewness is genetically associated with a shorter productive life span, lower body condition score, and higher ketosis in dairy cattle). Berghof *et al.,* (2019) also could not predict mortality or lesion scores of chickens using estimated breeding values for skewness. For this reason, skewness might not be a promising indicator of resilience.

Table 1: Published heritability estimates of the novel indicators of resilience using different types of longitudinal data.

Resilience indicators	**Livestock Species**	**Measurable trait**	**Sample Size**	***h*^{2} estimates**	**References**
Variance of Deviation	Cattle	**Milk Yield**			
		Parity 1	67,025	0.1	Elgersma *et al.,* 2018
		Parity 1	198,754	0.198 - 0.244	Poppe *et al.,* 2020
		Parity 1, 2 and 3, respectively	200,070, 155,723, and 89,963 respectively	0.20, 0.18, and 0.19, respectively	Poppe *et al.,* 2021
		Parity 1	199,074	0.17 - 0.18	Poppe *et al.,* 2021
	Chicken	Body Weight	1,593	0.1	Berghof *et al.,* 2019
Root mean Square Deviation	Pigs	Feed intake	1,341	0.21	Putz *et al.,* 2019
		Duration at a feeder	1,341	0.26	Putz *et al.,* 2019
Lag-one autocorrelation	Cattle	**Milk Yield**			
		Parity 1	198,754	0.083 - 0.095	Poppe *et al.,* 2020

		Parity 1, 2 and 3, respectively	200,070, 155,723, and 89,963 respectively	0.084, 0.073, and 0.058, respectively	Poppe *et al.,* 2021
		Parity 1	199,074	0.064 - 0.074	Poppe *et al.,* 2021
	Chicken	Body Weight	1,593	0.11	Berghof *et al.,* 2019
Skewness of Deviation	Cattle	Milk yield (Parity 1)	198,754	0.011 - 0.017	Poppe *et al.,* 2020
	Chicken	Body Weight	1,593	0.09	Berghof *et al.,* 2019
Slope of the reaction norm	Goat	Milk yield	20,546	0.11	Sánchez-Molano *et al.,* 2019
	Sheep	Body Weight	4,469	0.146	Sánchez-Molano *et al.,* 2020
		Milk yield	36,908	0.12 - 0.17	Tsartsianidou *et al.,* 2021
Absolute Value of the reaction norm	Goat	Milk yield	20,546	0.09	Sánchez-Molano *et al.,* 2019
	Sheep	Body Weight	4,469	0.138	Sánchez-Molano *et al.,* 2020

Table 2: Published genetic correlations of two resilience indicators: log-transformed variance of deviation (LnVar) and autocorrelation of deviation (r_{auto}) with fertility, health, metabolic, and production traits.

Trait	**Genetic Correlation**		**Sample Size**	**Species (Data used)**	**References**
	LnVar	**r_{auto}**			
Calving Interval	−0.22	−	67,025	Cattle (Milk yield)	Elgersma *et al.,* 2018
Interval-first to last insemination	−0.12	−	67,025	Cattle (Milk yield)	Elgersma *et al.,* 2018
Combined fertility	−0.09 to −0.17	−0.04 to −0.08	198,754	Cattle (Milk yield)	Poppe *et al.,* 2020
Combined fertility	−0.25 to −0.35	−0.11 to −0.05	89,963 to 202,202	Cattle (Milk yield)	Poppe *et al.,* 2021
udder health	−0.36	−	67,025	Cattle (Milk yield)	Elgersma *et al.,* 2018
udder health	−0.22 to −0.32	−0.09 to −0.19	198,754	Cattle (Milk yield)	Poppe *et al.,* 2020
udder health	−0.21 to −0.33	−0.07 to −0.27	89,963 to 202,202	Cattle (Milk yield)	Poppe *et al.,* 2021
Claw health	−0.07	−	67,025	Cattle (Milk yield)	Elgersma *et al.,* 2018
Hoof health	−0.03 to −0.04	−0.01 to 0.01	198,754	Cattle (Milk yield)	Poppe *et al.,* 2020
Hoof health	−0.09 to −0.19	−0.04 to 0.04	89,963 to 202,202	Cattle (Milk yield)	Poppe *et al.,* 2021

Ketosis	−0.52	−	67,025	Cattle (Milk yield)	Elgersma *et al.,* 2018
Ketosis	−0.27 to −0.33	−0.02 to −0.11	198,754	Cattle (Milk yield)	Poppe *et al.,* 2020
Ketosis	−0.41 to −0.48	−0.01 to −0.17	89,963 to 202,202	Cattle (Milk yield)	Poppe *et al.,* 2021
Natural Antibodies	−0.09	0.02	1,593	Chicken (Body Weight)	Berghof *et al*., 2019
Longevity	−0.30	−	67,025	Cattle (Milk yield)	Elgersma *et al.,* 2018
Longevity	−0.28 to −0.34	−0.03 to 0.01	198,754	Cattle (Milk yield)	Poppe *et al.,* 2020
Longevity	−0.04 to −0.18	−0.05 to 0.04	89,963 to 202,202	Cattle (Milk yield)	Poppe *et al.,* 2021
Body Condition Score	−0.29 to −0.40	−0.01 to −0.07	198,754	Cattle (Milk yield)	Poppe *et al.,* 2020
Body Condition Score	−0.22 to −0.42	−0.10 to 0.04	89,963 to 202,202	Cattle (Milk yield)	Poppe *et al.,* 2021
Dry matter Intake	−0.54 to −0.66	−0.07 to −0.19	198,754	Cattle (Milk yield)	Poppe *et al.,* 2020
Dry matter Intake	−0.30 to −0.59	−0.04 to −0.39	89,963 to 202,202	Cattle (Milk yield)	Poppe *et al.,* 2021
Average daily milk yield	0.75 to 0.79	0.15 to 0.20	198,754	Cattle (Milk yield)	Poppe *et al.,* 2020
305-day total milk yield	0.61 to 0.64	0.10 to 0.18	198,754	Cattle (Milk yield)	Poppe *et al.,* 2020
305-day total milk yield	0.48 to 0.69	−0.04 to 0.15	89,963 to 202,202	Cattle (Milk yield)	Poppe *et al.,* 2021

Despite the indicators listed and discussed above having generally low to moderate heritabilities, most of them have moderate genetic correlations have been reported between them and fitness related such as fertility, health, and longevity signifying their importance in dairy production. Direct assessment of fertility, longevity, and health is expensive in terms of time, cost, and labor as they require more and different datasets to be collected.

These empirical indicators can easily be integrated into selection indices for dairy cattle in SSA since they use same data that are used to assess other performance traits such as growth and production. Nevertheless, routine collection of data is a challenge in livestock production systems in sub-Saharan Africa. Perhaps the resources being allocated to quantify resilience in a trait-by-trait manner could be channeled to the frequent collection of quality longitudinal data such as milk yield, growth traits, and activity patterns. Improved data quality and quantity would not only help to assess resilience but also improve production performance.

3.2. Indicators of Specific Resilience

These indicators capture resilience of animals to macroenvironmental disturbances. Macroenvironmental stressors are the environmental disturbances such as heat stress, inadequate in supply of water and feed, and disease pressure, that affect the whole population. Therefore, these indicators capture severity of macroenvironmental disturbances and are specific to that type of disturbance. They measure how stable the animal performs in different intensity of a disturbance. Some of these indicators include:

3.2.1 Slope of the reaction norm

A reaction norm is the spectrum of phenotypic variation produced when individuals of the same genotype are exposed to varying environmental conditions. The slope of the reaction norm is the number that describes both the direction and the steepness of the reaction norm. It measures the phenotypic change in the performance of an individual animal in response to disturbances in the field (phenotypic plasticity). It indicates the severity of macro-environmental disturbance experienced by an individual animal.

Under the assumption that a stressor is reducing the trait values, animals that are not influenced by these disturbances are expected to have a positive slope or a slope of zero whereas those affected by the disturbance should have slopes below zero. The steeper the negative slope, the more the animal is influenced by the respective disturbance, and the more the animal is less resilient (Berghof *et al.,* 2019). The slope of the reaction norm had a weak but significant ($p<0.01$) positive genetic correlation (0.04 to 0.05) with total lifetime milk yield in goats (Sánchez-Molano *et al.,* 2019). This shows that animals with high milk production potential are more likely to have their production influenced by the changes in their environments.

3.2.2 Absolute value of the reaction norm

Absolute value of the reaction norm is the distance of the slope of the reaction norm from zero. It indicates the stability or volatility of animal performance in relation to the disturbances in the environment. The closer the absolute value to zero, the more stable and resilient the animal is. Previous studies showed that the absolute value of the reaction norm has a moderate genetic correlation with total lifetime milk yield (0.46) in dairy goats (Sánchez-Molano *et al.,* 2019) and a weak negative correlation (-0.152) with weight gain in sheep (Sánchez-Molano *et al.,* 2020). This implies that resilient animals do not allocate resources to the production of milk at the expense of their health and welfare. Resilient animals (with low absolute value of the reaction norm) have also higher average weight gain than less resilient animals.

4. Phenotypes Related to Resilience

These are phenotypes that can be utilized to quantify resilience of the animals either directly or by analyzing them using one of the methods named above. The phenotypes to be used to quantify resilience in SSA should be simple and easier, and cost and labor effective to measure. The tools used to collect these phenotypes should be easily available to make their use scalable. Some of the phenotypes that meet such criteria include body energy related traits, physical activity patterns, and milk production profile. Resilient animals are less affected by the changes in their environment and are expected to have limited deviations from the expected measurement value of the phenotype.

4.1. Body Energy Related Traits

These include body weight and related body linear measurements such as heart girth and body condition at a specific stage of life. They can indirectly inform about body fat mobilization, dry matter intake, and feed efficiency. Lactating cows mobilize their body fats to support milk production and other metabolic energy requirement deficiencies. When the energy obtained from dry matter intake is not enough, the animal is likely to catabolize some of its energy reserves to compensate for the deficit. These phenotypes include body weight and body condition score of animals.

4.1.1. Body Weight

The weight of the animal assesses the growth rate of the animals and determines of feed requirements, and the response of animals to changes in their environment (Lukuyu *et al.,* 2016). The most globally accepted and accurate method of measuring weight is the use of a calibrated mechanical or electronic scale. However, this method is expensive and not readily available in sub-Saharan Africa, especially in the case of smallholder dairy systems. Estimation of the body weight from the visual assessment is always subjective and is associated with a lot of errors (Machila *et al*., 2008). Therefore, the use of inexpensive, direct measuring tapes to measure the heart girth and body length for estimation of live weight is currently the most reliable method in SSA. Even though the body weights of animals vary, changes from the ideal weight can be utilized to inform about the resilience of the animals. Previous studies have shown genetic variation in fluctuations of body weight in different livestock species (Sánchez-Molano *et al*., 2020; Berghof *et al.,* 2019).

4.1.2. Body Condition Score

Body condition score is used to estimate the level of mobilization of body fat reserves. Various scoring procedures ranging from a visual and tactile assessment of the fat reserves on the back and pelvic region of the animals to the use of photographic mobile applications are applied. Animals have different levels of body fat mobilization depending on their genetics, health status, climatic condition, lactation stage, and the level of farm management. Therefore, BCS varies with animal and time of assessment. Scoring of body condition can be used to provide information on the wellbeing, nutrition, production, and reproductive performance, hence robustness of dairy herd (Heinrichs *et al.,* 2016; Kellogg 2010; Bewley and Schutz 2008). Deviations from ideal BCS negatively affects the production, reproduction, and health status of dairy cows (Garnsworthy and Topps 1982).

There is no one specific recommended BCS that applies across all stages of lactation as the energy requirement varies with stages of lactation. An ideal BCS at a given stage of lactation is that which optimizes milk production and reproductive performance and minimizes health disorders thereby ensuring optimal profitability (Bayram *et al.,* 2012). Dairy cows maintaining an ideal body condition score curve throughout the lactation, dry, and transition period are likely to have better reproductive performance and lower occurrence of disease (Roche *et al*., 2009; Gomez *et al.,* 2018). From different recommendations in the literature, an ideal body condition of cows on a scale of 1-5 should range between 2.5 to 3.75 with the lowest point (nadir BCS) witnessed at the early stage of the lactation (Table 3 and Figure 1).

Table 3: Recommended body condition score for dairy cows at different stages of lactation generated from published literature on a 1 - 5 scale.

Lactation stage	Cattle Breed/Type	Days in Milk	Minimum	Average	Maximum	Reference
Early Lactation	HF and J	At Service	2.00	2.25	2.50	Ohnstad 2013
	General	1-30	2.75	3.00	3.25	Heinrichs *et al*., 2016
	General	31-100	2.50	2.75	3.00	Heinrichs *et al*., 2016
	General	30-120	2.50	2.75	3.00	Klopčič *et al*., 2011
	General	30	2.50	2.75	3.00	Kellogg 2010
	General	100-120	2.50		3.25	Ferguson 1996
	General	At Service	2.50	3.00	3.50	Parker 2012
Mid Lactation	HF and J	2 months before dry-off	2.50	2.75	3.00	Ohnstad 2013
	General	101-200	2.75	3.00	3.25	Heinrichs *et al*., 2016
	General			3.0		Kellogg 2010
	General	120-240	2.75	3.00	3.25	Klopčič, Hamoen, and Bewley 2011
	High	Around 180	2.50	2.75	3.0	Parker 2012

	Producing					
	Average Producing	Around 180	3.00	3.25	3.50	Parker 2012
Late lactation to dry-off Period	HF and J	Dry off		3.00		Ohnstad 2013
	General	201-300	3.00	3.25	3.75	Heinrichs *et al*., 2016
	General	Dry-off	3.25		3.50	(Mishra *et al*., 2016
	General	>300	3.25	3.50	3.75	Heinrichs *et al*., 2016
	General	200 - Dry-off	2.75		3.50	Ferguson 1996
	General	Dry-off	3.25		3.50	Ferguson 1996
	General		3.25	3.50	3.75	Kellogg 2010
	General	>240	3.25	3.50	3.75	Klopčič *et al*., 2011
	General	Dry-off		3.5		Scanes 2011
	General	App. 270	3.25	3.50	3.75	Parker 2012

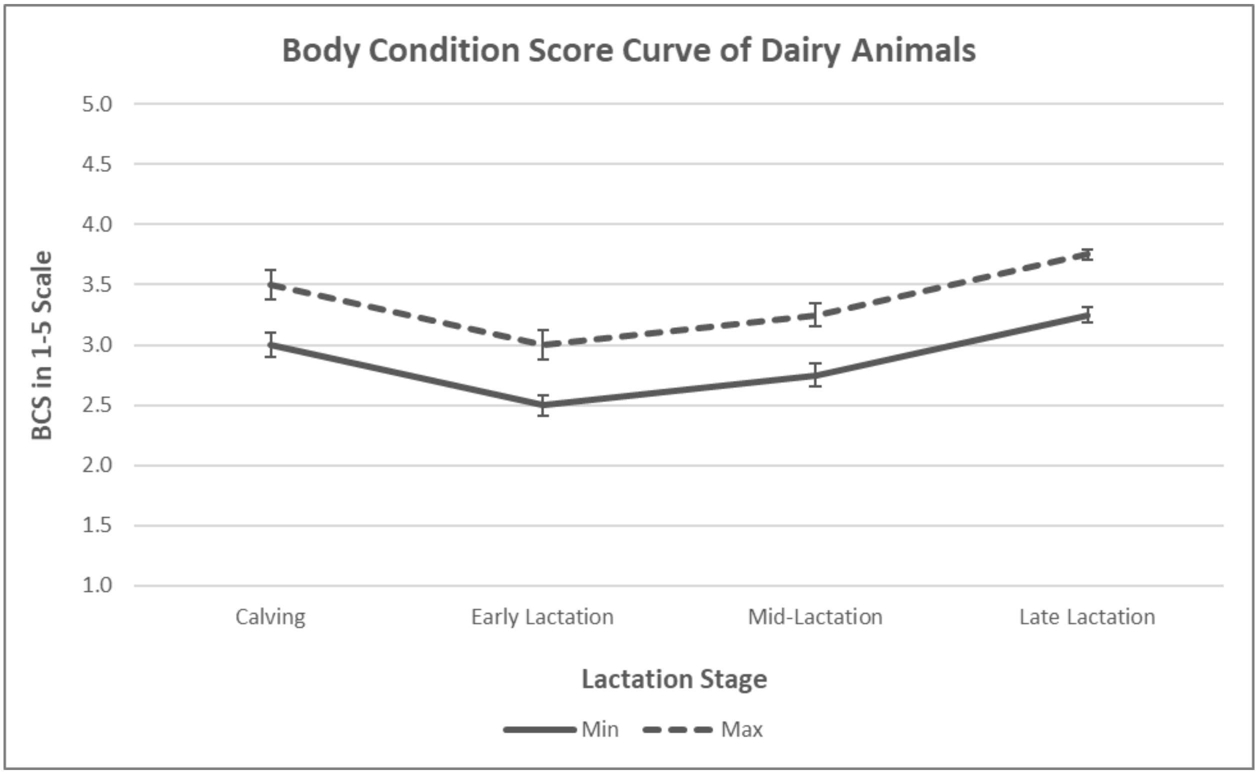

Figure 1: Ideal body condition curve of dairy cattle generated from various BCS recommendations in the literature

Despite the potential of BCS in assessing robustness of dairy herd, its assessment through visual observation is subjective as it is affected by the training and experience of the evaluator. The score an animal get would still vary among the experienced evaluators and could be influenced by previously observed cows (Bercovich *et al*., 2013). Advances in technology has seen smartphone applications with photographic sensors being developed and used in developed countries to score body condition of animals directly. Nonetheless, care should be taken before using such applications to score animals in sub-Saharan Africa as the body conformation of zebu and their crosses is different from that of taurine cattle and their crosses.

4.2. Animal Activity patterns

The activity patterns of animals differ depending on an individual, management practices, and regional differences (Krawczel 2014; Ito *et al*., 2014). Changes in activity patterns can help in detecting health and welfare issues of animals (EIP-AGRI 2018). Using activity pattern data, the resilience of animals can be estimated based on the average daily measurement after adjusting for encountered fixed effects. Depending on the required measurement, whether more or less, animals that perform below or above the population average could be more resilient. Another way of quantifying resilience would be based on the fluctuations from their normal activity pattern. Animals adjust their activity patterns such as lying, mobility, and feeding behavior in response to the stressors in their environment. These adjustments can be used to define resilience indicators to estimate their degree of resilience to these disturbances. Resilient animals are expected to have limited deviations from their normal activity patterns. Precision livestock farming (PLF) sensor-based technology has allowed data on the physical activities of the animals to be easily collected using activity meters and analyzed. Some of the activity data include but not limited to lying, standing, and stepping behaviors.

Lying behavior includes total lying time and the number of the lying bouts. Generally, cows spend from 4 to 19.5 hours lying with 1 to 28 lying bouts per day (Ito, Weary, and von Keyserlingk 2009). Limited lying is associated with low productivity and poor welfare whereas more than usual lying behavior could be an indicator of health issues. Animals stay in standing posture when feeding, drinking water, socializing, being milked, or moving from one point to another. Spending more than 11 hours per day standing could be a sign of heat stress and might increase the risk of lameness and decreased standing time could be an indicator of physical injuries, lameness, and other sicknesses (Temple *et al*., 2016). Animals move around in search of feed, mate, and resting areas as well as to the milking parlors. The stepping behavior during grazing could inform about feed efficiency and grazing type (Gregorini *et al*., 2015). A higher step count confers physical health benefits but is a risk factor for lameness. Lower than usual step count could indicate a health disorder.

Mobility scoring is used to assess lameness. Industry-standard 4-point mobility scoring on a scale from 0 to 3 is the commonly used scale with 0 signifying sound/good mobility and 3 indicating severely impaired mobility (Whay *et al*., 2003). Lameness leads to low milk production, poor reproductive performance, compromised animal welfare, and an increased risk of premature culling (Archer, Green, and Huxley 2010). It is also associated with physical injury and different kinds of clinical diseases (Murray *et al*., 1996). The incidence of lameness is influenced by the genetics of the animal (such as temperament and body conformation), management practices, and geographical region. The animals with constant high mobility scores are deemed to be less resilient as their movement in search of feed and water is impaired thus requiring extra labor to feed.

4.3. Milk Production Traits

These include milk yield, milk chemical composition especially fat and protein content, and somatic cells. Disturbances in the environment such as diseases and harsh climatic conditions are expected to cause a decrease in milk yield. Less resilient animals are highly affected by the perturbations and will deviate greatly from their expected milk production levels. For instance, animals that are greatly affected by heat stress will reduce their feed intake and consequently produce less milk yield and of lower quality than anticipated. Therefore, deviation of milk yield from the expected lactation curve of the animal can inform the resilience of the animals. Indeed, studies have already used the fluctuation in the milk yield to indicate resilience of the animals (Sánchez-Molano *et al*., 2019; Poppe *et al*., 2020, 2021; Tsartsianidou *et al*., 2021).

Variability of fat and protein content of the milk measured on test-days has also been shown to have genetic variance (Ehsaninia, Ghavi Hossein-Zadeh, and Shadparvar 2019). As an example, variations in fat content may indicate resilience to rumen acidosis or ketosis. It would be interesting though to use more frequent records of fats and protein content to define resilience indicators and estimate genetic correlations with health and fitness traits.

Somatic cell count (SCC) is the count of cells in a milliliter (mL) of milk sample. Its log-transformed form is called somatic cell score (SCS). SCC in the milk is used to indicate the status of udder health and mastitis infection. Generally, a healthy cow is expected to have up to 100,000 somatic cells per 1 mL of milk. A somatic cell count above 200,000cells/mL is considered an indicator of mastitis infection (El-Tahawy and El-Far 2010; Cinar *et al*., 2015).Variations in somatic cell scores could be used as an indication of resilience to mastitis (De Haas *et al*., 2008; Urioste *et al*., 2012). Mastitis is one of the most common production-related diseases in cows in SSA especially in small-scale dairy systems that result in huge economic losses following high rates of rejection of milk from the market (Chagunda *et al*., 2016). A resilient animal is expected to have few incidences and frequencies of mastitis infection or a high recovery rate from the infection.

Light and portable milk analyzers are commercially available and can be used to quickly measure milk chemical composition and SCC directly from the field. This reduces the cost, time and labor needed for laboratory analysis.

5. Conclusions

This review presents the need for breeding for resilience as one of the ways of improving dairy productivity in the tropics, and specifically in sub-Saharan Africa. It points to the difficulty associated with quantifying or measuring resilience and describes some of the indicators and phenotypes that can be used to quantify degrees of resilience in Sub-Saharan Africa. The indicators are broadly categorized into two; those that capture resilience to microenvironmental disturbances (general resilience) and those that measure resilience to macro-environmental disturbances (specific resilience). Indicators of general resilience include variance of deviation, Root mean square deviation, Lag-1 autocorrelation of deviation, and skewness of deviation. Indicators of specific resilience are slope and the absolute value of the reaction norm. All these indicators have genetic variation and heritabilities that are significant from zero hence can be used to select for resilience. In addition, easier to measure phenotypes that are routinely collected using available tools offer opportunities for characterizing resilience of dairy cattle in the Sub-Saharan Africa. Some of these phenotypes includes energy metabolism traits such as body weight and body condition score, milk production traits such as milk chemical composition and somatic cells count, and activity patterns such as time spent lying or standing and step counts.

However, using these indicators and phenotypes to quantify resilience require that large volume of related data be collected on animals and appropriately analyzed. African Dairy Genetic Gains (ADGG), a project led by International Livestock Research Institute (ILRI) and funded by Bills and Melinda Gates Foundation (BMGF), which is an integral part of the One-CGIAR's SAPLING initiative is capturing and managing large volumes of performance data from both small and large-scale farmers in eastern Africa and are pulling related weather data to derive indicative resilience traits. Future efforts aim to capture resilience indicator data using various sensor-based technologies more directly. Over time, accumulated data can be used in genetic evaluations. Using this data, analyses aimed at testing the potential of applying these indicators to breed for resilience and robustness of dairy cattle in Sub-Saharan Africa are underway. Preliminary results obtained so far show that indicators such as variance and autocorrelation of deviations have genetic variability and are reasonably heritable hence can be appropriately combined into a composite resilience measure that can be used to inform selection for resilience in sub-Saharan Africa.

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