APPLICATION OF POSITIVE DEVIANCE CONCEPT TO ASSESS AMELIORATION STRATEGIES FOR ENVIRONMENTAL STRESSES ON SMALLHOLDER DAIRY FARMS IN TANZANIA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this university or any other for the award of a degree.

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Recommendation

This thesis has been submitted with our approval as University supervisors.

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DEDICATION

This thesis is dedicated to my dear father, Mzee Said Shija Ngasa, who passed away on 10th November 2020 during the course of implementing my PhD research project. I loved you, till we meet again in the New World - *Revelation 21: 3, 4*. This thesis is also dedicated to my lovely wife Witness Elifuraha Malisa, our children Sandra, Jermaine, Jeff, Jess and Doreen, my mother Mrs. Helena Lubele, brothers, sisters and the entire Ngasa family.

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ABSTRACT

Heat load, feed scarcity and disease infections are prevalent environmental stresses (ES) which either limit or reduce productivity potential of dairy cattle in the tropics. Those prevalent ES impact negatively on production performance of dairy cattle and results in a loss of livelihood benefits from dairying. Among smallholders, a few farmers (positive deviant farms (PDs)) attain consistently outstanding dairy production performance. While majority (typical farms) attain poor performance and loose benefits from dairy cattle. However, literature generally associates outperformance of PDs with husbandry practices being deployed differently from those in typical farms. Empirical evidence is lacking on association of PDs with specific husbandry practices, disease infections, lactation and growth performance. The objective of this study was to contribute to high livelihood benefits from dairying by improving productivity through learning from PDs' ameliorative husbandry practices under contrasting stressful production environments in Tanzania. The severity of heat load stress on dairy cattle was estimated by temperature-humidity index (THI). A sample of 794 from 3800 smallholder dairy farmers benefiting from the African Dairy Genetic Gains Project was used. Positive deviants were identified based on criteria of consistently outperforming typical farms ($p<0.05$) in five production performance indicator variables simultaneously: daily milk yield ≥6.32 L/cow/day, energy balance ≥0.35 Mcal $NE_{L/d}$, age at first calving ≤1153.28 days, calving interval ≤633.68 days and disease-incidence density ≤12.75 per 100 animal-years at risk. The study used a two-factor nested design, with farms nested within the production environment classified as low- and high-stress. Results show that dairy cattle in low-stress environment were exposed to lower heat-stress levels (68.20±0.39 THI) while those in high-stress environment were exposed to mild to moderate heat-stress levels (77.29±0.39 THI). The application of Pareto-Optimality ranking technique complemented with multiple indicator-variable sorting isolated 3.4% PDs and were fairly distributed in low- (n=15) and high-stress environments (n=12). Results reveal significant variations ($p<0.05$) between PDs and typical farms. Dairy cattle in PDs consistently attained better production performance in low- and high-stress environments. The management practices that differentiated PDs from typical farms were provision of larger floor spacing (13.19±1.94 vs. 6.17±0.37 m^2/animal) in high-stress, cattle upgrading, and increased investment in housing, fodder, water and professional health services. These practices can be associated with amelioration of feed scarcity, heat load stresses, and disease infections, and better animal welfare status, which enabled attainment of consistent higher productivity levels in PDs. Therefore, typical farmers should learn from PDs on how to apply husbandry practices effectively to ameliorate feed scarcity, disease infections and heat load stresses.

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LIST OF ABBREVIATIONS

ADGG:	African Dairy Genetic Gains Project
AFC:	Age at first calving
ASDP:	Agricultural Sector Development Program
ASL:	Above sea level
CI:	Calving interval
°C:	Celsius degree
DGEA:	Dairy Genetics East Africa
DIM:	Number of days in milk
DM:	Dry matter
EB:	Energy balance
ECF:	East Coast Fever
FAO:	Food and Agriculture Organisation of the United Nations
ICAR:	International Committee for Animal Recording
ILRI:	International Livestock Research Institute
NWDCS:	Nronga Women Dairy Cooperative Society
PD:	Positive deviance
PDA:	Positive deviance approach
PDs:	Positive deviant farmers
RH:	Relative humidity
SHDF:	Smallholder dairy farms
SHDFs:	Smallholder dairy farming systems
SD:	Standard deviation
T:	Air temperature
TALIRI:	Tanzania Livestock Research Institute
TBDs:	Tick-borne diseases
TYPs:	Typical dairy farmers
THI:	Temperature-humidity index

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Dairy cattle are important livelihood assets in smallholder households in many parts of East Africa. This is because dairy cattle produce milk for consumption in households, generate income to meet financial needs, maintain soil fertility for crop production in mixed crop-livestock smallholder systems as well as relatively high financing and insurance values (Bebe *et al.,* 2003; Chawala *et al.,* 2019). However, the commercial dairy cattle genotypes are extremely sensitive to environmental stresses that are prevalent on smallholder dairy farms (SHDF), such as the high levels of heat load, nutritional scarcity and disease infections. These stresses result in substantial loss of the livelihood benefits from dairy cattle farming for households. Stress is associated with an animal's inability to adapt to its environment, leading to discomfort, reduced feed intake, increased susceptibility to diseases, impaired growth and development, reduced milk yield and quality, impaired immune system and suboptimal reproductive performance.

The production systems under which dairy cattle are kept in Tanzania can be classified in five criteria (FAO, 1998): these are climate, terrain, disease and parasites, resource availability and management approaches. These classification criteria reflects the common environmental stresses that influence the extent to which an animal express genetic potential in production performance. Three of these stresses are important for dairy production in Tanzanian SHDF: heat load, nutritional scarcity and infections with disease and parasites. These stresses are likely to increase in magnitude with the uncertainty of climate extreme events with negative implications on SHDF. Environmental stresses could further limit productivity of dairy cattle from increased parasitic infections (tick and tick borne diseases, internal parasites, flies), feed and water scarcity, and exposure to daily high heat load humidity index (Ekine-Dzivenu *et al.,* 2019; Gustafson *et al.,* 2015; Wangui *et al.,* 2018).

Stress arising from heat load reduce productivity of dairy cattle through its associated reduction in feed intake and milk production, impaired fertility performance, lowered birth weights, increased stillbirths and dystocia cases, disrupted haematological parameters, increased disease morbidity and mortality rates and hyperthermia (Ekine-Dzivenu *et al.,* 2019; Gustafson *et al.,* 2015). Animal response to heat load stress is by maintaining their body core temperatures higher than the surrounding air temperature thus allowing heat to escape through conduction, convection, radiation and evaporation (Dunshea *et al.,* 2013). Strategies for ameliorating heat load stress in dairy cattle include having improved housing management (shelter design, shading and cooling systems), use feed additives and sufficient water supplies, and selecting stress resistant breeds.

Seasonal forage and feed scarcity, and quality leads to seasonal milk production and supressed animal immune system. This leads to interrupted growth manifested in underweight for age, slow growth rate and poor lactation yields and impaired fertility (Gaughan *et al.,* 2010). An ameliorating strategy to forage inadequacy is supplementary feeding to meet animal nutritional requirements (Henriksen *et al.,* 2019). Raising concentrate and lowering the amount of fodder increases the diet's energy concentration while decreasing the quantity of intake required during the period of feed scarcity. Fodder production, especially the use of high yielding forages, conservation and feeding technologies are common ameliorative strategies that increase biomass for dairy production in stressful environments. Genetic selection and crossbreeding with more tolerant genotypes is an ameliorative strategy that can counteract nutritional stress for improved productivity (Khorshidi *et al.*, 2017).

Disease stress can lead to neuroendocrine disruption and immunosuppression, reduced productivity and profitability (Rushton, 2009). Amelioration strategies recommended include continuous genetic selection, artificial insemination (AI), embryo transfer, crossbreeding, provision of improved nutrition, timely treatments, vaccination, deworming, dipping animals by using recommended acaricides and improved housing (Das *et al.*, 2016; Lynen *et al.*, 2012). Where tick-borne diseases are common, particularly *Theileriosis* (ECF) and *Babesiosis*, dipping and spraying with acaricides and vaccination are ameliorative strategies that mitigate anemia-related mortality, body weight losses and strengthen animal immune systems against diseases (Chagas *et al.*, 2007; Lynen *et al.*, 2012).

In Tanzania, field data indicate that the level of *Bos taurus* inheritance influence daily milk yield and in this regard it is advised to utilise crossbred animals of intermediate exotic blood levels (62.5-75%) for good production performances on SHDF (Bee *et al.,* 2006). Smallholders frequently raise Ayrshire, Holstein-Friesian, Jersey, Simmental, and Tanzanian shorthorn zebu and Boran crossbred dairy cattle with 50% to 85% levels of exotic blood (Mujibi *et al.,* 2019; Swai *et al.*, 2005). The cows with 75% *Bos taurus* inheritance are able to produce more milk than the other *Bos taurus* levels with better fertility performance under the same production environments. For example, F_1 crosses are reported to perform better than high-grade animals with 34.6 months of AFC, 171 days of calving to first service, 182 days open with an average calving interval of 455 days (Asimwe & Kifaro, 2007). However, there is large variability in performance. For instance, if heat load stress suppresses feed intake and the amount of feed available is insufficient to sustain a higher milk yield, stress lowers cow fitness, fertility, and immune function, exposing animals to a variety of disease infections (Gustafson *et al.,* 2015; King *et al.,* 2006). Under stressful environments, total milk production on SHDF in Tanzania can reach 1700 kg per cow in 10-months and 1940 kg per cow over an extended lactation period of 12-months (Swai & Karimuribo, 2011).

Large variation in performance are observed in milk yield and fertility that reflect variations in management strategies. For example, the Dairy Genetics East Africa (DGEA) Project classifies producers on the basis of attaining 5 and 10 litres per cow per day to distinguish between best and typical smallholder dairy farmers (Chawala *et al.,* 2019). The 5 litres/cow/day is the typical actual milk output per cow for the majority of SHDF (about 90%) while the 10 litres per cow per day is attained by top 10% of the excellent SHDF. However, the authors do not explain the ameliorative strategies to doubling milk from 5 to 10 litres per cow per day under same stressful production environment.

The influence of environmental stresses limiting dairy productivity has attracted wider research interests (Gillah *et al.,* 2014; Richards *et al.,* 2015). From such studies, many ameliorative management strategies have been recommended for the prevalent environmental stresses to improve productivity and sustainable utilisation of dairy cattle on SHDF. Some of these strategies include genetic selection, crossbreeding, embryo transfer, provision of improved nutrition, timely treatment of diseases, vaccination, treatment of external and internal parasites, quarantine for new animals entering the farm, biosecurity measures and proper housing system (Das *et al.,* 2016; Gustafson *et al.,* 2015; Lynen *et al.,* 2012). However, despite of recommended strategies, a large proportion of SHDF continue to record suboptimal performance, such that the potential livelihoods benefits of dairy cattle production to the households are only marginally realized. Further, because of differences in agro-ecological zone such as highlands and coastal regions, type and breed of cattle, milk production levels are still low especially in typical farms with a yield gap of more than 50% as compared to their genetic potential. Even in those farms where management intervention is thought to be better, milk production ranges from 5.7 to 12.7 litres/cow/day (Gillah *et al.,* 2012; Gillah *et al.,* 2014). However, within a farming community, a few farmers are known to consistently succeed in maintaining high performance under the same production environment with the same prevalent stresses. These consistently outperforming farmers among their peers represent positive deviants. They likely apply ameliorative management strategies differently and innovatively that enable them to maintain high performance (Mertens *et al.,* 2016; Savikurki, 2013). The positive deviants provide local context learning lessons within their communities (Bradley *et* *al.,* 2009; Herington & Fliert, 2018; Sternin, 2002) about ameliorating strategies for prevalent environmental stresses to enable productive and sustainable utilisation of dairy cattle.

1.2 Statement of the Problem

Environmental stresses such as heat load, feed scarcity and disease infections negatively affect dairy cattle productivity, which, in turn, reduces or eliminates the potential livelihood benefits from dairying in the majority of SHDF. Among smallholder farmers, a few (positive deviant farms (PDs)) attain outstanding dairy production performance. While majority (typical farms) attain poor performance and loose benefits from dairy cattle. However, literature generally associates outperformance of PDs with husbandry practices being deployed differently from those in typical farms. Empirical evidence is lacking on association of PDs with specific husbandry practices, disease infections, lactation and growth performance. Through understanding how PDs successfully ameliorate stresses can inform choices and deployment of the management strategies (Hammond *et al.,* 2017; Savikurki, 2013). Learning from such SHDF through the application of positive deviance concept (Bradley *et al.,* 2009; Herington & Fliert, 2018; Savikurki, 2013), could inform how to ameliorate environmental stresses to improve productivity and sustainable utilisation of dairy cattle on SHDFs. Positive deviance concept is a practical strategy for finding and promoting practical solutions in a problem of interest. This is a limited learning process that informs on how to innovatively ameliorate prevalent environmental stresses limiting sustainable utilisation of dairy cattle on SHDFs. Innovations that address local prevalent environmental stresses to improve dairy productivity and livelihood benefits should have a high likelihood of success, acceptability and sustainability within a dairy farming community (Albanna *et al.,* 2022; Hammond *et al.,* 2017; Jaramillo *et al.,* 2008; Sternin, 2002).

1.3 Objectives of the Study

1.3.1 Broad Objective

The objective of this study was to contribute to high livelihood benefits from dairying by improving productivity through learning from positive deviant farms' ameliorative husbandry practices under contrasting stressful production environments in Tanzania.

1.3.2 Specific Objectives

The specific objectives of this study were as follows:

i. To identify positive deviant farms using Pareto-optimality ranking technique in a sample of smallholder dairy farms under contrasting stressful environments in Tanzania and estimate productivity, milk yield gap and total livelihood benefits.
ii. To characterise management practices that positive deviant farms deploy differently from typical farms to ameliorate local prevalent environmental stresses under contrasting dairy-production environments in Tanzania.
iii. To assess animal disease prevalence and mortality in smallholder dairy farms under contrasting management practices and stressful environments in Tanzania.
iv. To assess lactation curve characteristics of Holstein-Friesian and Ayrshire dairy cows managed under contrasting husbandry practices and stressful environments in Tanzania.
v. To assess growth-curve characteristics of dairy cattle heifers managed under contrasting husbandry practices and stressful environments in smallholder farms in Tanzania.

1.4 Research Questions

The research questions were as follows:-

i. Do the positive deviants significantly outperform typical farms in productivity, milk yield gap and total livelihood benefits under contrasting stressful environments in Tanzania?
ii. Do the positive deviant farms deploy management practices differently from typical farms to ameliorate prevalent environmental stresses under contrasting stressful environments?
iii. Do the animals managed in positive deviants and typical farms suffer different levels of disease infections and mortality, whether under low- or high-stressful environments?
iv. Do the cows in positive deviants and typical farms express lactation curve characteristics differently, regardless of the stress levels exposure in low- and high-stress environments?
v. Do the growth curve characteristics of heifers in smallholder dairy farms differs significantly under contrasting husbandry practices and stressful production environments?

1.5 Justification of the Study

Empirical evidence which are associated with appropriate packaging of the amelioration strategies for environmental stresses limiting sustainable utilisation of dairy cattle on SHDF are needed to improve livelihood benefits of smallholders (Hammond *et al.*, 2017), as well as national economic growth through increased animal productivity. This would also contribute to the formulation of government policies that support better matching of breed-type and levels of ameliorative management strategies to increase dairy productivity.

The research outputs provides a foundation for future investigations into efficient management strategies for dairy farms in the tropics, both in low- and high-stress environments. The research method developed in this study will be used in future studies to identify more sustainable management practices to improve smallholder dairy cattle farming systems. The current findings will benefit farmers and other stakeholders such as policymakers, researchers as well as non-technical decision-makers planning to maximize productivity and guarantee the long-term viability of dairy herds. This will support smallholder dairy farmers' economic development, poverty reduction as well as food and nutritional security.

Additionally, the findings of the current study contributes to the achievement of seven sustainable development goals. This is associated with Goal 1 (no poverty), Goal 2 (zero-hunger), Goal 3 (good health and well-being), Goal 8 (decent work and economic growth), Goal 12 (responsible consumption and production), Goal 13 (climate action) and Goal 15 (life on land) of the United Nations (United Nations, 2015). Finding solutions to address environmental stresses associated with heat load, feed scarcity and disease infections in dairy cattle is necessary to increase milk production, higher-quality food, and smallholder farmers' income. This aligns with the Tanzanian government's priorities aiming to improve dairy productivity and livelihood benefits.

1.6 Organization of the Thesis

This thesis is organised into eight chapters. Chapter One discusses the introduction comprising background information of the study, statement of the problem, objectives of the study, research questions and justification of the study. Chapter Two presents a literature review of relevant works related to this study and elaborates on the theoretical basis for this study. Chapter Three (Objective One) presents the abstract, introduction, materials and methods, and discusses the findings related to identification of positive deviant farms, dairy productivity, yield gap and total livelihood benefits attained from smallholder dairy cattle farming. Abstract, introduction, methodology, and discussion of the findings related to effective ameliorative management practices deployed to overcome feed scarcity, heat load stress and disease infections stresses limiting and/ reducing dairy productivity of dairy cattle genotypes managed on smallholder farms are presented in Chapter Four (Objective Two). Animal disease prevalence and mortality density in dairy cattle managed in positive deviants and typical smallholder farms under low- and high-stress environments in Tanzania is presented in Chapter Five (Objective Three). Chapter Six (Objective Four) presents the abstract, introduction, materials and methods, and discusses the findings related to lactation performance of dairy cattle managed in positive deviants and typical smallholder dairy farms. Chapter Seven (Objective Five) presents the abstract, introduction, materials and methods, and discusses the findings related to growth-curve characteristics of heifers managed in positive deviants and typical farms under low- and high-stress dairy-production environments in Tanzania. Chapter Eight presents a general discussion, conclusion, recommendations and areas for further research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Tanzanian Government Dairy Development Objectives

The government of Tanzania through the Livestock Master Plan promotes dairy production to meet the rising need for milk and dairy products. According to the Tanzanian Development Vision, by 2025, there should be a livestock industry that is commercially run, modern and sustainable, using improved and highly productive livestock genotypes to ensure food security, improved income for households, and a stronger economy for the country while preserving the environment (Bingi & Tondel, 2015; Michael *et al.*, 2018). As a result of interventions like artificial insemination (AI), improved feed and health services, and complementary policy changes, it is expected that national milk production will rise from the 2.159 billion liters recorded in 2017/18 to 3.816 billion liters in 2021/22 (an increase of 77%). The anticipated rise in milk production will allow for the achievement of the milk production goals set forth in the Agricultural Sector Development Program (ASDP II) and a 35% surplus over the expanding domestic milk requirement. The GDP contribution of the dairy industry is projected to increase by 75% as a result of a 281% increase in the number of crossbred dairy cattle genotypes and a 26-42% increase in milk production per cow. In order to close the projected 5.4 million liters of milk production-consumption gap in 2031/32, the government is prioritizing issues that are limiting dairy productivity by promoting AI along with improved animal feed and health services. In the same time frame, additional investments are predicted to result in a milk surplus of about 0.5 million liters (Makoni *et al.*, 2013; Michael *et al.*, 2018).

In addition, the roadmap for dairy development's primary goal (2017/18–2021/22) of raising milk production will come to reality by increasing the national dairy herd size and improving the health, nutrition, and genetics of dairy animals. At the national level, the number of improved dairy cattle genotypes has increased from 783000 by 2017/18 to 1.26 million crossbreds. Similarly, annual milk production has reached 3.4 billion litres (Ubwani, 2023). The government's top investment priority is to make sure that better genetics, health care, and feed are available to boost dairy productivity, generate higher income and support the country reach its development goals (Michael *et al.*, 2018; Twine *et al.*, 2018). The appropriate combination of different interventions aim to ensure availability of breeding technologies, and improve feed and healthcare services to address negative impact of heat load stress, feed scarcity and disease infections. To address the frequently observed nutritional deficiency, access to land suitable for grazing and pasture production should be improved. By introducing high yielding pasture on irrigated land, the government hopes to increase the availability of feed resources in both quantity and quality.

2.2 Farmers' Livelihood Objectives

The main objectives of smallholder farmers engaged in dairy farming is to accrue livelihood benefits from dairying such as milk for nutrition and income for cash needs. Many smallholder farmers in Tanzania rely on dairy farming as the primary means of nutrition and income, sharing the same objectives like others in Eastern Africa (Bingi & Tondel, 2015; Mwanga *et al.,* 2019). The requirement for fresh milk and other value-added milk products has recently increased due to the rise in population in the country. This increase in demand is the main motivating and stimulating factor for the expansion of smallholder dairy farming. This demand is reflected in all East African countries, which attach a common importance to livestock and specifically the dairy sector as a major driver for agricultural development (Mwanga *et al.,* 2019). However, genetic mismatch and the prevalence of stressful production environments such as intense heat load stress, disease infections and feed scarcity which are accelerated by poor dairy husbandry practices like housing and hygiene are the main reasons for a lower productivity per animal.

The unit productivity of dairy cattle needs to be raised to keep up with the rising demand for milk and value-added milk products to satisfy the world's human population which is expected to reach 9.15 billion in 2050 (UNPD, 2008). In this case, dairy cattle represents a highly valued and productive asset that is utilised by smallholder farmers to finance many of their basic needs such as food, healthcare, housing, education and clothing. However, SHDF have not fully utilized the potentiality of their animals to sufficiently meet their needs for own livelihood benefits which include milk for nutrition, income for financial needs, and waste material to keep the soil fertile for growing crops. Recent reports shows that under stressful production environments on SHDF in Tanzania, the total milk yield stands at 1,700 kg to 1,940 kg per cow per lactation which is below the genetic potential of dairy cattle genotypes (Swai & Karimuribo, 2011). In this context, it is crucial to use smart dairy farming innovations and the top local ameliorative strategies to fully exploit the potentiality of dairy animals to produce sufficient milk to satisfy consumer demand. For proper use of scarce resources, milk yield per cow should be increased rather than animal numbers. Given this, ameliorative management practices to boost dairy cattle production are required targeting SHDF, which accounts for a larger proportion of these farms in the country.

2.3 Dairy Production Environments in Tanzania

Smallholder dairy farming offers numerous opportunities to increase income, improve food security and promote equitable economic growth. Dairy production in Tanzanian environment is mainly concentrated in five milksheds, that is central (Tabora), lake Victoria (Mwanza, Mara, Kagera), eastern (Pwani, Morogoro, Tanga), northern (Arusha, Kilimanjaro, Manyara) and southern highlands (Mbeya, Iringa, Njombe) and growing at an average rate of 6% per annum (Makoni *et al.,* 2013; Swai & Karimuribo, 2011; Twine *et al.,* 2018). The Lake Victoria region accounts for 40 percent of total milk production which primarily comes from the traditional herd mainly comprising indigenous cattle. Kilimanjaro and Arusha regions have the greatest number of dairy cattle which vary in size from 3.2 to 38.9 animals perkm^2 and accounts for 50 percent of milk from improved dairy herd (Makoni *et al.,* 2013; Swai & Karimuribo, 2011). In contrast, Morogoro, Mwanza and Pwani regions have fewer dairy cattle. Similarly, registered SHDF are primarily active in regions with significant potential for dairy production such as Kilimanjaro, Arusha, Mbeya and Iringa as well as in the medium-potential regions of Tanga and Kagera.

Disease prevalence and their vectors, the differences in geo-climatic factors as well as the existence of a readily accessible milk markets among production environments appear to be the primary drivers that contribute to the uneven distribution of dairy cattle.For instance, the high density of dairy cattle in the Kilimanjaro and Arusha regions is due to the cool climate, which favours the year-round availability of animal feeds, low tick infestation and prevalence of TBDs. Animal health constraints such as *Theileriosis* (ECF), *Anaplasmosis* and *Babesiosis* are significant production challenges facing SHDF (Swai & Karimuribo, 2011). Other prevalent diseases that lower dairy productivity on SHDF include mastitis, foot-and-mouth disease, fertility issues, and metabolic diseases like hypocalcaemia and ketosis. Further observations suggest that dystocia, retained foetal membranes, abortion and nutritional deficiency are common on SHDF and possibly linked to a reduced animal productivity (Swai *et al.,* 2005). These constraints are further aggravated by the negative impact of climate change on the availability of natural resources such as water, suitable land for crop production and plant species (Gustafson *et al.,* 2015). Therefore, prevalent environmental stresses and limited infrastructure facilities significantly restricts smallholders' ability to utilize the full production potential of dairy cattle genotypes.

2.4 Dairy Cattle Genotypes Utilised on Smallholder Farms in Tanzania

Small-scale dairy farming is characterized by a low input/low yield production system. The primary features of smallholder dairy farming systems in the country are low dairy productivity levels, ownership of less than 5 ha of land, and keeping one to ten upgraded dairy cattle genotypes like Holstein-Friesian, Jersey, Ayrshire, and their crosses to the native cattle breeds (Maleko *et al.,* 2018a). The system is primarily integrated into smallholder mixed farming systems in the rural, peri-urban, and urban areas. Many smallholders use crossbred cattle in their mixed crop-livestock production systems, particularly in the medium- to high-potential production environments. Reports from field operations show that the level of *Bos taurus* inheritance in the crossbred cattle varies markedly. Smallholder dairy farms normally utilise crossbred animals of exotic blood levels ranging from 50 to 85%. However, researchers recommend the use of intermediate blood levels ranging from 62.5 to 75% for improved productivity (Bee *et al.*, 2006; Mujibi *et al.*, 2019; Swai *et al.*, 2005). Cows with 75% blood level of exotic breed seem to possess desirable attributes which can tolerate environmental stresses and produce more milk with better fertility performance. With this levels of exotic blood, dairy cows are able to produce more milk on SHDF ranging from 1,700 kg to 1,940 kg per cow per lactation (Swai & Karimuribo, 2011). However, this record is far below their genetic potential when subjected under good ameliorative strategies.

2.5 Performance of Dairy Cattle on Smallholder Dairy Farms

The production levels of milk in most of the milksheds is low as compared to the genetic potential of dairy cattle genotypes available in those regions. As the result of differences in agro-ecological zones and breed of cattle, milk production levels for example in urban and peri-urban SHDF in the Eastern milkshed was found to range from 5.7 to 17 litres per cow per day (Gillah *et al.,* 2012). In this case, a smallholder dairy farm is defined as a dairy unit keeping one to ten dairy cows with milk yields of less than 10 litres per cow per day (Shirima *et al.,* 2018; Swai *et al.,* 2010). Further, one study reported that foundation crossbred (F_1) are able to perform better than high-grade animals attaining earlier age at first calving (34.6 vs. 36.3 months) with less calving to first service interval (171 vs. 180 days), number of services per conception (1.51 vs. 1.59), number of days open (183 vs. 211 days) and calving interval (456 vs. 469 days) (Asimwe & Kifaro, 2007). These observations could be associated with factors such as feed scarcity and poor detection of heat for timely breeding.

Most of dairy cattle on SHDF mainly feed on native grasses supplemented with a varying amount of homemade concentrate mixture of cereal grains such as maize bran, cotton seed cake or sunflower seed cake. Heat load and disease stresses in humid zone may be responsible for the huge yield gaps and this result into economic implications because of low productivity levels, higher mortality rates and treatment costs. The mismatch between dairy cattle genotypes used and the production environment has also been identified in recent studies as a significant factor contributing to low productivity levels in most smallholder dairy farms (Chawala *et al.,* 2019). The huge milk yield gaps evidenced in SHDF is a result of low levels of actual productivity which could be due to environmental stresses depending on the strategies applied in the farm to ameliorative them (Chen *et al.,* 2015; Sejian *et al.*, 2012). However, estimates of the perceived yield gaps and the patterns of lactation curves, fertility, immunity, growth and development on SHDF are limited.

2.6 Environmental Stresses Limiting Dairy Cattle Production Performance

A description of environmental stresses limiting dairy performance has been established using five criteria. The five criteria are: climate, terrain, disease and parasites, resource availability and management interventions (FAO, 1998). Three of these are most important for dairy production: heat stress, nutritional scarcity both in quantity and quality, and disease infections (Table 2.1). Environmental stresses are becoming more important factors affecting dairy productivity due to uncertainty of weather patterns involving unpredictable extreme events like heat waves, drought, and infectious diseases (Gustafson *et al.,* 2015; Sejian *et al.,* 2012). As a result, there is an increasing recognition in the dairy industry to identify stressful environmental stresses and their ameliorative strategies under different production regions. This approach seems to be critical in order to develop and promote effective ameliorative strategies to improve productivity (Chen *et al.,* 2015).

The negative effect of environmental stresses on cattle is mainly in the growth and development, lactation, fertility and impaired immune system because of disease infections. Hitherto, different approaches for ameliorating environmental stresses to reduce its impact on dairy cattle breeds have been demonstrated in the field to improve productivity (Kadokawa *et al.*, 2012; Silanikove, 2000). The strategies include managing animal housing, modifying nutrition (such as seasonal specific feeding, feeding concentrates, vitamin and mineral supplementation, use of feed additives, and adequate water supplies), using biotechnology options (genetic selection, embryo transfer and choosing breeds that are stress resistant), and enhancing the delivery of animal health services (vaccination, timely treatment of diseases including internal and external parasites). Ameliorative management strategies for heat stress can be grouped into four main cost-effective heat mitigation measures such as open barns or shading, moderate forced ventilation, high fans or misting, and intense like air conditioning.

Table 2.1: Indicators of environmental stresses, animal performance and amelioration strategies on smallholder dairy farms.

Environmental stresses	**Stress indicators**	**Performance effects**	**Ameliorative strategies**	**Reference**
Heat load stress	Temperature-humidity index, rectal temperature, respiration and heart rates.	Impaired immune system, low milk yield, compromised reproduction and growth performance.	Suitable housing system, provision of adequate water, crossbreeding & embryo transfer.	Aguilar *et al.* (2009) Galán *et al.* (2018) Khorshidi *et al.* (2017)
Feed scarcity	Body weight, energy balance, body condition score, altered metabolic rate, pelvic angle & area.	Immune suppression, impaired growth, low milk yield, decreased protein & fat content, reduced body weight, impaired reproduction and altered blood profile.	Genetic selection and crossbreeding, feeding diet energy & protein concentrate, legume fodder, hay & silage supplementation, roughage & crop residue supplementation, produce adaptable high yielding forage, minerals, vitamins & feed additives supplies.	Khorshidi *et al.* (2017) Dunshea *et al.* (2013) Maleko *et al.* (2018b) Maleko *et al.* (2018a) Mordak & Stewart (2015)

Disease infections	Morbidity rate, mortality rate, circulating leukocyte, erythrocyte distribution, thrombocyte distribution.	Impaired immune system, reduced milk production, decreased protein & fat content, reduced body weight and impaired reproduction.	Genetic selection & crossbreeding, embryo transfer, vaccination, dipping, treatment of internal and external parasites, stocking density and biosecurity measures (e.g. use of footbath).	Marshall *et al.* (2019) Kadokawa *et al.* (2012) Lynen *et al.* (2012) Wang *et al.* (2010) Silanikove (2000) Collier *et al.* (2006) Dunshea *et al.* (2013) Gillah *et al.* (2014)
Common indicators	Body weight, body condition score, milk yield, non-return rate and dry matter intake.	Reduced body weight, reduced milk production, decreased protein & fat content, impaired fertility and increased mortality.	Legume fodder, hay & silage supplementation, production of adaptable high yielding forage, feeding diet energy & protein concentrate, artificial insemination, genetic selection & crossbreeding.	Maleko *et al.* (2018b) Maleko *et al.* (2018b) Dunshea *et al.* (2013) Khorshidi *et al.* (2017) Ojango *et al.* (2016)

Heat load stress, which is classified as an environmental factor, is the total of all external forces that act to raise an animal's body temperature above its resting level, which causes adverse changes in homeostasis. The temperature-humidity index (THI) makes it easy to gauge how much heat load stress is affecting dairy cattle. The degree of heat stress in dairy animals is frequently predicted using the temperature-humidity index (Allen *et al.,* 2015; Mbuthia *et al.,* 2021). The effects of temperature and humidity are combined into one value and used as a guide for estimating heat stress. Dairy cattle can maintain a physiological body temperature of 38.4–39.1°C with THI threshold values of 68 and 72 within the range of 16–25°C, which is considered their thermoneutral zone (Zimbelman *et al.,* 2010). The categories of the temperature-humidity index established by Zimbelman *et al.* (2009) range from heat load neutral (less than 68), heat stress threshold (68–71), mild to moderate heat stress (72–79), moderate to severe heat stress (80–89), severe heat stress (90–98), and critical heat stress (more than 98). Animals' behavioural, physiological, productive, and reproductive changes can be used as direct indicators of heat load stress. Physiological changes can be measured using several indicators which include endocrine system, respiration rate, panting rate/score, sweating rate, rectal temperature, intravaginal temperature, skin temperature as well as water intake, all of which are crucial for the general well-being and production performance of animals (Garner *et al.,* 2016; Wheelock *et al.,* 2010). However, rectal temperature, respiration rate, and dry matter intake are the three physiological measures used most frequently in animals (Galán *et al.,* 2018). Dairy cattle can therefore experience stress due to variations in environmental factors like air temperature, relative humidity, wind speed, and solar radiation. Its effect on lactating cows have been widely studied probably because of economic significance associated with production losses (Carabaño *et al.,* 2016).

A number of dairy production parameters are impacted by heat stress, especially in terms of decreased milk production, decreased fertility, lower birth weights, and even the potential for hyperthermia (Galán *et al.,* 2018; Kadokawa *et al.,* 2012). Raised body temperature is linked to a significant decrease in feed intake through the inhibition of the lateral appetite centre by satiety centre activated by rostral cooling centre in the hypothalamus, increased respiratory rates, alterations of blood flow and modifications to endocrine processes that impair an animal's capacity for production and reproduction (Silanikove, 2000). Additionally, it causes the rise in stillbirths, postpartum paralysis, dystocia cases, increased morbidity and mortality rates (Gustafson *et al.,* 2015). For example, in the humid and hot coastal lowland areas in Tanzania, the reported mortality cases resulting from increased activities of ticks is high up to 56% of all incidences (Swai *et al.,* 2009).

Nutritional scarcity is another environmental stress which significantly affects lactation milk production, fertility, survival, growth as well as development of an animal. The observed seasonality in milk production in most SHDF is considered to be a consistent characteristic of Tanzania's dairy industry (Twine *et al.,* 2018), of which to a large extent is caused by nutritional scarcity. The effect of nutritional scarcity causes variation that is uncertain within every season for some production variables. Therefore, nutritional stress occurring as a consequence of feed scarcity negatively impact overall body functions of an individual animal including immune system (Gaughan *et al.,* 2010). In this situation, poor nutrition obscures the superiority of dairy cattle genotypes leading to reduced growth performance, lactation, fertility and may also cause an impaired immune system. Due to a lack of feed and unfavourable pasture conditions, grazing dairy cattle typically experience nutritional stress within dry seasons. During rainy season, pastures are more plentiful and of higher nutritional quality. In contrast, during the dry season, pasture becomes scarce with more fibres and lower protein, which frequently lowers dairy productivity in comparison to rainy season. Because natural pasture has a low nutritional value and is typically in short supply during the dry season, animals experience intense nutritional stress (Soren, 2012). Moreover, nutritional stress may occur at many levels, involving specific micronutrients or inadequate intake of protein or energy leading to multifaceted effects such as reduced performance to below genetic potential.

Dairy cattle experience various environmental stresses including prevalence of disease infections throughout the production cycle that potentially inhibit overall productivity and well-being of animals. Diseases are among the most severe factors that negatively affect dairy productivity. Increased THI as a result of climate change is linked to the emergence and reemergence of diseases by raising the numbers and geographic distribution of insects that that serve as the primary carriers of several arboviruses, improving the ability of different viruses to survive from year to year, and enhancing conditions for new insect vectors that are constrained by colder temperatures (Colebrook & Wall, 2004; Gustafson *et al.,* 2015). Diseases that lower productivity and profitability are linked to the expense of their treatment, the disruption of local markets, global trade, and the escalation of poverty in rural, local, and regional communities.

Pathogens compete with animals' productive potential at the biological level and limit the proportion that can be extracted for human use (Rushton, 2009). Additionally, disease infections can result in immediate losses (mortalities, stunted growth, and lowered fertility). Furthermore, animal diseases can cause indirect loss of revenue as a result of added expenses for medicines and vaccines, as well as increased labour costs and reduced income because of denied access to better market prices for sick animals, quarantines and loss of public trust in dairy products

(Rushton, 2009; Swai *et al.*, 2005). Similar to this, food processors are impacted when zoonotic diseases limits the supply of high-quality raw milk, lower profitability as a result of the expense of mitigating the effects of the disease, and when there is a decline in the market value of the products that are produced. Hence, effective ways of applying ameliorative management strategies are required to control and prevent the occurrence of diseases and their frequency on SHDF.

2.7 The Concept of Positive Deviance Applied in Smallholder Dairy Production

The concept of positive deviance, which emphasizes unusual but sound practices that lower risk in communities with limited resources, has been successful in mobilizing communities and creating programs to improve better results (Marsh *et al.,* 2004; Walker *et al.,* 2007). Thus, positive deviance approach (PDA) is an approach to resolving community issues that places a greater emphasis on the positive deviants within the community than on the needs of the community. This strategy employs community-based solutions to create long-lasting behavioural and social change. The method implies that creative solutions to problems could be discovered and improved based on the outlying behaviour, which start out as different or deviant ideas (Jaramillo *et al.,* 2008; Mertens *et al.,* 2016). This technique has been used within development interventions that address social and healthcare issues to find out successful solutions from within community since 1970s before gaining popularity in different disciplines. Positive deviance is described in these applications as a useful tactic for discovering and fostering exceptionally high performance in an interest of the problem domain (Bradley *et al.,* 2009; Herington & Fliert, 2018). The fundamental principle of a PDA is that solutions to issues facing any community are frequently found within that community, and that some members have knowledge that can be applied generally to boost the performance of their fellows. Most of these tactics make use of resources that are already available in local communities, which can increase their acceptance and sustainable use (Walker et al., 2007).

Positive deviance concept is a strength-based approach based on around five core principles: first, that communities possess the solutions and expertise to best address their own problems; second, that these communities are self-organising entities with sufficient human resources and assets to derive solutions to communal problems, third, that communities possess a collective intelligence, equally distributed through the community, which the PDA seeks to foster and draw out; fourth, that the foundation of any PDA rests on sustainability and the act of enabling a community to discover solutions to their own problems through the study of local PDs, and fifth, that behaviour change is best achieved through practice and the act of doing.

However, the question is: when should one consider applying a PDA in dairy farming to identify and disseminate effective management strategies successfully?

Similar to healthcare projects implemented to improve performance of health organisations and social development (Bradley *et al.*, 2009; Mertens *et al.*, 2016; Sternin, 2002), the application of a methodology that takes a PDA to understanding and scaling up best management strategies from successful farmers are normally conducted through a number of stages that are designed to achieve the desired objectives. Firstly, the strategy needs clear and comprehensible performance measures. For example, in dairy cattle farming systems, a researcher would require validated performance measures and therefore, dairy farms can be classified on the basis of performance indicator variables, and PD within the system can be identified. However, it would be challenging to conduct PD studies in cases where there are no performance records. Secondly, the PDA functions when there is variation in the performance variables, with some farmers achieving top performance in a noticeable and consistent manner while others do not. Additionally, the strategy works best when farmers are eager to share their expertise for exceptional results. Thirdly, the strategy works best when larger representative samples can be used to test hypotheses based on the experience of top-performing dairy farms. Empirical results from statistical testing are especially helpful when presenting data to industry stakeholders because farmers are more likely to find such data to be credible and valid given that their support is frequently essential to successful changes on their farms (Mertens *et al.*, 2016). Finally, for prospective adopting dairy farmers, the perception of the significance of improvement on the chosen performance variables can improve effective dissemination. By making a practice more compatible with the context of the farms, involving potential adopters in its development and testing can hasten the pace and extent of uptake.

Positive deviance concept in dairy production is used in learning from positive examples within the system. In fact, PDA has not been previously used in livestock production, and is just recently started to be applied in biodiversity, conservation, agro-ecology and livestock production. Thus, this approach is an early application of a methodology that takes a PDA to understanding and scaling up successful dairy strategies from outperforming farmers. Examples on the application of PDA include an analysis of PDs among organic dairy farmers in The Netherlands which was conducted to study the performance of excellent farmers at farm level and environmental aspects (de Adelhart Toorop & Gosselink, 2013). From such a study it was evident that modern dairy farming emphasises the concept of wholeness which imply the systematic connection or coordination of the whole farm to gain more livelihood benefits (IFOAM, 2013). Another situational analysis by an intervention research program in Ghana noticed a number of farms performing differently, having more animals, better market off-take while employing uncommon practices which raised interest in such kind of behaviour. Further research findings from smallholder crop-livestock farming systems reported the presence of PDs who own large herds and areas in cultivation by employing uncommon management strategies and offering supplementary feeding, vaccination, deworming and housing all animals at night (Savikurki, 2013). The evidence from such a study set a base for creating an enabling environment for institutional changes as regards to farmers' attitudes, service and input delivery. With the same resources, and despite the same barriers such as environmental stresses, PDs manage to employ differing practices and strategies which lead to better productivity. But, this kind of capacity to act depends on the resources and competencies such as skills, material and financial resources of dairy farmers.

Through observation and data analysis, positive deviant farmers are identified, and the community works to pinpoint the most important PDs among them. This strategy, as it has been applied to healthcare, makes the assumption that existing organizations that consistently perform exceptionally well already possess the knowledge of what works (Bradley *et al.,* 2009; Herington & Fliert, 2018). Similar to this, identifying farmers who perform better than their peers in terms of performance and encouraging communities to adopt the practices that account for the increased productivity are effective ways to bring about change. The PDs in farming system are identified and named by the community members themselves. Then, members of the farmers' association existing in the community are charged with pointing out the well performing farmers within that community (Savikurki, 2013). In this way, PDA in dairy farming could be useful in accomplishing two major objectives: the identification of performance-enhancing tactics and encouraging the adoption of these methods within the dairy industry through the following stages:- identify dairy farms that consistently perform at an exceptionally high level (PDs); utilising qualitative research methods, thoroughly examine those farms in order to develop hypotheses regarding the procedures that enable them to perform at the highest level; statistically test hypotheses in more comprehensive, representative samples of the farms; and collaborate with important dairy stakeholders, including potential adopters, to spread information about newly characterized best practices.

CHAPTER THREE

IDENTIFYING POSITIVE DEVIANT FARMS USING PARETO-OPTIMALITY RANKING TECHNIQUE TO ASSESS PRODUCTIVITY AND LIVELIHOOD BENEFITS IN SMALLHOLDER DAIRY FARMING UNDER CONTRASTING STRESSFUL ENVIRONMENTS IN TANZANIA

Abstract

In smallholder dairy-cattle farming systems, identifying positive deviants that attain outstanding performance can inform targeted improvements in typical, comparable farms under similar environmental stresses. Mostly, positive deviants are identified subjectively, introducing bias and limiting generalisation. The aim of the study was to objectively identify positive deviant farms using the Pareto-optimality ranking technique in a sample of smallholder dairy farms under contrasting stressful environments in Tanzania to test the hypothesis that positive deviant farms that simultaneously outperform typical farms in multiple performance indicators also outperform in yield gap, productivity and livelihood benefits. The selection criteria set five performance indicators: energy balance ≥0.35 Mcal NEL/d, disease-incidence density ≤12.75 per 100 animal-years at risk, daily milk yield ≥6.32 L/cow/day, age at first calving ≤1153.28 days and calving interval ≤633.68 days. Findings proved the hypothesis. A few farms (27: 3.4%) emerged as positive deviants, outperforming typical farms in yield gap, productivity and livelihood benefits. The estimated milk yield gap in typical farms was 76.88% under low-stress environments and 48.04% under high-stress environments. On average, total cash income, gross margins and total benefits in dairy farming were higher in positive deviants than in typical farms in both low- and high-stress environments. These results show that the Pareto-optimality ranking technique applied in a large population objectively identified a few positive deviant farms that attained higher productivity and livelihood benefits in both low- and high-stress environments. However, positive deviants invested more in inputs. With positive deviant farms objectively identified, it is possible to characterise management practices that they deploy differently from typical farms and learn lessons to inform the uptake of best practices and extension messages to be directed to improving dairy management.

3.1 Introduction

Smallholder dairy farming has multifunctional livelihood roles and benefits in rural households. Smallholders integrate subsistence and market objectives in their production systems (Moll *et al.,* 2007; Piech & Rehman, 1993). In Tanzania, for instance, dairy cattle provide nutrition and food security for household wellbeing, income for cash needs, and manure used in restoring soil fertility for crop production. Furthermore, cattle are live productive assets which households can liquidify in emergency or hold to accumulate wealth and gain the benefits of financing and insurance roles (Bebe *et al.,* 2003b; Mwanga *et al.,* 2019).

However, there are large variations in the extent to which households derive livelihood roles and benefits from dairy cattle farming. This is because dairy-cattle genotypes which smallholders utilise are sensitive to prevalent environmental stresses of heat load, nutritional scarcity and infections (Gustafson *et al.,* 2015; Soren, 2012). Under pervasive exposure to these environmental stresses, dairy cattle experience discomfort, and subsequently reduce their feed intake and become prone to an impaired immune system and increased susceptibility to disease (Gustafson *et al.,* 2015). The aggregate impacts of environmental stresses are suboptimal performance in growth, fertility and milk yield. With the production potential suppressed, dairy cattle manifest significant low productivity, yield gaps and the loss of livelihood benefits to farmers who keep dairy cattle for livelihood and market benefits (Mayberry *et al.,* 2017).

However, in the production environments, where smallholder dairy-cattle farming predominates, some farmers do successfully ameliorate environmental stresses. By so doing they attain higher productivity, lower the yield gaps and gain more livelihood benefits from dairy farming under the same stressful production environment (Mayberry *et al.,* 2017; Modernel *et al.,* 2018). The farmers who attain outstanding performance are labelled positive deviants while the average performers are labelled typical farmers.

Achieving outstanding performance under same local production circumstances suggests that positive deviant farms deploy more effective ameliorative strategies in addressing the effects of environmental stresses. Because of their remarkable success in production performance, positive deviant farms stand out within their communities and therefore could be local model farms from which lessons can be learned.

The identification of positive deviants in a population to inform one's choice of ameliorative practices for managing environmental stresses in a locality has been applied in community health, ecology, agriculture and livestock (Adelhart Toorop *et al.,* 2020; Modernel *et al.,* 2018). In identifying positive deviants, researchers have mostly applied purely subjective approaches, involving peers and expert knowledge dialogues, participatory ranking and snowballing sampling (Adelhart Toorop *et al.,* 2020; Modernel *et al.,* 2018). The data sources are cross-sectional surveys complemented with expert knowledge typologies and peer judgement to construct farm clusters. The participatory ranking has been based on observable assets as subjectively judged by knowledge experts or key informants. In addition, the outperformance of subjectively identified positive deviants in a population was mostly conducted on the criterion of a single performance indicator.

The subjective identification of positive deviants in a population on a single performance indicator introduces biases. Some workers have addressed bias in the identification of positive deviants. For instance, Modernel *et al.* (2018) and Steinke *et al.* (2019) applied empirical methods that assess multiple development dimensions simultaneously (food security, income, nutrition, environmental sustainability, and social equity). In a population with similar resource levels, positive deviants outperformed typical farms in the food-security indicator, but were not markedly better in social equity. Because dairy cattle on smallholder farms are pervasively exposed to multiple environmental stresses, multiple performance indicators are impacted. With this knowledge, the objective identification of positive deviants would be more informative and of broader application if the criteria are on multiple performance indicators. In contrast to subjective and biased approaches, objective approaches in the identification of positive deviants have applied multivariate statistics including principal component analysis with cluster analysis using a set of selected performance variables to distinguish farm types. The use of multivariate statistics has the advantage of reproducibility (Musafiri *et al.,* 2020). However, multi-collinearity remains a problem when multiple performance-indicator variables are used.

A deviation from other studies is the application in this study of an objective and quantitative approach, using the Pareto-optimality ranking technique to identify truly positive deviant farms in a population. With the application of the Pareto-optimality ranking technique, this study tested the hypothesis that positive deviant farms that simultaneously outperform typical farms in total energy balance, disease-incidence density, daily milk yield, age at first calving and calving interval also outperform in productivity, yield gap and livelihood benefits under similar environmental stresses. The milk yield gap is defined as the difference between actual and potential attainable yield. The actual yield is the average yield attained while the potential yield is the maximum attained yield (Mayberry *et al.,* 2017; van Ittersum *et al.,* 2013). This hypothesis was tested among smallholder dairy farms in high- and low-stress production environments using 42-month-period longitudinal observations of animal performance data.

3.2 Materials and Methods

3.2.1 The Study Area

This study was conducted in Tanzania, specifically in the northern milkshed (Kilimanjaro region) and eastern milkshed (Tanga region). These two milksheds were selected to represent low- and high-stress dairy production environments, respectively (Figure 3.1). Both low- and high-stress environments have a high concentration of dairy cattle and are beneficiaries of the African Dairy Genetic Gain (ADGG) Project. The ADGG is a dairy development intervention, collecting on-farm performance data which is used to identify and prove superior dairy crossbred bulls and heifers for delivery to farmers.

On average, herd size is 4 to 7 dairy cattle per farm, with a wide range from 1 to 30 animals. The breeds and genotypes can be a mixture of Holstein-Friesian, Ayrshire, and Jersey cattle breeds, or their crosses with the local zebu cattle breeds. The milk yield was estimated recently at 8.3 L/d, translating to a lactation milk production of under 2500 litres (Mrode *et al.*, 2021).

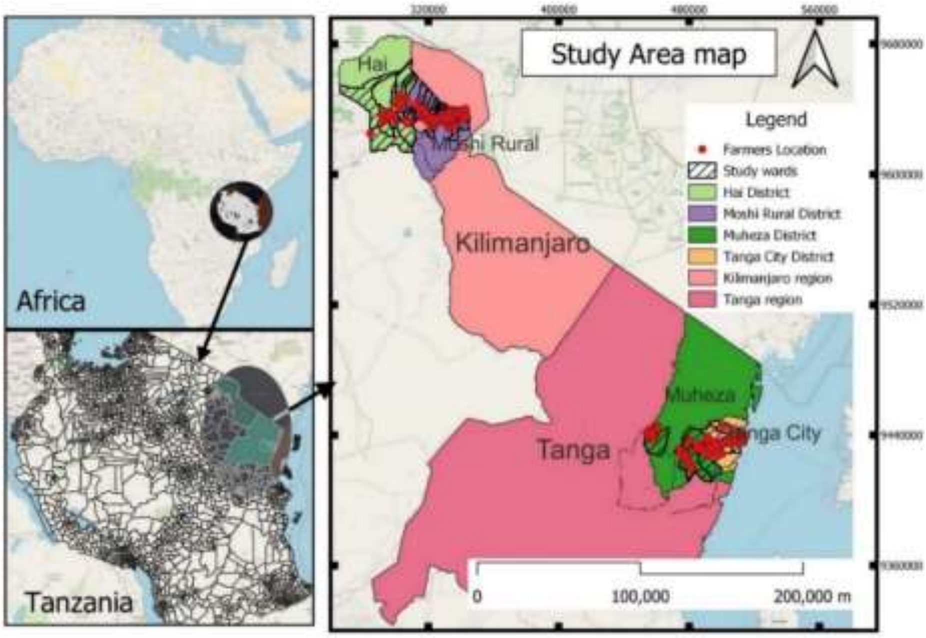

Figure 3.1: Study area map showing low- and high-stress production environments from the two milksheds in Tanzania**.**

The areas representing low-stress environments were Hai and Moshi Rural districts located between latitude 3.1747° to 3.3949° S and longitude 37.0596° to 37.5893° E based on farm locations. These areas are in the upper highland zone with high altitude (1228.67 to 1384 M ASL) and reliable, bimodal rainfall (1558 mm annual). The high altitude moderate tropical temperatures to lower levels towards those of temperate conditions, which do not favour the thriving of many tropical disease vectors. The bimodal rainfall patterns in the low-stress environment support year-round fodder biomass supply for dairy cattle feeding, hence a thriving dairy industry.

Representatives of a high-stress environment were Muheza (646.95 M ASL) and Tanga City (18.99 M ASL) districts. These districts are located in the coastal lowland zone between latitude 5.0152° to 5.2615° S and longitude 38.4372° to 39.1247° E based of farm locations. The areas are in the lowland zone at an average altitude of 499.46 M ASL. The annual rainfall ranges from 800 to 1400 mm with a bimodal distribution pattern. These conditions support crop production and fodder biomass for dairy-cattle feeding. A combination of high humidity, low altitude and high temperature in the coastal zone is associated with high heat load and high prevalence of many tropical diseases. Common tropical diseases include East Coast Fever, *Babesiosis, Anaplasmosis* and helminths infections.

3.2.2 Research Design

The study used a two-factor nested research design, with farms nested within the environment. The factors were environmentally classified into low- and high-stress levels and the farm defined by level of production performance as positive deviant or typical farms. The individual farms represent the experimental units (Tempelman, 2009). All dairy farms in this study were affiliated to the ADGG Project. The project offered access to a monthly test-day database for animal performance data collected from October 2016 through July 2020. The database is hosted by the International Livestock Research Institute (https://www.adgg.ilri.org/uat/auth/auth/login).

3.3 Data Collection and Processing

This subsection describes how data for the temperature–humidity index (THI), animal performance indicators and livelihood benefits were collected and processed. The data on temperature and humidity were sourced from a meteorological database for local stations within the two milksheds. Farm data was collected by trained Livestock field officers also known as performance recording agents (PRAs) operating open data kit (ODK) installed on Android tablets. These enumerators used a structured questionnaire designed to collect data on production performance and management practices. These practices included animal health, feeding, watering, housing, breeds and breeding practices. Additional market data on product prices were sourced from government departments and from literature to compute livelihood roles and benefits (financing and insurance roles) of dairy farming in rural economies.

3.3.1 Temperature–Humidity Index

Monthly THI was computed from monthly averages of air temperature (°C) and relative humidity (%) data and were obtained from meteorological database sources (https://www.worldweatheronline.com/machame-weather/kilimanjaro/tz.aspx and https://www.worldweatheronline.com/tanga-weather/tanga/tz.aspx, accessed on 18 December 2019). The THI is an indicator for heat-load stress that dairy cattle are exposed to at the level of production environment (Dikmen & Hansen, 2009; Zimbelman *et al.,* 2009). Mean THI was calculated *apriori* for each environment using 42 monthly averages, applying a formula from Dikmen and Hansen (2009). The formula is:

$$\mathrm{THI} = (1.8 \times \mathrm{T} + 32) - [(0.55 - 0.0055 \times \mathrm{RH}) \times (1.8 \times \mathrm{T} - 26.8)] \quad (3.1)$$

where T is air temperature (°C) and RH is relative humidity (%). The THI categories as developed by Zimbelman *et al.* (2009) represent neutral heat load (<68), heat stress threshold (68 to 71), mild to moderate heat stress (72 to 79), moderate to severe heat stress (80 to 89), severe heat stress (90 to 98) and extremely severe heat stress (>98).

3.3.2 Animal Performance Indicator Variables

A literature review of environmental stresses in dairy cattle reared in the tropics informed the selection of animal performance indicators. The total energy balance was selected as an objective indicator for nutritional stress and disease-incidence density as an indicator for disease stress (Tedeschi *et al.*, 2006; Thrusfield, 2007). The other performance indicators were daily milk yield, age at first calving and calving interval, which are animal-production and functional traits of economic importance in dairy farming (Dono *et al.,* 2013). These performance indicators are sensitive to environmental stresses and subsequently impact on the livelihoods and benefits that farmers gain from dairy farming (Atashi *et al.*, 2021). The individual dairy farms were selected on the criteria of having a complete set of these five performance indicators (total energy balance, daily milk yield, age at first calving, calving interval and incidence density) for identifying outperforming farms (positive deviants). With the data extracted from the ADGG database including monthly test-day milk yields, farm averages were computed for total energy balance, disease-incidence density, daily milk yield, age at first calving and calving interval. The computational process for each indicator is provided:

(i) Total energy balance (change in total energy balance (ΔTEB) per cow in the farm) is an indicator of nutritional stress and was calculated using an equation adapted from Tedeschi *et al.* (2006):

$$\Delta TEB_i = TE_i - TE_{I-1}; i \geq 2 \quad (3.2)$$

where ΔTEBi is a change in total energy (Mcal), and subscripts i and *i − 1* represent actual and previous TE values, respectively. The TEB values are obtained following Tedeschi *et al.* (2006) as:

$$TE_i = 9.367 \times TF_i + 5.554 \times TP_i \quad (3.3)$$

where TF_i is the amount of body fat (kg), TP_i is the amount of body protein (kg), TE_i is the total energy (Mcal), and the subscript *i* is the i^{th} period. A negative ΔTEB value indicates a situation where reserve energy is mobilized for milk production. The amount of milk produced, supported from mobilized reserves, is added to the diet-allowable milk production. A positive ΔTEB value indicates that the energy intake is greater than the energy required for milk production. In this case, part of the available energy is used for reserve deposition besides milk production. Therefore, the amount of energy deposited can be used to reduce the diet-allowable milk production.

(ii) Disease-incidence density at farm level is an indicator of the rapidity with which new cases of disease develop overtime. In this study, disease-incidence density is an indicator of tick-borne diseases and helminths infections in the entire herd and is computed as the number of new cases that occurred in a population over a period of 42 months, adapting the formula of Thrusfield (2007):

$$ID = \left(\frac{\text{number of new cases diagnosed and treated in 42 months}}{\text{the sum, over all individuals, of the length of time at risk}}\right) \quad (3.4)$$

where ID refers to disease-incidence density, the number of new cases diagnosed and treated in 42 months refers to the number of cattle diagnosed and treated for diseases in a particular farm during a period of 42 months; and the sum, over all individuals, of the length of time at risk refers to the sum, over all individuals, of the length of time at risk of developing disease in a particular farm. As computed, the disease-incidence density is the rate per animal-years at risk in a predefined period and was translated into a rate per 100 animal-years at risk (by multiplying them by 100). The periods at risk, or animal days at risk, are the total number of days the study animals were present during the observation period. The contribution of each animal to the total animal days was the difference between its date of exit (including death or the end of study) and its date of entry (or the beginning of the study).

(iii) The daily milk yield (MY) in litres per cow in the farm was calculated from monthly test-day lactation records obtained from ADGG database collected over a period of 42 months for 1551 cows in 794 farms.

(iv) Age at first calving (AFC) for female animals in each herd was calculated as the number of days from birth to first calving over a period of 42 months. Data on AFC were available for 1625 heifers in 794 farms.

(v) The calving interval (CI) for the cows within each herd was calculated as the interval in days between two consecutive normal calvings. Data on calving interval were available from 1348 records of 1348 cows in 794 farms.

3.3.3 Estimating Livelihood Benefits

This subsection describes how livelihood benefits were estimated. Livelihood benefits were computed on an annual basis per animal in the herd for fair comparison and to account for multiple functions of cattle in smallholder households. To estimate livelihood benefits, indicators were selected for both tangible and intangible benefits frequently used in smallholder dairy-farming systems in the tropics. These functions include: milk, stock, manure as fertiliser, financing and insurance benefits derived by smallholder farmers from keeping dairy cattle. Tangible benefits of dairy cattle include milk, stock and manure as fertiliser. Intangible benefits reflect unobserved income components resulting from products other than milk or stock which include financing (credit buffer) and insurance (security for the producers during emergencies). In contrast, intangible benefits account for a substantial proportion of the total benefits in smallholder dairy-production systems in the tropics (Lekasi *et al.,* 2001). The economic value of milk was computed by multiplying the total monthly milk produced by the market milk price (TZS 842.00 per litre; TZS 2297.5295 = USD 1 at the exchange rate on the 1st of July 2020 (https://www.bot.go.tz/ExchangeRate/, accessed on 1 July 2020)). Monthly milk production was estimated from monthly records:

$$\text{MILK} = \text{Milk output (litres)} \times \text{average milk price per litre} \qquad (3.5)$$

where MILK is the total economic value of milk, and milk output in litres is the quantity of milk produced for the number of days in milk.

The value of manure was computed from the average daily dry-matter faecal output and the average nitrogen and phosphorus contents of the faecal dry matter (faecal DM). Manure production was computed by multiplying the live weights of the average herd by 0.8% in reference to faecal DM in a day for a ruminant animal, with the DM of 40% (Lekasi *et al.,* 2001; Weiler *et al.,* 2014). Manure has a value as organic fertiliser (Lekasi et al., 2001): 1.4% nitrogen, 0.6% phosphorus and 1.34% potassium, which can be equated to synthetic N fertiliser (Alary *et al.,* 2011) hence it was priced at the value of N in DAP and urea (at the average price of a 50 kg bag):

$$\text{MANURE} = \text{Fertilizer price} \times (\text{N}_{\text{manure}} + \text{P}_{\text{manure}}) \quad (3.6)$$

where MANURE (TZS) is the total economic value of manure at the herd level used as fertiliser for one year, fertiliser price is the economic value of DAP and urea fertilisers (TZS/kg); N_{manure}, and P_{manure} are kg N and kg P in manure used as fertiliser. The N and P of manure used for fertilising were computed by multiplying the amounts of manure produced on the farm for the period of one year.

In a rural economy, a household avoids paying interest on loans by selling cattle to finance a cash need at hand, unlike borrowing from a bank or from an informal money lender (Weiler *et al.*, 2014). Building on this, the financing benefit of the credit buffer of cattle is related to the avoidance of paying interest on borrowed money and hence was computed as:

$$\text{FINANCE} = \text{Head}_{\text{price}} \times \text{b}_{\text{f}} \quad (3.7)$$

where FINANCE is the economic value of cattle as finance or the benefit of financing or having a credit buffer during one year (TZS); $\text{Head}_{\text{price}}$ is the economic value of cattle in the herd if they were sold to finance a household's cash needs during the observation period or the value of cattle sold due to reasons of finance; b_f is the prevailing local interest rate per annum. For this case, an interest rate of 17% was applied, corresponding to the interest rate charged by a popular bank (National Microfinance Bank (NMB)). An average market price observed when disposing cattle for cash need in the study areas was TZS 731,250 and 689,564.03 and 600,000 and 547,156.86 per head in positive deviants and typical farms under low- and high-stress dairy-production environments.

The insurance (security) function or cover of dairy cattle arises from cattle having the potential to be sold during emergencies. Therefore, the benefit of insurance is estimated by assuming that the whole herd is available to provide household insurance or security through liquidation at any time when cash is needed or an emergency arises (Bosman *et al.*, 1997). It was quantified as a product of the insurance factor (estimated from the opportunity cost of insurance) and the monetary value of the annualized household herd. This was calculated as follows:

$$\text{INSURANCE} = \text{Stock}_{\text{value}} \times \text{b}_{\text{i}} \quad (3.8)$$

where INSURANCE is the economic value of the cattle stock as an insurance for the household (TZS); $\text{stock}_{\text{value}}$ is the economic value of the average cattle stock for one year (computed by the average number of animals during the study period); b_i is the insurance premium or factor, that is, the cost that cattle owners would need to pay to purchase insurance cover equal to the capital value of their herd (the value of the annualized household herd during the observation period). An insurance premium of 6% was applied for all farms. The size of b_i was determined based on the existing insurance rate charged by most banks in the country.

Additionally, credit-processing benefits (a loan-processing fee) of 0.75% charged by NMB Bank were similarly applied for all farms. Therefore, the net benefits of keeping dairy cattle or the total benefit from dairy activities counted for tangible and intangible benefits less total production costs (feed, watering and healthcare-management costs).

$$\text{TB} = \text{VA} + \text{Financing benefits} + \text{Insurance benefits} + \text{Credit processing benefits} \quad (3.9)$$

where,

$$\text{VA} = \text{TCI} - \text{PC} \quad (3.10)$$

$$\text{TCI} = \text{Milk sales} + \text{Manure sales} \quad (3.11)$$

$$\text{PC} = \text{Feed cost} + \text{Healthcare cost} + \text{Watering cost} \quad (3.12)$$

where TB is the total livelihood benefits from dairy activities, VA is the total value added, TCI is the total cash income attained from the tangible benefits of keeping dairy cattle and PC is the total production cost incurred.

Gross margins due to milk sales is an economic indicator of productivity attained by farmers from the production costs incurred in rearing the animals. Thus, this is a measure of profitability in the use of resources available in smallholder dairy cattle farming systems. The production costs in this case included feed, watering and healthcare-management costs. Thus, gross margins at farm level were computed using the model:

$$\text{Gross margins} = \text{Gross production value} - \text{Production cost} \quad (3.13)$$

where gross margins are the margins due to milk production value, and gross production value is the value at farm level, which was the product of selling prices and quantity of milk produced in litres.

3.4 Identification of Positive Deviants Using Pareto-Optimality Ranking Technique

This subsection describes how positive deviant farms were identified through the Pareto-optimality ranking technique in a sample of 794 smallholder dairy farms. The Pareto-optimality ranking technique is an objective and quantitative approach with which it is possible to isolate positive deviants in a population on multiple performance indicators simultaneously without a bias (Adelhart Toorop *et al.*, 2020; Steinke *et al.*, 2019). This technique is not sensitive to multi-collinearity and avoids bias in the identification of the positive deviants. The technique identifies the farms that outperform others in one or more indicators, without being outperformed in any other indicator themselves. The technique is implemented without subjective weighting to avoid bias. The pioneering application of the Pareto-optimality ranking technique in recent years was by Goldberg (1989) and later by others in ecology, agriculture and livestock studies with cross-sectional surveys (Modernel *et al.,* 2018; Steinke *et al.,* 2019). But longitudinal data on smallholder dairy farming systems have not been used. Pareto-optimality ranking software was freely accessed (Adelhart Toorop *et al.,* 2020).

The identification of positive deviants was implemented in four steps: (i) quantification of current farm performance in all performance-indicator variables; (ii) quantification of threshold points for each performance-indicator variable, (iii) execution of the Pareto-optimality ranking technique using standardised indicator variables to generate a set of Pareto ranking solutions; (iv) comparison of the Pareto-optimal solutions based on current farm performance with a threshold point to isolate truly deviating farms from a wide array of Pareto-optimal solutions.

The first step involved computing averages for each performance indicator in each of the 794 individual farms. The second step was the computation of overall farm averages for each performance indicator in order to set the threshold points (population mean). The threshold points are presented in Table 3.2.

Table 3.2: A summary of threshold points for each performance-indicator variable set for identifying positive deviant farms in 794 sample farms

Performance indicator variables	Population mean threshold point for positive deviant farms	Data
Energy balance	≥0.35 Mcal NE_L/d (1.46 MJ NE_L/d)	1551 cows
Milk yield	≥6.32 L/cow/day	1551 cows
Age at first calving	≤1153.28 days	1625 heifers
Calving interval	≤633.68 days	1348 records of 1118 cows
Disease-incidence density	≤12.75 per 100 animal-years at risk	1912 health treatment events of 849 animals

In step three, the averages of each performance indicator for each of the 794 individual farms obtained in step one was standardised by z-transformation to obtain *z*-scores. The *z*-scores are computed from the residuals divided by their standard deviation (Steinke *et al.,* 2019). For each indicator variable, the distribution mean was subtracted from the score to obtain the distance from the mean in standard deviation units. This process makes the indicator distributions comparable despite being originally of different units and scales. The resultant performance scores for the 794 sample farms were subjected to the Pareto-optimality ranking algorithm (Adelhart Toorop *et al.,* 2020). The procedure allows for the choice of direction, whether to maximise or to minimise the indicator variable. In this study, the preferred directions of change were: maximizing total energy balance and daily milk yield, while minimizing age at first calving, calving interval and disease-incidence density. The preferred directions reflected the management goals in dairy production for increasing productivity and livelihood benefits.

Pareto-optimality ranking assigns Pareto-optimal solutions to rank 1 for farms not dominated by other farms. The Pareto-optimal solutions are those farms with Pareto-optimal performance for the performance-indicator variables. These farms outperform other farms with equivalent characteristics in at least one dimension without being outperformed in any other dimension. Next, the farms with rank 1 are removed from the set and the procedure is repeated by identifying the next set of non-dominated farms, which are assigned to rank 2. This ranking procedure is repeated until the sample farms are all ranked. The resulting farms are called Pareto-optimal or non-dominated solutions.

The set of Pareto-optimal solutions define the Pareto frontier while the solutions below the frontier are performing below the potential optimal level (suboptimal or dominated solutions). These suboptimal solutions can be improved in multiple indicators up to the Pareto frontier, which, therefore, represents the scope of improvement within the population (Adelhart Toorop *et al.,* 2020; Modernel *et al.,* 2018). However, Pareto-Optimality ranking identifies a wide array of Pareto-optimal solutions, including extreme cases, which are solutions that excel in one indicator but perform very poorly in all the others. Confronted with such cases, Modernel *et al.* (2018) turned to expert knowledge to rule out the win-lose and lose-win farms to define the win-win farms amongst Pareto-optimal solutions (Adelhart Toorop *et al.,* 2020). In this study, instead of turning to expert knowledge, a comparison was made between the individual farm performance obtained in step one and the threshold points set in step two to identify the truly positive deviant farms.

In the last step (step four), comparison of farm performance was made against a threshold value to identify which farms do truly deviate from the average or beyond expected performance on each indicator variable. From a set of Pareto-optimal farms, the sorting of multiple indicator variables was applied to select farms that had all indicator variables above the threshold points for milk yield and energy balance and below threshold points for disease-incidence density, age at first calving and calving interval (Table 3.2). The selection process involved the sorting of multiple indicator variables to complement the Pareto-optimality ranking. In other words, a true positive deviant farm had to score a total of five points, one point for each qualifying performance indicator variable. This exercise defined a narrow set of truly positive deviant farms with consistent outstanding performances for each of the indicator variables simultaneously from rank 1.

Additionally, the selection was extended to include all farms that scored rank 2 and 3 with all other criteria held constant. This was done to increase the positive deviant sample size for subsequent analyses. As implemented, a farm having a high value in one indicator does not decrease the values of the other indicators, although they do not necessarily perform best on one of the indicators. The result is that the true positive deviant farms were those farms that consistently outperformed above threshold points among Pareto-optimal solutions on five performance indicators simultaneously.

3.5 Statistical Analyses

Following data collection and processing, this subsection describes the statistical analysis for THI, productivity, milk yield gap and livelihood benefits.

3.5.1 Determining Temperature-Humidity Index (THI)

The THI was subjected to generalised linear model procedure of SAS software (SAS Institute Inc, 2013) to assess the extent of cattle exposure to heat-load stress between low- and high-stress environments. The statistical model fitted was specified as:

$$Y_{ij} = \mu + PE_i + e_{ij} \qquad (3.14)$$

where Y_{ij} = THI, μ = overall mean, PE_i = fixed effect of production environments (low- and high-stress) and e_{ij} = random error.

3.5.2 Determining Productivity and Yield Gap

The farm averages of total energy balance, milk yield, age at first calving, calving interval and disease-incidence density at the farm level were compared between the positive deviant and typical farms, building upon already objective identification of these farms in section 2.4. These production performance-indicator variables were subjected to the linear mixed model analysis procedure of SAS software (SAS Institute Inc, 2013). This procedure can fit variables that are correlated or with no constant variability and where the response variable is not necessarily normally distributed. The fitted model was specified as:

$$Y_{ijk} = \mu + PE_i + FT(PE)_{j(i)} + e_{ijk} \qquad (3.15)$$

where, Y_{ijk} = dependent variable of total energy balance, milk yield, age at first calving, calving interval and disease-incidence density, μ = overall mean, PE_i = fixed effect of production environment (low- and high-stress dairy-production environments), $FT(PE)_{j(i)}$ = random effect of farm-type nested within production environment and e_{ijk} = random error. Means separation used least significant difference for direct mean pairwise comparisons.

Adopting the definition already in application (van der Linden *et al.*, 2021), the milk yield gap in this study was defined as the difference between the actual yield as obtained on typical farms and the potential yield as the yield achieved on positive deviant farms. The potential yield implies average milk yield under the limitations set by the prevalent environmental stresses in a production environment.

3.5.3 Estimating Livelihood Benefits

Following objective identification of positive deviants and typical farms, a comparative analysis between these farms was performed to establish differences in livelihood benefits. A mixed model analysis of variance in SAS software (SAS Institute Inc, 2013) was used to test for difference in livelihood benefits at the farm level:

$$Y_{ijk} = \mu + PE_i + FT(PE)_{j(i)} + e_{ijk} \qquad (3.16)$$

where, Y_{ijk} = dependent variable (i.e., total production cost, total cash income, gross margins and total benefits at farm level), μ = overall mean, PE_i = fixed effect of stressful production environment (low and high), $FT(PE)_{j(i)}$ = random effect of farm-type (positive deviants and typical dairy farms) nested within production environment and e_{ijk} = random error. Differences in least square means were tested using Fisher's least significant difference, with a PDIFF option.

3.6 Results

3.6.1 Temperature-Humidity Index (THI) Estimate

Table 3.3 presents mean THI estimates to give indication of the levels of exposure to heat-load stress that dairy cattle were experiencing in the low- and high-stress environments. The results show that dairy cattle were exposed to significantly (p<0.0001) lower heat-stress levels in the low-stress environment than in the high-stress environment. Dairy cattle in the low-stress environment were exposed to lower heat-stress threshold conditions (68.20 ± 0.39 THI units) while those in the high-stress environment were exposed to mild to moderate heat-stress levels (77.29 ± 0.39 THI units).

Table 3.3: Least square means of temperature-humidity index (THI) for the low- and high-stress dairy-production environments

Production environment	THI Units
Low-stress	68.20 ± 0.39
High-stress	77.29 ± 0.39
p-value	<0.0001

3.6.2 Positive Deviants and Typical Farms Identified

The application of the Pareto-optimality ranking technique to a sample of 794 farms isolated 105 (13.22%) farms located on the trade-off frontier (rank 1 or Pareto-optimal solutions). Further, subjecting these Pareto-optimal solutions (farms) to multiple indicator-variable sorting isolated only 17 (2.14%) farms. When multiple indicator-variable sorting was extended to include farms scored in rank 2 and 3, an additional of 10 (1.26%) farms were isolated, resulting in 27 (3.4%) positive deviant farms. These farms were the true positive deviant farms that consistently performed above threshold points among Pareto-optimal solutions on the five performance indicators simultaneously. These positive deviant farms were fairly distributed within low- (n=15) and high-stress environments (n=12).

Variations on the five performance-indicator variables between positive deviants and typical farms nested within the environments are presented in Table 3.4. Results reveal considerable significant variations ($p<0.05$) between positive deviants and typical farms, with animals in positive deviant farms attaining better performance in both low- and high-stress environments. In positive deviant farms, the total energy balance and daily milk yield were higher, age at first calving earlier, calving interval shorter and disease-incidence density lower, when compared with typical farms.

Though not significantly different, animals tended to experience a lower positive energy balance and higher disease-stress exposure in the high-stress environment relative to animals in the low-stress environment. In terms of production performance, average daily milk yield was higher by 0.63 litres in the low-stress environment than the milk yield attained in the high-stress environment ($p<0.001$). Though age at first calving and calving interval were not significantly different between low- and high-stress environments ($p>0.05$), a pattern is observed that animals tended to attain first calving age earlier (0.61 months) but realised a longer calving interval (0.97 months) in low- relative to high-stress environments.

Table 3.4: Estimated means (LSMEANS±SE) for performance-indicator variables of cattle managed on positive deviants and typical smallholder dairy farms nested within production environments.

Factor	**Level**	**EB (Mcal NE_L/d)**	**MY (L/d)**	**AFC (Months)**	**CI (Months)**	**ID**
Production environment	Low-stress	5.09 ± 3.28	8.86 ± 0.15	35.60 ± 0.85	18.01 ± 0.57	6.25 ± 1.70
	High-stress	6.65 ± 2.28	8.23 ± 0.11	36.21 ± 0.91	17.04 ± 0.67	9.55 ± 1.89
	p-value	0.6956	0.0006	0.6219	0.2707	0.1945
Farm(environment)	Low-stress					
	Positive deviants	9.53 ± 6.45	11.32 ± 0.29	32.56 ± 1.65	15.66 ± 1.11	2.89 ± 3.33
	Typical	0.64 ± 1.19	6.40 ± 0.06	38.64 ± 0.39	20.36 ± 0.28	9.60 ± 0.67
	p-value	0.1757	<0.0001	0.0003	<0.0001	0.0489
	High-stress					
	Positive deviants	12.10 ± 4.48	9.83 ± 0.21	34.04 ± 1.80	14.13 ± 1.31	2.73 ± 3.73
	Typical	1.19 ± 0.82	6.64 ± 0.04	38.39 ± 0.34	19.95 ± 0.27	16.37 ± 0.65
	p-value	0.0166	<0.0001	0.0175	<0.0001	0.0003

EB = Energy balance (Mcal NE_L/day); MY = Milk yield (Litres/day); AFC = Age at first calving (Months); CI = Calving interval (Months); ID = Disease-incidence density (per 100 animal-years at risk).

3.6.3 Attained Yield Gap, Productivity and Livelihood Benefits Differentiating Positive Deviant Farms from Typical Farms

Table 3.5 presents the milk yield gap estimates in typical farms relative to positive deviant farms and in the low-stress relative to the high-stress environment. The difference in milk yield between positive deviant and typical farms and between low- and high-stress environments represents the yield gap, as the potential percentage improvement in the actual yield presently realised. Animals in the low-stress environment attained 0.63 litre more milk per cow compared to animals in the high-stress environment, which translates to 7.65% yield gap in the high-stress environment. Relative to animals in typical farms, the animals in positive deviant farms produced 4.92 litres more milk per cow per day in the low-stress environment translating to 76.88% yield gap while in the high-stress environment animals produced 3.19 litres more milk per cow per day, translating into 48.08% milk yield gap.

Table 3.5: Means (±SE) for milk yield and yield gaps in typical farms relative to positive deviant farms and in low-stress environment relative to high-stress environment.

Factor	Level	Milk Yield (L/cow/d)	Yield Gap	
			Milk Yield (L/cow/d)	**% Increase**
Environment	Low-stress (*n* = 386)	8.86 ± 0.15	0.63	7.65
	High-stress (*n* = 498)	8.23 ± 0.11		
	p-value	0.0006		
Farm(environment)				
	Low-stress			
	Positive deviants (*n*=15)	11.32 ± 0.29	4.92	76.88
	Typical (*n*=371)	6.40 ± 0.06		
	p-value	<0.0001		
	High-stress			
	Positive deviants (*n*=12)	9.83 ± 0.21	3.19	48.04
	Typical (*n*=396)	6.64 ± 0.04		
	p-value	<0.0001		

Figure 3.2 illustrates production cost and total cash income while Figure 3.3 illustrates gross margins and total benefits from dairy cattle farming obtained in positive deviants and typical farms when farms are nested within the environments. The units are TZS per animal

per year for fair comparison between the farms. Results show that positive deviant farms incurred higher production cost, with which they attained higher total cash income (Figure 3.2), gross margins and total benefits (Figure 3.3) than typical farms both in low- and high-stress environments. There was a significant difference ($p<0.05$) in total cash income between positive deviant and typical farms in the low-stress environment. Positive deviants attained 235,541 TZS higher total cash income than typical farms under the low-stress environment. However, under the high-stress environment, positive deviant farms attained 221,024 TZS higher than typical farms, but not significantly different. The overall results show that positive deviant farms significantly ($p<0.05$) gained more than typical farms in total cash income, gross margin and total benefits by 228,283, 208,319 and 222,129 TZS per animal per year.

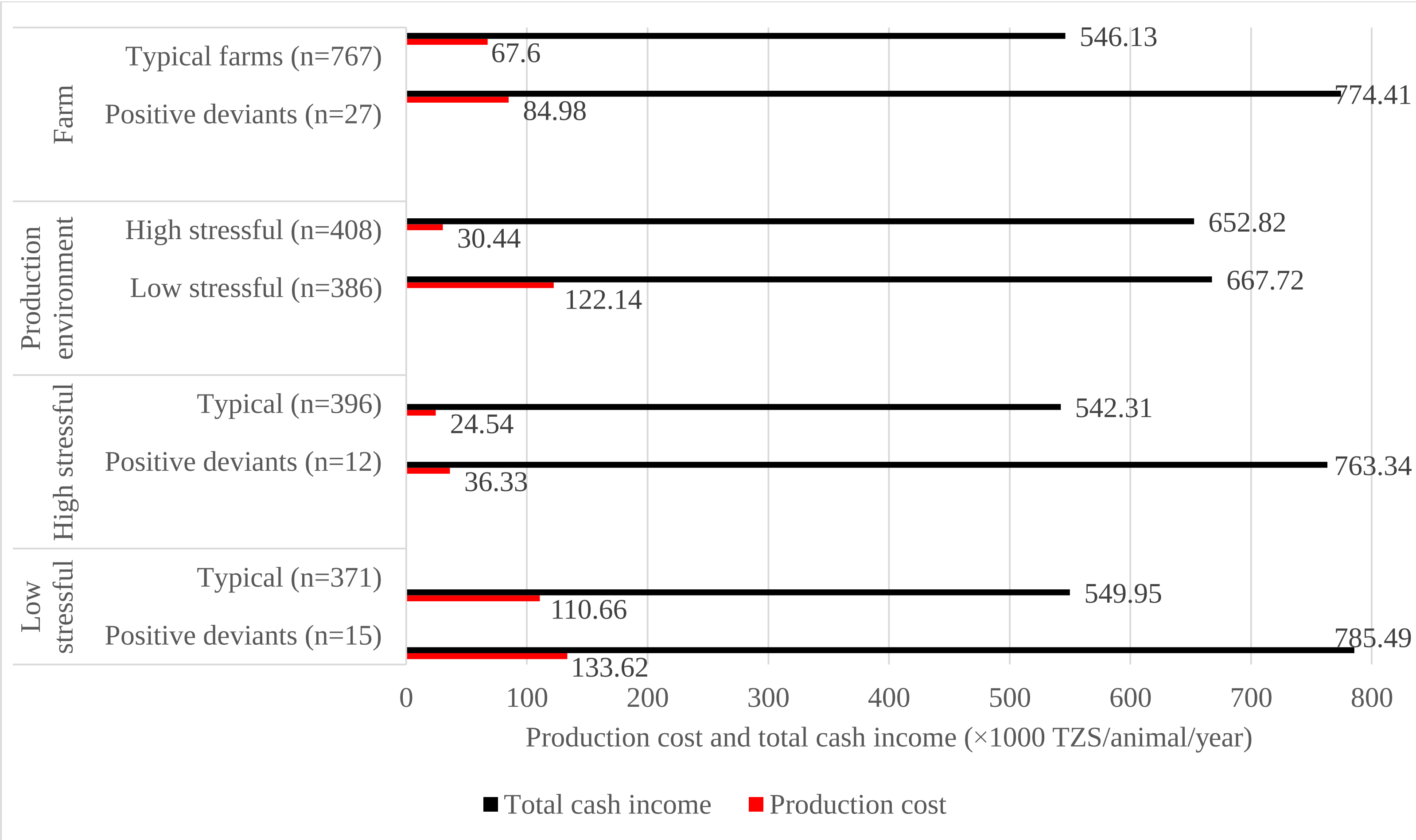

Figure 3.2: Total production cost and total cash income from dairy cattle on positive deviants and typical farms nested within production environment (Exchange rate 2297.5295 Tanzanian Shillings (TZS) = 1 US dollar).

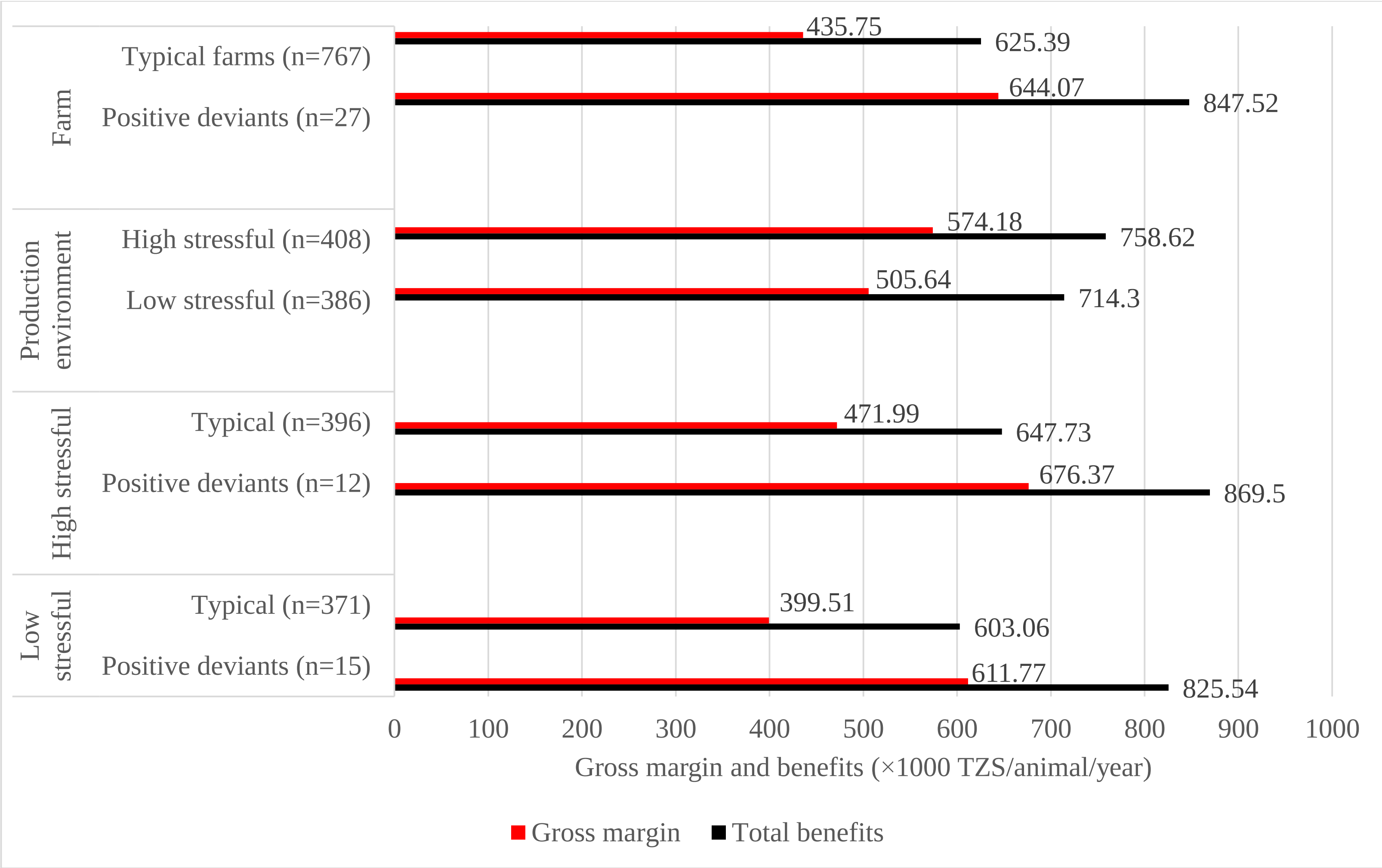

Figure 3.3: Gross profit margins and total benefits from dairy cattle on positive deviant and typical farms nested within production environments (Exchange rate 2297.5295 TZS = 1 USD).

3.7 Discussion

3.7.1 Temperature-Humidity Index (THI) Estimate

The THI indicated that dairy cattle were exposed to relatively higher heat stress, in the mild to moderate range, in the high-stress environment than were the animals in the low-stress environment ($p<0.0001$). These findings suggest that interventions are required to address heat stress in smallholder dairy farming in the high-stress environment because THI exceeded 72 threshold points when dairy cattle begin to be affected and thus need protection from heat stress. If dairy cattle are exposed to mild heat stress peaks in the afternoons during the dry seasons, the animal increases physiological and haematological responses (Wangui *et al.,* 2018). Farmers have several options to ameliorate heat stress affecting their dairy cattle. The options include careful selection of genotypes, improved nutrition, watering and physical modification of the environment such as adequate house floor spacing per animal to create suitable microclimate in the cowshed (Edwards-Callaway *et al.,* 2021). These practices are more important for farmers keeping Holstein-Friesian cattle in the high-stress environment, because the breed is sensitive to thermal stress.

3.7.2 Identifying Positive Deviants in a Sample Population

The approach of identifying positive deviants in a population in this study deviates from previous studies in many ways to avoid subjectivity and bias so as to support broad generalisation of the findings. This was achieved with the Pareto-optimality ranking technique that accounted for multiple production performance indicators. Production performance indicators that were used in this study included total energy balance, daily milk yield, age at first calving, calving interval and disease-incidence density. Unlike most of positive deviance studies conducted in the agricultural domain with cross-sectional surveys (Modernel *et al.,* 2018; Steinke *et al.,* 2019), the data in this study was longitudinal measurements over a period of 42 months in a random sample of 794 farms. The advantage of longitudinal study is that the variables of interest can be monitored and checked for movement towards or away from deviance behaviour over time. The selected performance indicators are sensitive to the prevalent environmental stresses, with impacts manifesting in attained productivity levels and the magnitude of livelihood benefits from dairy farming.

With application of the Pareto-optimality ranking technique, 27 (3.4%) positive deviant farms were identified that consistently outperformed comparable farms (average or typical farms) exposed to similar environmental stresses in a production environment. These few individual positive deviant farms are the positive outliers, exhibiting positive deviance behaviour with the achievement of outstanding performance under similar environmental stresses. The approach used identified far fewer positive deviants (3.4%) than are observed in many other related studies of the positive deviance phenomenon. Mostly, positive deviants are in the range of ten percent (10%) of the sample, when a single performance indicator is used as the criterion (Mayberry *et al.,* 2017) or less when multiple performance indicators are used (Modernel *et al.,* 2018). Modernel *et al.* (2018), who used Pareto-optimality ranking on multiple performance indicators complemented by expert knowledge, isolated a smaller proportion of positive deviants (1.79%: 5/280). In contrast, Steinke *et al.* (2019), who also used Pareto-optimality ranking on multiple performance indicators, isolated a larger proportion of positive deviants (10.8%: 54/500). Similarly, Adelhart Toorop *et al.* (2020) ended up with a larger proportion of positive deviants (13.95%: 6/43), which originated from a smaller sample size with limited heterogeneity. This is likely due to differences in sorting farms scored rank 1 to complement the Pareto-optimality ranking where multiple indicator variables are involved. The present study included farms scored rank 2 and 3 to define a narrow set of truly positive deviants with consistent outstanding performances for each of the five indicator variables simultaneously. The present study indicates that when multiple-objective indicator variables, obtained longitudinally, are simultaneously considered in a large and random population, positive deviants attaining exceptional performance will be fewer than five percent (5%). This was the case in the present study in contrasting stressful environments, where only 3.9% (15/386) positive deviant farms in low- and 2.9% (12/408) in high-stress environments could be isolated objectively. This is in contrast to studies that set a singular performance-indicator variable such as milk yield to identify positive deviants, and then equate the top 10% of performers in a sample with the positive deviants (Mayberry *et al.,* 2017).

Most previous studies that identified positive deviants relied on a single performance-indicator variable to classify a group of outperforming farms in a sample obtained in a cross-sectional survey (Chawala *et al.,* 2019). Given the complexity of livestock production systems that smallholders manage, where farmers pursue multiple objectives, there is likely no one single best indicator variable of performance suited for an objective identification of positive deviants. For the multiple-objective system that smallholder dairying is, the Pareto-optimality ranking technique, a multi-objective analytic technique, offers advantages over expert knowledge or participatory approaches accompanied by a single indicator variable when identifying positive deviants in a sample. The identification of positive deviants with the criteria of multiple indicator variables better reflects the exposure to multiple environmental stresses. In addition, having multiple indicator variables reflects the multiple roles of cattle and livelihood benefits that smallholder farmers desire from their dairy farming. With multiple indicator variables, farms that emerge as positive deviants are a better reflection of their cumulative outstanding performance outcome that they effectively ameliorate environmental stresses with the management practices.

The Pareto-optimality ranking technique achieved these advantages without subjective weighting or biases while accommodating multiple indicator variables simultaneously in the process of identifying consistently outstanding farms (Adelhart Toorop *et al.*, 2020). Therefore, management practices on positive deviant farms can better inform good local lessons for innovating and up-scaling ameliorative management practices to overcome prevalent environmental stresses.

3.7.3 Attainable Productivity and Livelihood Benefits in Positive Deviant Farms

Within a production environment with similar prevalent environmental stresses, dairy cattle in positive deviant farms outperformed those in typical farms in production and functional trait indicator variables. This suggests differences between positive deviants and typical farms in how they deploy management practices to ameliorate prevalent environmental stresses. Dairy cattle in positive deviant farms attained better performance, both in high- and low-stress environments. For example, the total energy balance was positive but higher in positive deviant farms than in typical farms, indicating that positive deviant farms were more effectively ameliorating nutritional stress. This could be achieved with provision of a well-balanced diet of fodder adequately supplemented with concentrates. Similarly, disease-incidence density, a proxy measure of disease stress, was lower in positive deviant farms than in typical farms, pointing to positive deviant farms as more effectively ameliorating disease stresses through animal-health practices.

These observations corroborate the assessment of environmental stresses in dairy production in several studies that have used THI to assess heat-load stress, total energy balance to assess nutritional stress and disease-incidence density to assess disease infection stress (Ammer *et al.,* 2018). In the high-stress environment, a lower total energy balance for animals in typical farms is likely a consequence of a decrease in nutrient intake, alteration in rumen function during heat stress and hormonal imbalance (Bernabucci *et al.,* 2010). As a consequence, a depression in milk yield follows because a decrease in dry matter intake accounts for an up to 35% reduction in milk yield with the remainder (65%) attributable to other physiological effects of heat stress (Rhoads *et al.,* 2009). The associated effects of lower energy balance and higher heat stress in the high-stress environment can be extended to the observed older age at first calving and longer calving intervals attained in typical farms. Under heat stresses and inadequate nutrition, 50% of the standing periods of oestrus pass undetected, with a resultant delayed age at first calving and long calving interval (Nyman *et al.,* 2016). Pervasive exposure of dairy cattle to heat stress of greater than the 72 THI threshold impacts production and functional traits when deliberate effective ameliorative strategies are not deployed to check the stresses. The earlier age at first calving, shorter calving intervals and higher daily milk yields attained in positive deviant farms compared to typical farms are further supportive evidence of a likelihood of more effective amelioration of environmental stresses in positive deviant farms than in typical farms. Because of these apparent differences in management practices, characterising specific practices that positive deviant farms deployed differently to more effectively ameliorate stresses of heat load, nutritional scarcity and infections becomes necessary. This is for lesson learning, to inform the uptake of best practices and by extension messages at the farm level.

The shorter calving interval could be explained by relatively higher energy balance in high-stress environment compared to low-stress environment though was not significant different. Msanga *et al.* (2000) associated long calving intervals to either nutrition deficiency and/or failure of dairy farmers to detect heat for timely breeding. Additionally, the genotype and year-effect can also be associated with the observed differences between high- and low-stress environments (Million *et al.,* 2022). For example, long calving interval in the dry and short rainy seasons is expected because cows that calve during the rainy season receive sufficient quantity of feeds, hence could regain within a short period of time compared to those that calve during the long dry season where there is insufficient supply of animal feeds.

With a larger herd size that attained better performance in production and functional traits, positive deviant farms realised higher daily milk productivity levels, up by 3.19 litres in high- and 4.92 litres in low-stress dairy production environments. This difference translates to a huge yield gap in typical farms, the extent being larger in a low- than in a high-stress environment (76.88% vs. 48.04%). The yield gap implies a greater opportunity to increase milk production in typical than in positive deviant farms and in low- than in the high-stress environment. This is because heat stress has a reduction effect on production in livestock. This points to the need to invest more in heat-stress-management practices in order to optimise benefits when nutritional and disease stresses are ameliorated.

The quantification of tangible and intangible economic benefits resulting from dairy-cattle farming was to account for the multiple livelihood benefits of dairy cattle to rural farming households, who integrate the objectives of subsistence needs with profit making. In this study, the total monetary value of dairy farming was a summation of multiple functions which contribute to the total benefits of keeping dairy cattle in a smallholder household (Weiler *et al.*, 2014). However, quantifying intangible benefits is challenging and should be interpreted with caution as all animals in the herd regardless of class were assumed to provide multiple functions to the household. The total benefits could not account for some important socio-cultural values where cattle are part of status display or have a value in dowry payments. This is because households do not provide reliable data on these aspects.

Results showed that positive deviant farms gained more than typical farms from dairy-cattle farming in total cash income, gross margins and total benefits both in high-and low-stress environments. The gains were greater ($p<0.05$) in positive deviants than typical farms per animal annually in TZS by 235,541 in cash income, 212,263 in gross margins and 222,483 in total benefits in the low-stress environment. Total cash income, gross margins and total benefits were higher in positive deviants than typical farms by 221,024, 204,375 and 221,775 TZS in the high-stress environment. It is possible that positive deviant farms attained these higher gains with higher investment and effective utilisation of ameliorative practices targeted to the prevalent environmental stresses. This is because their average production cost was 22,958 and 11,799 TZS more than was in typical farms in low- and high-stress environments (Figure 3.2). Furthermore, the observation points to positive deviant farms paying more attention to ameliorating environmental stresses than typical farms because the total cash incomes, gross margins and total benefits realised were significantly higher in positive deviant farms (Figures 3.2 and 3.3). These results support the need to invest more in ameliorative practices, technologies and innovations in the high-stress environment. In such an environment, a combination of limitation factors (nutritional scarcity) and production-reducing factors (heat-load and disease stresses) aggregately impact attainable yield gaps, productivity and livelihood benefits in dairy-cattle farming.

3.8 Conclusions

The findings of this study show that the Pareto-optimality ranking technique applied in a large population objectively identified a few positive deviant farms that attained higher productivity and livelihood benefits in both low- and high-stress environments. The Pareto-optimality ranking technique objectively accounted for multiple indicator variables which limit (nutritional scarcity) and reduce livestock production (heat-load and disease stresses). The variables used to identify positive deviants have relevance for the aggregate impact on productivity and livelihood benefits in dairy-farming systems. They are also relevant to accounting for the multiple functions of dairy farming in smallholder households. These results suggest the need to invest more in ameliorative management practices, technologies and innovations to address the different forms of environmental stresses hindering dairy productivity, especially in typical farms. Thus, where positive deviants have been isolated, those ameliorative practices can be characterised to better understand which practices distinguish positive deviants from typical farms. This is valuable lesson learning to inform best practices and the design of extension package that target improvements in typical farms.

CHAPTER FOUR

CHARACTERISING MANAGEMENT PRACTICES IN HIGH AND AVERAGE PERFORMING SMALLHOLDER DAIRY FARMS UNDER CONTRASTING ENVIRONMENTAL STRESSES IN TANZANIA

Abstract

This study characterised breeding, housing, feeding and health management practices in positive deviants and typical average performing smallholder dairy farms in Tanzania. The objective was to distinguish management practices that positive deviant farms deploy differently from typical farms to ameliorate local prevalent environmental stresses. In a sample of 794 farms, positive deviants were classified on criteria of consistently outperforming typical farms ($p<0.05$) in five production performance indicators: energy balance ≥0.35 Mcal NEL/d, disease-incidence density ≤12.75 per 100 animal-years at risk, daily milk yield ≥6.32 L/cow/day, age at first calving ≤1153.28 days and calving interval ≤633.68 days. The study was a two-factor nested research design, with farms nested within the production environment, classified into low- and high-stress. Compared to typical farms, positive deviant farms had larger landholdings, larger herds comprising more high-grade cattle housed in better quality zero-grazing stall units with larger floor spacing per animal. Positive deviants spent more on purchased fodder and water and more frequently sourced professional veterinary services ($p<0.001$). These results show that management practices distinguishing positive deviants from typical farms were cattle upgrading, provision of larger animal floor spacing and investing more in cattle housing, fodder, watering, and professional veterinary services. These distinguishing practices can be associated with amelioration of feed scarcity, heat load stresses, and disease infections, and better animal welfare in positive deviant farms. Nutritional quality of the diet was not analysed, for which research is recommended to ascertain whether the investments made by positive deviants is in quality of feeds.

4.1 Introduction

Smallholder dairy farming in the tropics is practiced under multiple and variable environmental stresses, of which prevalent are feed scarcity, disease infections and heat load stresses. These environmental stresses either limit or reduce dairy productivity (van der Linden *et al.*, 2015; VanLeeuwen *et al.*, 2012), and so subsequently impact on livelihood benefits of dairy farming to the households. For improving smallholder livelihoods, it becomes necessary to identify management practices that enable farmers to ameliorate prevalent environmental stresses and minimise the resultant limitation or reduction in dairy productivity. Research institutions and development agencies have invested in identifying and scaling appropriate management practices which smallholder farmers can deploy to ameliorate the prevalent environmental stresses (ILRI, 2019). Of importance are management practices that farmers can adopt or adapt in their local production systems to attain livelihood benefits from dairy farming (Gojam *et al.,* 2017; Mbuthia *et al.,* 2021; VanLeeuwen *et al.,* 2012).

Positive deviance is an approach gaining importance in identifying management practices deployed to ameliorate local prevalent environmental stresses under similar production circumstances. In a population, the success in ameliorating local environmental stresses have been associated with a few farmers exhibiting positive deviance behaviour. The positive deviants exhibit outstanding performance, implying that they deploy positive deviance behaviour that enable them to successfully ameliorate locally prevalent environmental stresses. The success of positive deviant farmers can then be shared, learnt and scaled in the locality to peer farmers who as well face similar biophysical or resource constraints (Cadilhon *et al.,* 2016; Gellynck & Kühne, 2010; Mekoya *et al.,* 2008). Interactions between different stakeholders can hasten the learning process of deploying those appropriate management practices in the locality.

Positive deviance behaviour was initially applied in designing food supplementation programmes in Central America. Identification of dietary practices developed by mothers for their children was endogenous in nature (Wishik & Vynckt, 1976). The successes were extended to designing food supplementation and other nutritional promotion in the larger population. This was on the assumption that endogenously developed practices, although atypical, would be feasible and culturally acceptable, having been developed indigenously and not extraneously in the locality. Since then positive deviance behaviour has attracted research attention and application in public health, academia, security, agriculture and even in smallholder livestock systems (Adelhart Toorop *et al.,* 2020; Albanna & Heeks, 2019; Albanna *et al.,* 2022; Herington & Fliert, 2018).

In several studies of positive deviants in a population facing similar production challenges, distinguishable management practices is apparent. For example, in Northern Ghana, positive deviants deployed supplementary feeding, health management, animal housing at night and increased landholdings for growing crops and fodder (Savikurki, 2013). In deploying these practices, they increased feed resource base with which they were able to enlarge the number of animals, improve animal welfare and address animal theft and production constraints. In pastoral community dominated area of West Gollis in Somaliland, positive deviants practice rotational reseeding, strip grazing a mixture of Rhodes grass (*Chloris gayana*) and Lablab legume (*Lablab purpureus)* pastures, and sourcing alternative feeds (Abdullahi *et al.,* 2021; Albanna *et al.,* 2022). In deploying these practices, they succeeded in preserving their rangelands and addressed feed scarcity by assuring stable access to animal feeds throughout the year. In the Ecuadorian Amazon, positive deviant farms that adopted rotational grazing and sourcing alternative sources of animal feeds were able to reduce pressure on pasture and slowdown grazing induced deforestation (Albanna *et al.,* 2022; Grijalva *et al.,* 2021). Management practices distinguishing positive deviant farms in organic dairy farming have also been documented in the Netherlands. By integrating and balancing the whole farm system, the positive deviant farms managed to keep healthy animals and realized optimal productivity with minimal use of antibiotics (de Adelhart Toorop & Gosselink, 2013).

These previous studies of positive deviance especially in smallholder livestock farming, used cross sectional survey data to distinguish associated management practices. This assume that indicator variables observed reflect average animal performance overtime. However, smallholder dairy farming is very dynamic and complex because of multiple roles that animals play and valued by the households. In such case, longitudinal dataset provides more informative average animal performance from which may be discovered transferable management practices defining outperformance under similar level of environmental stresses (de Adelhart Toorop & Gosselink, 2013; Savikurki, 2013). Longitudinal data has the advantage that it allows variables of interest to be assessed over time, and to monitor changes towards or away from positive deviance behaviour.

Another weakness in the previous studies is sampling design that do not account for contrasting environmental stresses when assessing production performance. Using the same sample of farms as used in the present Chapter, positive deviant farms have been quantitatively isolated from average typical performing farms under low- and high-stress dairy-production environments (Chapter Three). But the study did not distinguish management practices underpinning observed outperformance. The longitudinal data was for a period of 42 months, which is sufficient to allow for distinguishing management practices over time to account for the dynamic nature and complexity of smallholder dairy farming. Dairy cattle persistently exposed to multiple environmental stresses experience disrupted physiological functioning, depressed welfare status and immune system and subsequently fail to express full genetic production potential. Longitudinal data can reveal distinguishable management practices that positive deviant farms deploy differently to ameliorate persistent multiple environmental stresses in their production systems. This study characterised breeding, housing, feeding and health management practices in positive deviants and typical farms to distinguish management practices that they deploy to ameliorate local prevalent environmental stresses.

4.2 Materials and Methods

4.2.1 Data Source

This study is an extension of Chapter Three in which methodology was described in detail. The study area, research design, data collection and identification process of positive deviants and typical farms are described in section 3.2.1, 3.2.2, 3.3 and 3.4 of Chapter Three, respectively. In this Chapter, complementary and objective specific information is described.

4.2.2 Data Collection and Processing

From ADGG database, management data was extracted for processing to create the variables needed for differentiating management practices deployed in positive deviant farms from typical farms. The variables included land size in acres, number of animals in a herd, house floor spacing per animal, cowshed construction materials (wood, stone/brick walls, grass/makuti roofing and corrugated iron sheet roofing), main dairy cattle breeds (Holstein-Friesian, Ayrshire and Jersey), breed composition/genotype (25%, 50% or >75% of exotic blood levels and purebred), type of cowshed (either permanent or semi-permanent), feeding systems, proportion of different feed resources in the animal diet (fodder, crop residues and concentrates). Some of the variables were computed from obtained information, which includes the cost of feeds, watering and health services.

Health cost accounted for deworming, dipping and vaccination costs while health treatment cost accounted for drugs and service costs only. Feed cost accounted for fodder growing, feed purchase and transportation while watering cost during dry season was for water bills and transportation expenses. The dimensions of the cowshed including length and width were measured using a rolling tape. Floor spacing/area (m^2) per animal was computed as the total width × length of the cowshed (including stalls, alleys and crossovers) divided by the number of dairy cattle present in the cowshed at the time of assessment. Animal health service providers were grouped into professional animal health service providers (animal health service providers/paravets, government veterinarians, project/NGO staff, co-operative/group staff and agrovet shops) and fellow farmers (self with professional advice, neighbour with professional advice, self without professional advice and neighbour without professional advice).

4.2.3 Statistical Analysis

All statistical analyses for scale variables were performed in SAS software (SAS Institute Inc, 2013), fitting linear mixed model to account for variables that could be correlated or with non-constant variability. Means separation was achieved with least significant difference for direct pairwise comparisons between means. Statistical testing was set at α = 0.05 and the model fitted was in the form:

$$Y_{ijk} = \mu + PE_i + FT(PE)_{j(i)} + e_{ijk} \quad (4.1)$$

where, Y_{ijk} = dependent variables, μ = overall mean, PE_i = fixed effect of production environment (low- and high-stress environments), $FT(PE)_{j(i)}$ = random effect of farm nested within the production environment, and e_{ijk} = random error. The dependent variables were land size, number of animals, house floor spacing per animal, and the cost of watering, feed, and health costs. Analyses for categorical and count data was performed in SPSS software (IBM Corp., 2017). A bivariate correlation was performed to determine the association between feed cost and milk yield. Chi-Square tests was used for count and categorical data to test for the differences in the observed frequencies.

4.3 Results

4.3.1 Housing and Breeding Management Practices

Results indicate that majority of farmers were males, and were aged over 45 years, regardless of whether were positive deviants or typical farmers in low- or high-stress environments. The average landholding, number of animals and floor spacing per animal in stall zero-grazing units is presented in Table 4.1 for positive deviants and typical farms and for low- and high-stress environments. Results reveal differences ($p<0.05$) between positive deviants and typical farms in landholding size owned in both low- and high-stress environments, the number of animals in low-stress environment and in house floor spacing per animal in high-stress environment. Compared to typical farms, positive deviant farms were larger in size, about three times larger (2.7-2.9) in low- and high-stress environments. However, the number of animals was only higher in positive deviant farms found in low-stress environment, about two times larger (1.7) relative to typical farms. In the positive deviant farms, house floor space per animal was about two times larger only in high-stress environment. A comparison between positive deviants and typical farms revealed no difference ($p>0.05$) in the number of animals under high-stress environment and in floor spacing under low-stress environment.

Table 4.1: Means (±SE) of land size, the number of animals and stall floor spacing per animal in positive deviants and typical farms under low- and high-stress environments.

Factor	Level	Land size (acres)	Number of animals	Stall floor spacing (m^2/animal)
Environment				
	Low-stress	4.85±0.78	5.89±0.68	7.80±0.82
	High-stress	7.92±0.95	4.33±0.82	9.68±0.99
	Mean difference	3.07^{*}	1.55^{NS}	1.88^{NS}
Farm(Environment)				
	Low-stress			
	Positive deviants	7.08±1.52	7.33±1.32	7.54±1.59
	Typical	2.61±0.37	4.44±0.32	8.06±0.38
	Mean difference	4.47^{**}	2.89^{*}	0.53^{NS}
	High-stress			
	Positive deviants	11.83±1.86	4.17±1.61	13.19±1.94
	Typical	4.00±0.35	4.50±0.31	6.17±0.37
	Mean difference	7.83^{***}	0.34^{NS}	7.01^{***}
Farm				
	Positive deviants	9.46±1.20	5.75±1.04	10.36±1.25
	Typical	3.31±0.25	4.47±0.22	7.12±0.27
	Mean difference	6.15^{***}	1.28^{NS}	3.24^{*}

Table 4.2 presents the distribution frequency of type of cattle housing and construction materials in positive deviants and typical farms under low- and high-stress environments. Cattle in both positive deviants and typical farms were predominantly housed in stalls (≥94.4% farms) but the quality was comparatively better in positive deviants, where permanent housing were more (76.9% vs. 47.8%) with cement or brick walls (80% vs. 60%) and iron sheet roofing (100% vs. 74%).

Table 4.2: Distribution frequency (percentage) of cattle housing and construction materials in positive deviant and typical farms under stressful production environments.

Factor	Positive deviant farms (n=15)	Typical farms (n=322)	Chi-Square Test
Housing type (%)			
Permanent house	76.9	47.8	*
Semi-permanent house	23.1	52.2	
Housing materials (%)			
Wood	100.0	87.9	NS
Stone/brick wall	80.0	60.1	NS
Grass/makuti roofing	0.0	25.5	*
Corrugated iron sheet roofing	100.0	74.1	*

*$p<0.05$, $^{NS}p>0.05$

Holstein-Friesian dominated over Ayrshire or Jersey dairy cattle breeds in smallholder farms (Table 4.3). Difference in breed composition was observed between the environments (p<0.001) but not between the farms (p>0.05). Results reveal dominance of Holstein-Friesian cattle breed under high-stress environment, despite being considered to suffer high sensitivity to disease infections, heat loads and higher nutritional demand needed to support potentially high productivity levels.

Table 4.3: Distribution frequency (percentage) of main dairy cattle genotypes in positive deviant and typical farms under stressful environments

Factor	Level	Holstein-Friesian	Ayrshire	Jersey	Chi-Square tests
Environment					
	Low-stress (n=1059)	68.5	26.0	5.6	***
	High-stress (n=1819)	81.3	16.1	2.6	
Farm (Environment)					
	Low-stress				
	Positive deviants (n=51)	60.8	37.3	2.0	NS
	Typical (n=1008)	68.8	25.4	5.8	
	High-stress				
	Positive deviants (n=59)	81.4	13.6	5.1	NS
	Typical (n=1760)	81.3	16.1	2.6	
Farm					
	Positive deviants (n=110)	71.8	24.5	3.6	NS
	Typical (n=2768)	76.8	19.5	3.7	

n = number of animals, ***$p<0.001$; $^{NS}p>0.05$

Crossbreeding is a common practice of upgrading dairy cattle in smallholder farming systems. The animal distribution frequency by upgrading levels in positive deviants and typical farms under stressful environments is summarized in Table 4.4. Cattle upgraded to higher grade levels (≥75% exotic breed) were a larger proportion of the total number of animals in positive deviant farms than in typical farms in both high-stress (76% vs. 61.7%) and low-stress environments (14.3% vs. 8.4%). Higher grade (≥75% exotic breed) cattle were also a larger proportion of the total number of animals in high-stress environment than in low-stress production environment (62.3% vs. 8.8%).

Table 4.4: Distribution frequency (percentage) of breed upgrading levels in positive deviant and typical farms under stressful environments

Factor	Level	Upgrading level				Chi-Square tests
		25%	50%	≥75%	Purebred	
Environment						
	Low stress (n=973)	7.0	84.3	6.7	2.0	***
	High stress (n=1068)	5.1	32.6	61.6	0.7	
Farm-(Environment)						
	Low stress					
	Positive deviants (n=42)	4.8	81.0	11.8	2.4	NS
	Typical (n=931)	7.1	84.4	6.4	2.1	
	High stress					
	Positive deviants (n=50)	-	24.0	72.0	4.0	**
	Typical (n=1018)	5.3	33.0	61.1	0.6	
Farm						
	Positive deviants (n=92)	2.2	50.0	44.6	3.2	*
	Typical (n=1949)	6.2	57.6	35.0	1.3	

n = number of animals, ***p<0.0001, **p<0.001, *p<0.05,^{NS}p>0.05

4.3.2 Feeding and Health Management Practices

Table 4.5 presents the mean proportions of fodder, concentrates and crop residues in a cattle diet on positive deviants and typical farms under contrasting stressful environments. Diet composition only differed between the environments ($p<0.05$) but not between positive deviants and typical farms ($p>0.05$). Under low-stress environment, purchased fodder was a larger proportion of the diet in positive deviant farms, 11 to 13% more than was observed in typical farms. Diets were relatively higher in fodder and crop residues in low-stress environment than in high-stress environment. The fodder consisted of green fodder and pastures from on-farm, communal land or market purchases. A larger proportion of purchased fodder and crop residues in the diet was observed in low-stress environment, while a larger proportion of on-farm fodder and pasture in the diet was observed in high-stress environment.

Table 4.5: Mean (±SD) proportions and differences of feed in the diet fed to dairy cattle in positive deviants and typical farms under low- and high-stress dairy production environments.

Factor	**Level**	**Fodder**	**Concentrates**	**Crop residues**
Production environment				
	Low-stress (n=164)	0.50±0.20	0.20±0.04	0.30±0.20
	High-stress (n=173)	0.40±0.08	0.30±0.03	0.20±0.10
	Mean difference	0.01^{**}	0.10^{NS}	0.01^{**}
Farm(Environment)				
	Low-stress			
	Positive deviants (n=9)	0.50±0.10	0.30±0.01	0.30±0.10
	Typical (n=155)	0.40±0.20	0.20±0.04	0.30±0.20
	Mean difference	0.10^{NS}	0.10^{NS}	0.00^{NS}
	High-stress			
	Positive deviants (n=6)	0.50±0.01	0.30±0.01	0.30±0.01
	Typical (n=167)	0.40±0.10	0.30±0.03	0.20±0.01
	Mean difference	0.10^{NS}	0.00^{NS}	0.10^{NS}
Farm				
	Positive deviants (n=15)	0.50±0.10	0.30±0.01	0.30±0.10
	Typical (n=322)	0.50±0.20	0.30±0.01	0.30±0.10
	Mean difference	0.00^{NS}	0.00^{NS}	0.00^{NS}

$^{**}p<0.01$; $^{NS}p>0.05$

Figures 4.1, 4.2, 4.3 and 4.4 illustrates the differences in feed cost, watering cost, and health management cost as percentage difference and the mean difference in cost per treatment event under low- and high-stress environments. A positive value for low-stress environment indicated that the cost was higher in low-stress environment than was in high-stress environment while a positive value for positive deviants indicated that the cost was higher in positive deviants than was in typical farms. A negative value indicated the opposite.

Feeding was predominantly in stalls, deploying a cut and carry feeding practice locally popular as zero-grazing. This was regardless of the farm management style (100% positive deviants vs. 94.4% typical farms). Figure 4.1 reveals that higher feed cost was incurred in low-stress environment than in high-stress environment and in positive deviants than in typical farms under high-stress environment but not under low-stress environment. A bivariate correlation between feed cost and milk yield was positive and highly significant ($r = 0.275$, $p<0.001$), indicating that milk yield increased with increased investment in feeds.

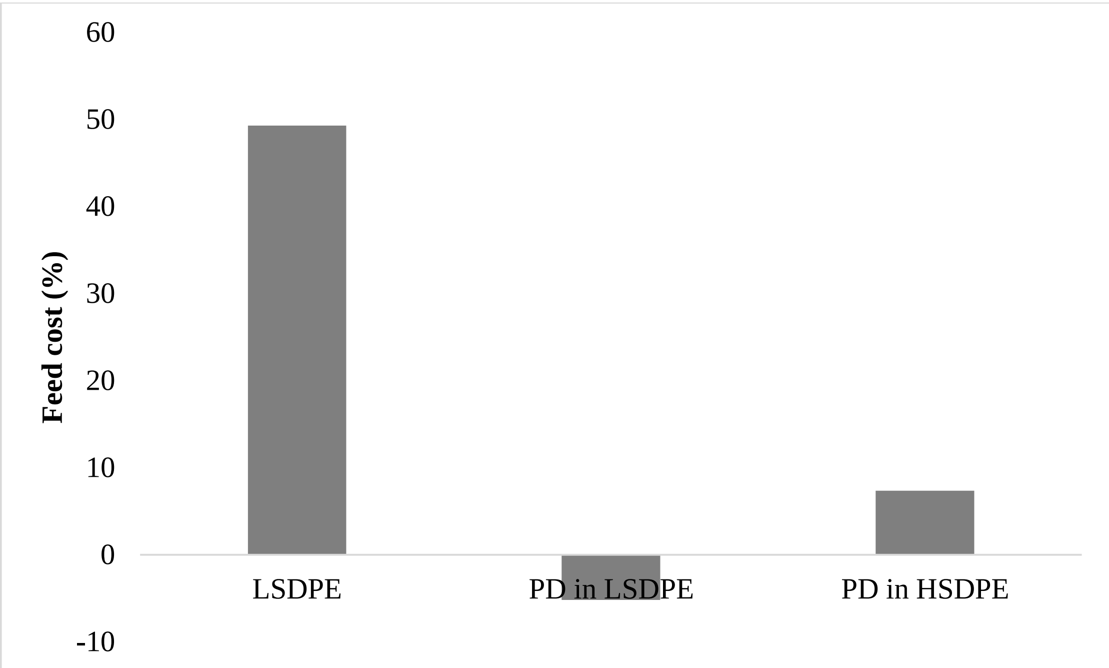

Figure 4.1: Mean percentage differences in feed cost per animal per year in positive deviants (PD) and typical farms under low- (LSDPE) and high-stress (HSDPE) dairy production environments in Tanzania.

Watering cost illustrated in Figure 4.2 reveals that this was lower in low-stress environment than in high-stressful environment. By farms, watering cost was higher in positive deviants than in typical farms under low-stress environment but lower under high-stress environment. On average, positive deviant farms incurred more on water (1.9%) for cattle than was incurred in typical farms. Regardless of the farm management style, the source of water was predominantly tap water or wells. A bivariate correlation between watering cost and distance from the farm to the main water source during dry season was positive and significant ($r = 0.336$, $p<0.001$), indicating that during dry seasons the cost of water increased with the increase in distance to the water source.

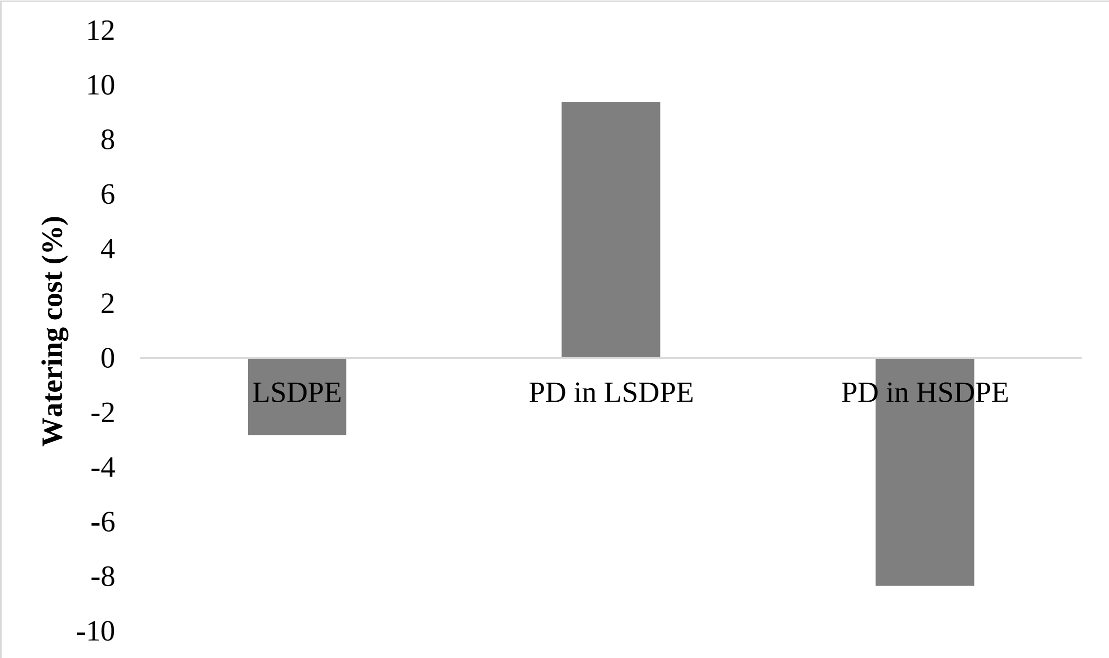

Figure 4.2: Mean percentage differences in watering cost per animal per year in positive deviants (PD) and typical farms under low (LSDPE) and high-stress (HSDPE) dairy production environments in Tanzania

The health cost illustrated in Figure 4.3 show that health management cost (deworming, dipping and vaccinations) was substantially lower in low-stress environment than in high-stress environment. However, comparison between farms show that health cost was relatively lower (7.6%) in positive deviant farms compared to typical farms in low-stress environment, and marginally higher (1%) in positive deviant farms than in typical farms under high-stress environment.

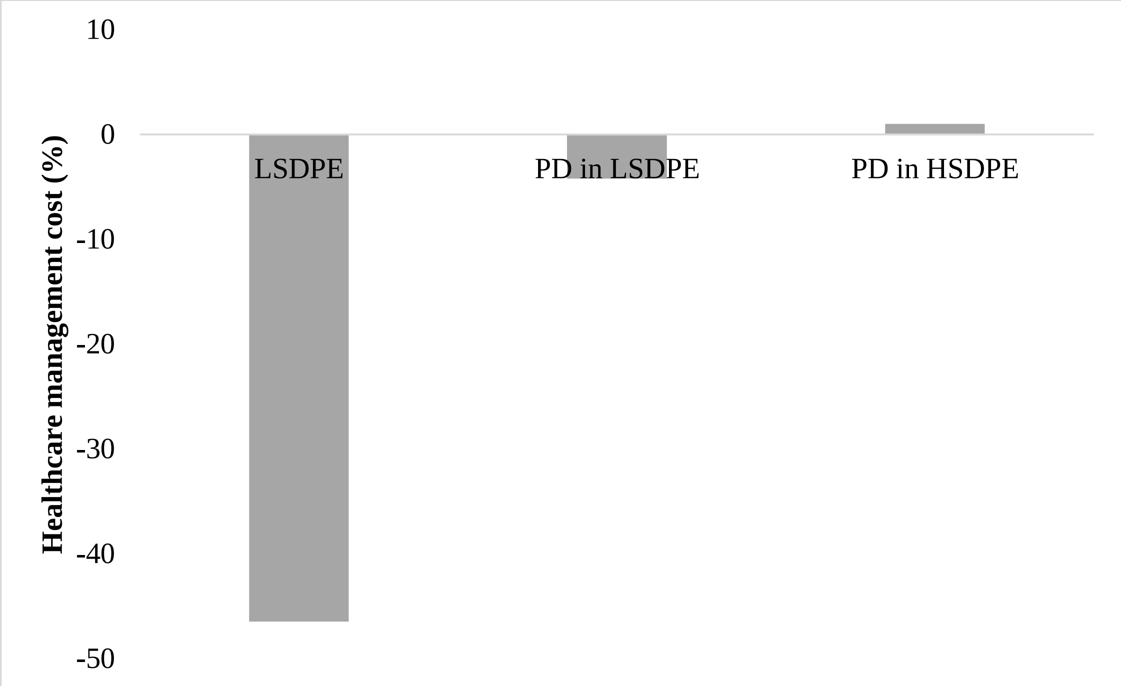

Figure 4.3: Mean percentage differences in healthcare management cost per animal per year in positive deviants (PD) and typical farms under low (LSDPE) and high-stress (HSDPE) dairy production environments in Tanzania.

The mean differences in cost per treatment per animal (drugs plus service costs) between positive deviants and typical farms under low- and high-stress environments are illustrated in Figure 4.4. Per case of treatment, results reveal that positive deviant farms were on average spending more ($p<0.05$) than typical farms to treat a reported case. Results presented in Table 4.6 reveal that this higher treatment costs in positive deviant farms were related to more frequent sourcing of professional animal health service providers in both high-stress environment (45.5 vs. 40.6%) and low-stress environment (75.0 vs. 66.5%). Positive deviant farms more frequently sourced professional animal health services in low-stress environment than in high-stress environment (67.0 vs. 40.7%).

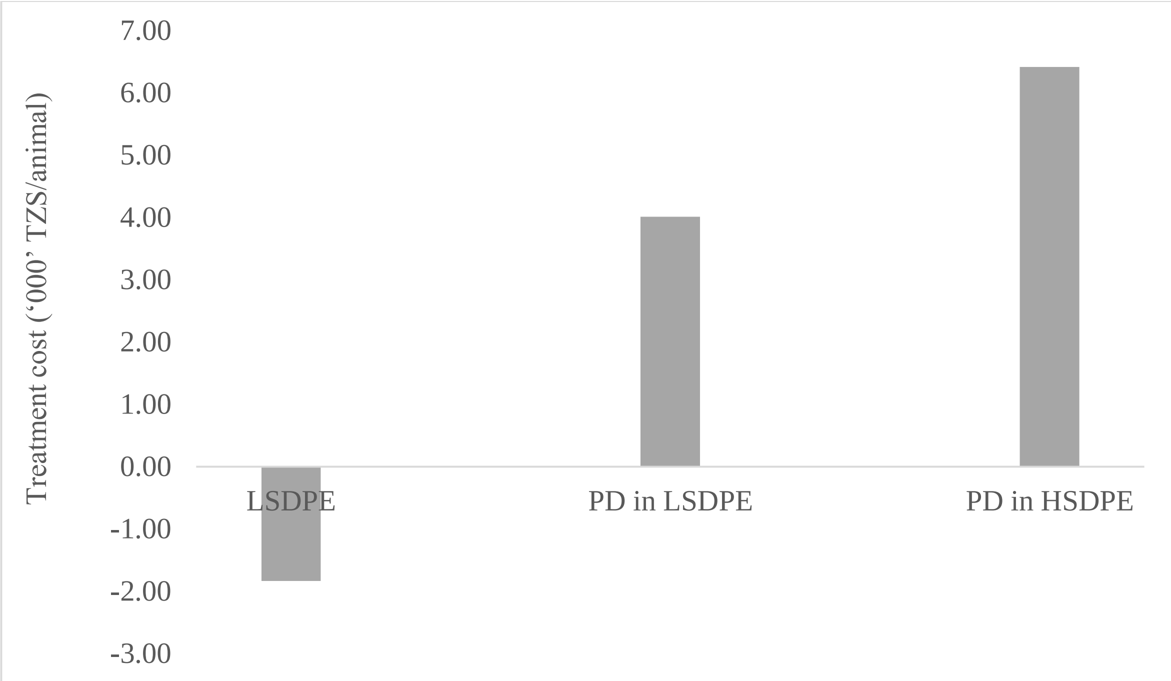

Figure 4.4: Mean differences in treatment cost per animal ('000' TZS/animal) in positive deviants (PD) and typical farms under low (LSDPE) and high-stress (HSDPE) dairy production environments in Tanzania (2297.53 TZS = 1 US Dollar).

Table 4.6: Distribution frequency (percentage) of animal health service providers to positive deviant and typical farms under low- and high-stress dairy production environments

Factor	Level	Fellow farmers	Professional animal health service providers	Chi-Square tests
Production environment				
	Low-stress (n=221)	33.0	67.0	***
	High-stress (n=297)	59.3	40.7	
Farm (Environment)				
	Low-stress			
	Positive deviants (n=12)	25.0	75.0	NS
	Typical (n=209)	33.5	66.5	
	High-stress			
	Positive deviants (n=11)	54.5	45.5	NS
	Typical (n=286)	59.4	40.6	
Farm				
	Positive deviants (n=23)	39.1	60.9	NS
	Typical (n=495)	48.5	51.5	

***$p<0.001$, $^{NS}p>0.05$

4.4 Discussion

This study characterised management practices that differentiate positive deviants from average typical farms under similar levels of environmental stresses. Characterisation was on breeding, housing, feeding and health management practices which farms may deploy to ameliorate heat load stress, feed scarcity or disease infections, because these either limit or reduce dairy productivity (Gustafson *et al.,* 2015; Polsky & von Keyserlingk, 2017). The identification of positive deviant farms was with the use of Pareto-Optimality ranking technique. Multiple production performance indicators as used in Pareto-Optimality ranking technique corresponds to econometric measure of farm efficiency that accounts for multiple inputs (Kibiego *et al.,* 2015). Farm efficiency has two components: technical efficiency, which reflects the firm's capacity to maximize output from a given set of inputs, and allocative efficiency, which reflects the capacity of a firm to utilize the inputs in the best combinations possible, given their respective prices.

The two-factor nested research design employed in this study is multilevel model suitable for analyzing hierarchical data. For this study, the objective was to identify the management practices that positive deviant farms deploy differently from typical farms nested within low- and high-stress environments. The nesting allowed for fitting random effects to analyse variability in the layers of the hierarchical structure (Field, 2009; Krzywinski *et al.,* 2014).

4.4.1 Breeding Practices

Breeding practices that differentiated positive deviant farms from typical farms were the large number of animals comprising higher-grade cattle (≥75% exotic blood), predominantly the Holstein-Friesian cattle. This points to positive deviant farmers pursuing cattle upgrading objective and preference for breeds with high milk-yielding potential. Dairy cattle upgrading is a technological intervention deployed to improve milk production and productivity, especially for a small number of animals, characteristically less than ten animals (Kebebe *et al.,* 2017). High grade Holstein-Friesian dairy cattle are potentially higher yielding than the Ayrshire or Jersey breeds (Mbuthia *et al.,* 2021). To a household, high milk yielding potential is important in breed choice for provision of a regular stream of milk for quality food as a source of protein and for income. This is supportive to the production objective of smallholders in adopting improved dairy cattle to increase milk production for both home consumption and marketable surplus for cash income (Bebe *et al.,* 2003b; Marshall *et al.,* 2020; Vercillo *et al.,* 2015).

Higher levels of upgrading dairy cattle observed in positive deviants than typical farms under high-stress environment points to positive deviants being early adopters of artificial insemination (AI) and improved bulls. This dairy upgrading has further been promoted by the ADGG project since 2016 in the study areas (ILRI, 2019). The project facilitates farmer access to superior dairy crossbred heifers, improved bulls and AI services (Mrode *et al.,* 2021). Both positive deviants and typical farms had access to these dairy breeding technologies, so early adopter behaviour of positive deviants is likely to be aided by ownership of more production resources and commercial orientation in production. In the high-stress environment, there is a milk processing plant (Tanga Fresh Ltd) with uptake capacity of 50,000 L/day of raw milk. This is a milk market that commercially oriented positive deviant producers can find attractive to invest in dairy production. This observation is supported by the results which indicated that positive deviants were investing more in dairy than typical farmers. This could be as a result of positive deviants accessing credit facility from Tanga Model to buy quality heifers from public and private dairy multiplication farms established in high-stress environment (Cadilhon *et al.,* 2016; Solidaridad, 2019). Tanga Model is a credit facility operated in high-stress environment to promote dairy cattle farming. Therefore, empowering typical farmers to engage in these economic opportunities to improve their production performance is necessary.

Upgrading dairy cattle adaptable to local production environment through crossbreeding is a common management practice in smallholder farming. Crossbreeding between indigenous and exotic dairy cattle has been implemented extensively in the tropics to improve production performances of indigenous cattle (Gojam *et al.,* 2017). It is hypothesised that crossbred cattle would be more productive and resilient to prevalent environmental stresses in smallholder farming systems. However, in most cases crossbreeding in the tropics and in particular smallholder farming system is not well structured resulting in farmers keeping a range of mixed crossbred genotypes aiming to improve productivity (Mbuthia *et al.,* 2021; Ojango *et al.,* 2019). Appropriate organizational structures to support long term planned crossbreeding program thus remains necessary.

4.4.2 Housing Management

The cattle housing management practices differentiating positive deviants from typical farms were larger floor spacing per animal (10.4 vs. 7.1 m^2/cow) in better quality zero-grazing stall units. The recommended floor spacing is 7.4 to 9.3 m^2/cow to allow for proper air movement and natural expression of animal behaviour (Bewley *et al.,* 2017). This is because natural air movement increases convection which reduce environmental temperatures and accumulation of ammonia gas inside the zero-grazing stall units. Therefore, in typical farms, animals were allowed inadequate spacing (6.2 m^2 per animal), especially under high-stress environment where animals most needed to be protected from heat stress exposure. On positive deviant farms, floor spacing area per animal allowed exceeded the recommended area, so a larger floor spacing can be associated with more comfort and better animal welfare and these do have ameliorative effect on heat load stresses (Bang *et al.,* 2021; Moran & Doyle, 2015).

Under tropical conditions, adequate house floor spacing per animal can be associated with improved cow comfort. This is supported by observations that increasing floor area per animal has a decreasing effect on air temperature inside the cow barn (Bang *et al.,* 2021; Bewley *et al.,* 2017; Galama *et al.,* 2020). This is important in high-stress environment where ameliorating heat stress will improve microclimate in animal housing (Beaver *et al.,* 2019; Bewley *et al.,* 2017; Galama *et al.,* 2020). Animals in good welfare status have improved dry matter intake and are able to utilise the nutrients for milk production, which explains the observed higher production performance of the cattle in positive deviant farms.

Better comfort and improved animal welfare is especially important in the coastal lowland zone classified a high-stress dairy-production environment (Armstrong, 1994; Britt *et al.,* 2021). Here animals were exposed to mild to moderate heat stress indicated by lower spacing of 6.2 m^2 per animal in typical farms and THI of 77.29 (Mbuthia *et al.*, 2021), a level at which animals begin to exhibit heat stress signs. In dairy cattle, heat stress signs are associated with poor growth, suboptimal reproduction and lower milk production because of elevated blood insulin and protein catabolism (Wang *et al.*, 2020).

In positive deviant farms, the zero-grazing stall units were made of durable materials (cement or brick walls and concrete floors with corrugated iron sheet roofing), which confer a better quality housing condition. This allows for easy cleaning to maintain high standards of hygiene, subsequently improving animal comfort, health and welfare status. Use of durable construction materials in positive deviant farms indicates high quality housing and more investment to improve animal welfare but also to secure livestock assets from theft (Savikurki, 2013). Durable construction materials can help to protect animals against bacterial infections because of ease of cleaning to improve sanitation (Bang *et al.,* 2021; Beaver *et al.,* 2019; Gillah *et al.,* 2014; Slaghuis, 1996). However, current findings suggest that positive deviant farmers were ameliorating environmental stresses more successfully with increased investments in dairy farming because they were spending more to purchase inputs, probably being more resource endowed.

4.4.3 Feeding Practices

Feeding practices that differentiated positive deviants from typical farms were greater investment in external sourcing of fodder and water to address feed scarcity. This investment was important for improving dairy productivity because feed scarcity is a production limitation in smallholder dairy farming. Positive deviant farms were larger landholding, which can be associated with producing more fodder and accessing more crop residues for dairy cattle feeding. Though positive deviants had about three times larger landholdings relative to typical farms (9.5 vs 3.3 acres), they still sourced fodder externally, indicating insufficient on-farm fodder production. With a large number of animals of high-grade Holstein-Friesian cattle, positive deviant farms were likely under more pressure to supply fodder from own farm sources (Brett, 2019; Chagwiza, 2022; Kebebe *et al.,* 2017). Own-produced fodder can reduce feed costs associated with market sourced feeds. By investing more in producing milk, positive deviants used more inputs. This corroborates findings of Kibiego *et al.* (2015) who observed that farmers increased milk produced with increasing the variable costs. In this study, feed quality of on-farm and market sourced fodder was not assessed to inform on whether investment is also on quality of the feed. This is a knowledge gap in this study for which research is recommended to inform dairy farmers and extension services for decision making purposes.

Fodder supply indicated that more feed is needed in high-stress environment than in low-stress environment. This contrasts a previous study in the same sample farms which did not reveal any significant difference in energy balance (Mcal NE_L/d) for lactating cows between low- and high-stress environment (Chapter Three). It can be interpreted that feed scarcity is experienced in both low- and high-stress environments, but at a greater magnitude in high-stress environment. For optimal productivity, options to increase feed supply cheaply is sourcing alternative feeds rich in energy and protein because conventional feed resources are costly. For example, growing a mixture of Rhodes grass and Desmodium species or Lablab legume in addition to outsourcing can assure stable access to animal feeds throughout the year in both production environments. For successful dairy cattle farming, reliability in supply of sufficient and quality fodder is necessary to support higher productivity levels (Britt *et al.,* 2021; Collier & Dercon, 2014). Producing improved fodder needs capacity building among farmers especially in the selection of suitable forage species, agronomic practices and soil management to sustain year-round quality forage supply (Marshall *et al.,* 2019; Marshall *et al.,* 2020).

Higher investment in water supply observed in positive deviant farms can be associated with ameliorating heat stress and improving animal welfare status (Bang *et al.,* 2021; Polsky

& von Keyserlingk, 2017). This is alternative to heavier investment needed in using high energy demanding technologies such as fans, misters and showers to ameliorate heat stress in dairy cattle. Effective use of watering to ameliorate heat stress for cattle in the zero-grazing stall units will however require adequate water supplies at increased investments. This brings to the need for public investment in water harvesting, storage and supply infrastructure in dairy milksheds, more particularly in the high-stress environment.

4.4.4 Animal Health Management Practices

Animal health management practices could be differentiated between positive deviants and typical farmers. More investment in professional veterinary services and lower cost in healthcare management differentiated positive deviants from typical farmers. Lower healthcare management cost can be related to spending more on preventive than curative health practices, as positive deviants more frequently consulted professional veterinary service providers, in both low-stress (75.0 vs. 66.5%) and high-stress (45.5 vs 40.7%) environments. It is more important in high-stress environment, which is a coastal lowland zone classified as such because of persistent animal exposure to a combination of high humidity with mild to moderate heat stress (77.29 THI units) and prevalent disease infections. The combination of high humidity and air temperatures facilitates multiplication of disease causing agents and their spread in dairy cattle.

After 72 THI units, animals begin to exhibit heat stress signs, which physiologically depresses feed intake and subsequently lowers their immune system as well. Hence, more frequently sourcing professional animal health services observed among positive deviant farms indicates that they were ameliorating disease infections at a fee. In other words, this implies that they had higher ability to reliably pay for the veterinary services.

Frequent sourcing of professional services could mean that there is investment in preventive than curative healthcare management in positive deviant farms compared to typical farms. In regularly consulting professional health service providers, positive deviants were more likely to ensure appropriate prescription for the right veterinary product, thus avoiding unnecessary costs and misuse of drugs (Schumacher, 2020). Professional animal health service can also be associated with delivery of high-quality services, which is supportive to keeping high-grade dairy cattle in better health status to attain increasing productivity (Campbell *et al.*, 2021; Marshall *et al.*, 2020). However, farmers need resources to spend on disease preventive and curative services. Farmers with limited resources spent much less on treatment than those who are better off in resource ownership, and this is important for diseases with a high morbidity but comparatively low mortality rates (Heffernan, 2009).

Among smallholder dairy farms, positive deviants were relatively more production resource endowed than typical farms. This is indicated by ownership of larger landholding and the number of dairy cattle, more capital invested in water, veterinary and durable and quality animal housing. These enabled positive deviants access quality veterinary inputs and services (Schumacher, 2020). This supports the need for cooperative membership to allow farmers access quality veterinary inputs and services to ameliorate disease infection stresses (Schumacher, 2020; Sumner *et al.,* 2018; Thapa Shrestha *et al.,* 2020). This show that technical innovations that enhance management of cow health, genetic quality and nutrition are critical for increasing dairy productivity. Along these improvements, it is necessary to improve the efficiency of the dairy supply chain through organizational and institutional innovations which should include access to affordable credits (Wairimu *et al.,* 2022). Farmer cooperative movements offer viable interventions for both positive deviants and typical farms because cooperatives can hire professional veterinarians and stock quality inputs and arrange access to these inputs and services at affordable and conveniently a pre-arranged credit facility. This should improve delivery of animal health services for smallholder dairy farmers (Perry *et al.,* 2002).

Implementation of the strategies proposed here can benefit from deeper understanding of underlying farmers' attitudes, intention and perceptions that influence positive deviants' motives to improve their management practices. This is because the adoption of management practices is a highly nuanced multivariate behaviour (Dezdar, 2017). This requires considering a number of factors when promoting effective management strategies, including farmers' attitudes and neighbour pressure that can drive the subjective norm as was observed in the Loess Plateau of China (Deng *et al.,* 2016). In addition, perceptions of farmers' ability to effect recommended innovations is a significant determinant of farmers' intention to adopt and apply dairy innovations. In the current study areas, members of cooperative societies be able to access affordable credit to accelerate adoption of dairy innovations (Kibiego *et al.,* 2015; Wairimu *et al.,* 2022).

4.5 Conclusions

Empirical evidence generated in this study show that management practices differentiating positive deviants from typical farms are cattle upgrading, allowing for larger animal floor spacing and investing more in cattle housing, fodder, water, and professional animal health services. Investing more in fodder and watering reflects efforts to ameliorate feed scarcity. Cattle upgrading is crossbreeding that improves adaptability of dairy breeds under tropical stresses, larger animal floor spacing and investing more in cattle housing, professional animal health services are interventions supportive to ameliorating disease infections. Dairy cattle crossbreeding in the upgrading, larger animal floor spacing, and investing more in cattle housing and, watering reflects interventions to ameliorate heat stress. Therefore, these practices can be associated with amelioration of feed scarcity, disease infections and heat load stresses, subsequently supporting better animal welfare status and lowering health management cost in positive deviant farms. However, nutritional quality of the diet was not analysed to inform whether positive deviants direct the investments to improving feed quality. This knowledge gap will need research to close.

CHAPTER FIVE

ASSESSING DISEASE PREVALENCE AND MORTALITY OF DAIRY CATTLE IN SMALLHOLDER FARMS UNDER CONTRASTING MANAGEMENT PRACTICES AND STRESSFUL ENVIRONMENTS IN TANZANIA

Abstract

In dairy farming, deploying effective animal husbandry practices minimise disease infections and animal mortality. This improves animal health and welfare status, which is important in tropical smallholder dairy farming, where animals are persistently exposed to multiple environmental stresses. The hypothesis of this study was that animals managed in positive deviants and typical farms suffer different levels of disease infections and mortality, whether under low- or high-stress environments. The study adopted a two-factor nested design with farms contrasting in the level of animal husbandry (positive deviants and typical farms) nested within environments contrasting in the level of environmental stresses (low- and high-stress). A total of 1,999 animals were observed over 42 month period in the coastal lowlands and highlands of Tanzania. The disease prevalence was lower ($p<0.05$) in positive deviant farms than in typical farms under low-stress (10.13 vs. 33.61 per 100 animal-years at risk) and high-stress (9.56 vs. 57.30 per 100 animal-years at risk). Cumulative disease incidence rate was also lower ($p<0.05$) in positive deviant farms than in typical farms under low-stress (2.74% vs. 8.44%) and high-stress (2.58% vs. 14.34%). The probability of death for a disease infected dairy cattle was relatively lower in positive deviant farms compared to typical farms under low-stress (0.57% vs. 8.33%) and high-stress (0.60% vs. 6.99%). Per 100 animal-years at risk, the mortality density of cattle was lower ($p<0.05$) in positive deviant farms compared to typical farms, 15.10 lower in low-stress and 2.60 lower in high-stress. These results show that compared to typical farms, positive deviant farms consistently attained ($p<0.05$) lower animal disease infections and subsequent deaths, regardless of the level of environmental stress that the animals were exposed to. This implies that positive deviant farms deployed animal husbandry practices that more effectively minimised animal disease infections and deaths and therefore could maintain their animals in better health and welfare status.

5.1 Introduction

Disease prevalence and mortality rates are metrics relevant in monitoring the animal health status in a dairy herd. In addition, these metrics have influence on animal well-being and farm profitability (Haagen *et al.*, 2021; Ries *et al.*, 2022a). Disease infections and mortality in a dairy herd can account for significant economic loss from losses in financial, wealth, nutrition, improved genetic materials and investment. Disease exposure and infections contribute to reduced productivity levels attainable in smallholder dairy cattle farming. In chronic and severe incidences, disease exposure and infections lead to huge yield gaps (van der Linden *et al.,* 2015; VanLeeuwen *et al.,* 2012), and subsequent loss of livelihood benefits to the households (Hernández-Castellano *et al.,* 2019).

Involuntary loss of heifers before calving increases the need for externally sourced heifer replacements to offset the loss of potential replacements (Haagen *et al.*, 2021). In young stock, disease infections can lead to suboptimal performance in later adult age, including older age at first calving (Heinrichs & Heinrichs, 2011), but also increased risk of exiting the herd before first calving (Waltner-Toews *et al.,* 1986). Disease infections causing mortality are variable between management practices that farmers deploy, production systems and production environments (Compton *et al.,* 2017). In dairy cattle, up to 31.0% morbidity rate and 58.4% mortality rate have been reported (Dagne *et al.*, 2018) and variations occur between production environments, depending on the magnitude of stress to animals (Kerario *et al.,* 2017; Kasaija *et al.,* 2021; Swai *et al.,* 2009).

The magnitude of economic loss value experienced in smallholder dairy farming can be substantial with adverse impacts on the livelihood benefits (Wong *et al.,* 2021). This necessitates estimating disease prevalence rates and associated animal mortality rates to inform animal health interventions. Good animal health status is a determinant of productivity and livelihood benefits in a dairy herd (Ries *et al.*, 2022b). However, keeping a herd in good health status comes with increased investments in quality housing, feeds and animal health services as has been observed by Schumacher (2020).

In studying distinguishable management practices between positive deviants and typical farms, the study has observed that positive deviant farms deployed management practices differently from typical farms. The study findings also revealed that cattle were exposed to higher levels of heat stress in high-stress environment than in low-stress environment (77.29 ±0.39 vs 68.20 ±0.39 THI). These observations would imply that animal disease infections and mortalities are variable between farms with contrasting management practices and between contrasting stressful environments. The hypothesis tested that animals managed in positive deviants and typical farms suffer different levels of disease infections and mortality, whether under low- or high-stress environments. The study used sample smallholder dairy farms in two prominent milksheds found in the northern highlands and eastern coastal lowlands of Tanzania.

5.2 Materials and Methods

5.2.1 The Data Source

This is an extension of Chapter Three in which methodology was in detail of the study area, research design, data collection and identification process of positive deviants and typical farms are described in section 3.2.1, 3.2.2, 3.3 and 3.4 of Chapter Three, respectively. In this section, complementary and objective specific information is described.

5.2.2 Data Collection and Processing

Information about disease and treatment events was captured during monthly farm visits. The ADGG engaged farmers in collecting routine animal performance data recording service offered by trained para-professional veterinary assistants (PPVAs) who visit the individual farms once or twice on the monthly basis. The PPVAs record animal performance in an Open Data Kit tool installed in Android Tablets. In this study, the disease events occurred between 1st of January 2017 and 31st of July 2020. A dynamic cohort approach was adopted to account for additional animals recruited provided that they were either born after initial recruitment or acquired (purchase or gift). Clinical signs and treatments were recorded for each case.

Treatment events that were recorded simultaneously with a vaccination or routine animal health management records were excluded as it was not possible to determine if the record was associated with disease treatment or prevention. A disease was considered unique and was recorded as a new event for a given animal if it occurred 14 days or more from the termination of a previous similar disease episode. This timeframe was determined based on recommended on-farm protocols designed to identify new cases of disease as opposed to retreatment of the same disease episode (Wenz & Giebel, 2012). In this context, disease diagnosis was based on differential clinical signs consistent with the type of disease observed in a susceptible animal.

The major diagnostic features included weight loss, diarrhoea, dullness, thriftiness, loss of appetite, laboured breathing, ocular discharges, nasal discharges, paleness of ocular and buccal membranes, enlarged superficial lymph node (parotid or pre-scapular or pre-crural), constipation and pyrexia (elevated body temperature >40°C). The presence of these clinical features is directly indicative of seroconversion to most common disease infections in dairy cattle (Magona *et al.*, 2008). Seroconversion is the transition from the point of disease infection to when antibodies of the disease causing agents become present in the blood.

After all edits, 794 farms had a total of 1999 dairy cattle with a total of 1912 health treatment events on 849 diseased cattle available for analysis. In addition, a total of 69 dairy cattle (≥18 months of age) died during the study period. Table 5.1 provides a summary of the number of dairy farms, animals, diseased animals and deaths that occurred during the study period in positive deviants and typical farms by the environments. In this study animal disease prevalence, cumulative disease incidence, case-fatality rate and animal mortality density were used to assess health status of dairy cattle managed in positive deviants and typical farms under low- and high-stress environments.

In this study, morbidity events were estimated in terms of crude disease prevalence in a stepwise process. First, disease incidence density which is the number of new cases that occurred in a population over a period of time was quantified at the individual herd level monitored over a period of 42 months. This is an indicator measuring the rapidity with which new cases of disease develop overtime to derive disease prevalence (Fukushima *et al.*, 2020; Thrusfield, 2007). Disease incidence density was computed according to Thrusfield (2007):

$$\text{Disease incidence density} = \left(\frac{\text{number of events occurred during observation period}}{\text{sum of animal years at risk of developing disease}}\right) \quad (5.1)$$

Table 5.1: Distribution of numbers of farms, animals, diseased animals, deaths and total animal-years at risk in the database used for the analyses

Factor	**Level of stress**	**Number of farms**	**Number of animals**	**Number of diseased animals**	**Number of deceased animals**	**Number of animal-years at risk**
Environment						
	Low-stress	386	930	348	31	3044.7
	High-stress	408	1069	501	38	3430.6
	Total	794	1999	849	69	6475.3
Farm (environment)						
	Low-stress					
	Positive deviants	15	39	4	2	182.2
	Typical farms	371	891	344	29	2862.5
	Total	386	930	348	31	3044.7
	High-stress					
	Positive deviants	12	31	5	3	114.3
	Typical farms	396	1038	496	35	3316.3
	Total	408	1069	501	38	3430.6
Farm	Overall					
	Positive deviants	27	70	9	5	296.5
	Typical farms	767	1929	840	64	6178.8
	Total	**794**	**1999**	**849**	**69**	**6475.3**

The resulting disease incidence density expressed per animal-years at risk was used to derive disease prevalence rate. Disease prevalence is defined as the number of instances of disease or related attributes (e.g., infection) in the study population, at a designated time or over a specified time period (period prevalence) without distinction between old and new cases. Since disease prevalence depends on the duration and disease incidence (Thrusfield, 2007), therefore, disease prevalence was computed from the relationship:

$$Disease\ prevalence \propto Disaese\ incidence\ \times Duration \tag{5.2}$$

For clarity, the disease prevalence is presented as per 100 animal-years at risk (multiplying by 100). The periods at risk, or animal days at risk, are the total number of days the study animals were present during the observation period. The contribution of each animal to the total animal days was the difference between its date of exit or end of the study and its date of entry (or start of the study).

In addition, cumulative disease incidence which is used to predict an individual's change in health status was estimated. This indicator shows the probability of an individual becoming ill over a specified period of time. Therefore, cumulative disease incidence was estimated from disease incidence density obtained in equation (5.1) using the following function:

$$Cumulative\ incidence = 1 - e^{-(Incidence\ density)} \tag{5.3}$$

Further, case-fatality rates was calculated based on the number of deceased cases to the total number of diseased animals in the population (Thrusfield, 2007; Wong *et al.*, 2021). This is defined as the number of deaths occurred during the study period to the total number of diseased animals in the population.

Mortality density measures are analogous to incidence measures where the relevant outcome is death rather than new cases of a specific disease. This is computed in a similar way as incidence density (λ: number of deaths in a population per unit of animal-time during a given period). The numerator comprise the number of deaths. For this study, mortality was defined as any observed death, irrespective of the cause. Confirmation of mortalities was done by PPVAs or by examining the farmers' disease event records during subsequent farm visits. Following confirmation, mortality density (λ) was computed at herd level for the entire period of study. Thus, crude λ was estimated from applying the following equation:

$$\lambda = \left(\frac{\text{number of deceased animals that occurred during observation period}}{\text{sum of animal years at risk of dying}}\right) \tag{5.4}$$

The resulting λ represented the rate per animal-years at risk in a predefined period and was translated into a rate per period at risk per defined time period (i.e. year). Thus, the λ for predefined period was presented as per 100 animal-years at risk (multiplying by 100).

5.2.3 Statistical Analyses

Statistical analysis was to test the hypothesis that in smallholder dairy farming, animal disease infections and mortality significantly differs between positive deviants and typical farms whether under low or high stressful environments. All statistical analyses were performed in SAS software (SAS Institute Inc, 2013), fitting linear mixed model to account for variables that were correlated or with non-constant variability. Means separation was achieved with least significant difference for direct pairwise comparisons between means. The statistical model was as follows:

$$Y_{ijk} = \mu + PE_i + FT(PE)_{j(i)} + e_{ijk} \qquad (5.5)$$

where, $Y_{(i)jk}$ is either estimated disease prevalence, cumulative incidence and mortality density rates; μ is the overall mean, PE_i is the fixed effect of environment, $FT(PE)_{(i)j}$ is the random effect of farm (positive deviants and typical) nested within the environment (low- and high-stress) and $e_{(i)jk}$ is the random error.

5.3 Results

Table 5.2 shows the estimated means for crude diseases prevalence and cumulative disease incidence rates in positive deviant and typical farms under low- and high-stress environments. Results reveal that positive deviant farms realised lower crude diseases prevalence and cumulative disease incidence rates ($p<0.001$) in both low- and high-stress environments. The disease prevalence was lower in positive deviant farms than in typical farms in both low-stress environment (10.1 vs. 33.6 per 100 animal-years at risk) and high-stress environment (9.6 vs. 57.3 per 100 animal-years at risk). Also, cumulative disease incidence rate was lower in positive deviant farms than in typical farms in both low-stress environment (2.7 vs. 8.4%) and high-stress environment (2.6 vs. 14.3%).

Table 5.2: Least squares mean (±SE) of crude disease prevalence per 100 animal-years at risk and cumulative disease incidence rate (%) in dairy cattle raised in positive deviant and typical farms under low and high stressful environments.

Factor	Level	Crude disease prevalence per 100 animal years at risk	Cumulative disease incidence rate (%)
Production environment			
	Low-stress (n=386)	21.8±5.9	5.6±1.5
	High-stress (n=408)	33.4±6.6	8.5±1.6
	Mean difference	11.6^{NS}	2.9^{NS}
Farm(environment)			
	Low-stress		
	Positive deviants (n=15)	10.1±11.7	2.7±2.9
	Typical (n=371)	33.6±2.4	8.4±0.6
	Mean difference	23.5^{*}	5.7^{NS}
	High-stress		
	Positive deviants (n=12)	9.6±13.1	2.6±3.2
	Typical (n=396)	57.3±2.3	14.3±0.6
	Mean difference	47.7^{***}	11.7^{***}

$^{***}p<0.001$; $^{*}p< 0.05$; $^{NS}p>0.05$.

Average case-fatality rates (%) for animals in positive deviants and typical farms in both high- and low-stress environments are reported in Figure 5.1. The case-fatality rate measures the probability of death in diseased animals. The results reveal a lower probability of death for dairy cattle in positive deviant farms compared to those in typical farms, in both low-stress environment (0.57 vs. 8.33%) and high-stress environment (0.60 vs. 6.99%). Further, results reveal a lower probability of death for animals under low-stress environment relative to high-stress environment (3.65 vs. 4.48%). This indicated that disease infected animals had a higher survival rate in positive deviant farms regardless of the level of environmental stress.

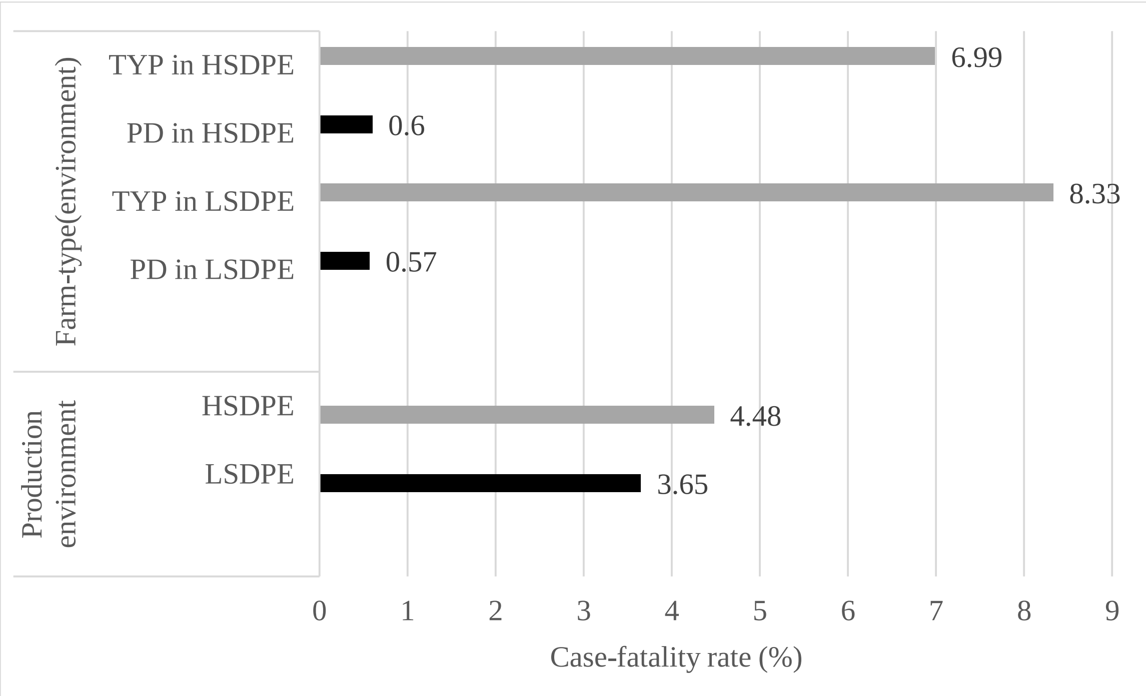

Figure 5.1: Estimated case-fatality rates of cattle managed in positive deviants (PD) and typical (TYP) farms under low-stress (LSDPE) and high-stress (HSDPE) environments.

Mean differences in animal mortality density (per 100 animal-years at risk) by farm and environment is illustrated in Figure 5.2. A positive value for low-stress environment indicated higher mortality density in low-stress environment than was in high-stress environment while a positive value for positive deviants indicated a higher mortality density in positive deviant farms than was in typical farms. A negative value indicated the opposite. The mortality density per 100 animal-years at risk was lower in positive deviant farms (9.93) compared to typical farms (18.75), regardless of the production environments. Positive deviant farms recorded a lower animal mortality density per 100 animal-years at risk, 15.10 (5.30 vs. 20.36) lower in low-stress and 2.6 (14.56 vs. 17.14) lower in high-stress environment (Figure 5.2). Further, animal mortality density was a marginal 3.02 (12.83 vs. 15.85) per 100 animal-years at risk lower in low-stress environment compared to those in high-stress environment.

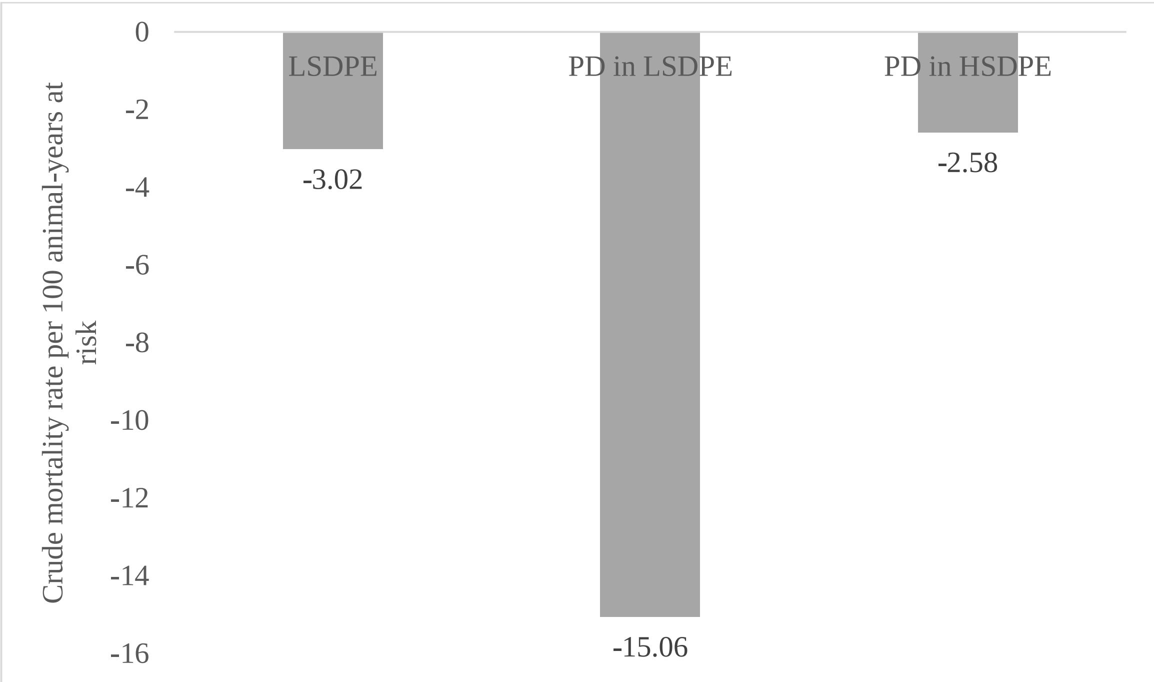

Figure 5.2: Means difference in mortality density of dairy cattle raised in positive deviants (PD) and typical farms under low-stress (LSDPE) and high-stress (HSDPE) environments.

5.4 Discussion

The animal disease prevalence, cumulative disease incidence, case-fatality and mortality density estimated in this study are to indicate the deployment of animal husbandry practices that improve animal health and welfare status. The differences observed between positive deviants and typical smallholder dairy farms reveal the extent to which animal husbandry practices deployed have been effective in minimising disease infections and animal mortality. In smallholder farming, where dairy cattle are persistently exposed to multiple environmental stresses, the level of animal husbandry practices has influence on the animal health and welfare status that can be attained. The results presented in Chapter Four with the same farms had revealed that positive deviant farms do deploy management practices differently from typical farms and with positive outcomes in performance. Distinguishing positive deviant farms from typical farms were consistent outperformance in five production performance indicators. With this knowledge, this study assessed whether animals managed in positive deviants and typical farms suffer different levels of disease infections and mortality under similar environmental stresses. A study design suited to testing this hypothesis was identified and implemented. This was a two-factor nested design with contrasting levels of environmental stresses (low- and high-stress) as fixed effect and farms contrasting in level of animal husbandry practices (positive deviants and typical farms) nested within the environment.

The data from which estimates were made of the disease prevalence rate and mortality density was reasonably of high reliability level, suited to testing the hypothesis. The data was from sufficiently large sample of 794 farms, 1999 animals observed over 42 months longitudinal period in which 1912 health treatment cases were recorded on 849 diseased animals. The farms, especially the positive deviants, frequently sourced professional veterinary services that accorded closer monitoring of sick cases and other animal health practices (Chapter Four). Also, a dynamic cohort approach was adopted in which clinical signs and treatments were recorded for each case longitudinally and additional animals recruited after verifying their origin (birth after initial recruitment, purchase or gift). The estimated disease prevalence and cumulative disease incidence rate are indicative of the extent to which animal husbandry practices deployed effectively minimised disease infections. The estimated case-fatality as a probability of death for a disease infected animal and mortality density are indicative of the extent to which animal husbandry practices deployed effectively minimised animal mortality.

The animal disease prevalence and cumulative disease incidence rates obtained in positive deviant farms were consistently lower than those in typical farms in both low-stress and high-stress environments. In positive deviant farms, the disease prevalence was 3.3 times lower (10.1 vs. 33.6 per 100 animal-years at risk) in low-stress environment and >6.0 times lower (9.6 vs. 57.7 per 100 animal-years at risk) in high-stress environment when compared to typical farms. Cumulative disease incidence rates in positive deviant farms were 3.1 times lower (2.7 vs. 8.4) in low-stress environment and 5.5 times lower (2.6 vs. 14.3%) in high-stress environment when compared to typical farms. This is a strong evidence that disease infections were more minimised in the positive deviant farms, whether in low- or high-stress environments. It is argued that positive deviant farms deployed animal husbandry practices that more effectively minimised disease infections than were the husbandry practices deployed in the typical farms.

Higher rates of disease prevalence and cumulative incidences in typical farms can be associated with the reliance on fellow farmers for provision of veterinary services unlike the positive deviant farms who frequently sourced professional animal health service providers (Chapter Four). This observation corroborates that of Singh *et al.* (2020) in India where smallholder farmers had reliance on untrained fellow farmers for provision of veterinary services. Rarely are fellow farmers adequately trained in veterinary service delivery, so such a practice potentially can lead to misdiagnosis of diseases or misuse of drugs. There are disadvantageous when farmers source unqualified veterinary services because of associated poor management outcomes (Proch *et al.,* 2018). For instance, a previous study reported unqualified farmers to incorrectly dilute and apply highly poisonous acaricides to control ticks at a shorter intervals of 1-2 weeks (Ogden *et al.*, 2005). With such a practice, the efficacy of acaricides become compromised when under-dosing because this encourages the stronger and most resistant parasites to survive and acquire resistance (Muvhuringi *et al.*, 2022).

The challenges associated with accessing unqualified veterinary services can be addressed by strengthening farmer cooperative movements that also act as hubs for veterinary services. This collective approach to delivering veterinary practices offers affordable access to professional veterinary services (Cadilhon *et al.,* 2016; Notenbaert *et al.,* 2020; Solidaridad, 2019; Swai *et al.*, 2009). In Tanzania, presently, some smallholder dairy cooperatives like Tanga Dairies Cooperative Union in the high-stress environment and Nronga Women Dairy Cooperative Society Limited in the low-stress environment operate several milk collection centres (MCCs). These milk collections centres can be focal hubs for input and veterinary service delivery to farmers. Such an approach will require organisational innovations by the cooperatives. Success with such hubs have been recorded in Kenya that can inform replication in Tanzanian set up (Kilelu *et al.,* 2017). Setting dairy hub service centres is highly relevant in the high-stress environment where disease prevalence and incidences were high.

The estimated case-fatality and mortality density in positive deviant farms were consistently lower than those estimated in typical farms in both low-stress and high-stress environments. The estimated case-fatality rate in positive deviant farms was 14.6 times lower (0.57 vs. 8.33%) in low-stress environment and 11.7 times lower (0.60 vs. 6.99%) in high-stress environment than was observed in typical farms. The case-fatality rate estimates being indicative of the probability of death in diseased animals, shows that animals managed in positive deviant farms had a lower probability of death whenever were disease infected compared to those animals managed in typical farms, in both low-and high-stress environments.

Per 100 animal-years at risk, mortality density in positive deviants when compared to typical farms was 15.06 (5.30 vs. 20.36) lower under low-stress and 2.58 (14.56 vs. 17.14) lower under high-stress environments. Lower animal mortality rate in positive deviant farms in both low-stress and high-stress environments provides good evidence that risk of death from disease related causes were more minimised in the positive deviant farms, whether in low- or high-stress environments. This is indicative evidence that positive deviant farms deployed animal husbandry practices that more effectively minimised risk of death to their animals, even in the event of disease infections (Alvåsen *et al.,* 2012). This was realised in positive deviant farms with closer monitoring of sick animals as they had frequent access to high-quality professional veterinary services.

Frequently accessing quality veterinary services can be argued empowered positive deviant farmers with capacity to more effectively implement disease preventive health practices and corrective measures in more timely and effective manner. However, frequent access to professional veterinary services comes at cost, implying that positive deviant farms minimised disease infections, case-fatalities and mortalities at greater investment relative to typical farms. This suggest resource endowment is a distinguishing attribute between positive deviants and typical farms when it is necessary to improve animal health and welfare status (Derks *et al.,* 2014; Ries *et al.,* 2022a). This has implications on pro-poor animal health service delivery system. The low resource endowed farms could be vulnerable to disease infections and loss of livestock assets when mortality occurs. This necessitates public investments in infrastructure that is supportive to efficient veterinary service delivery (FAO, 2020; Katjiuongua & Nelgen, 2014).

Minimising the risk of death for animals from disease related causes attained in positive deviant farms shows that animals had higher survival rates, which reduce the need to rear replacement heifers. The survival rates obtained are consistent with the previous studies under same high-stress dairy production environment (Tanga coastal lowlands zone) that estimated a mean morbidity of 8.3% and mortality of 12.0 per 100 animal-years at risk (Swai *et al.,* 2009). High animal survival rates attained in positive deviant farms demonstrates better animal health performance outcomes, even under high-stress environment, where heat load, disease infections and feed scarcity are prevalent (Cadilhon *et al.,* 2016; Notenbaert *et al.,* 2020; Solidaridad, 2019; Swai *et al.,* 2009). The high-stress in Tanga coastal lowlands zone is associated with a combination of lower altitude, high humidity and high temperature reaching 72 to 79 THI units. These are conditions that are favourable to thriving of tick-borne and non-tick borne disease infections (Bang *et al.,* 2021; Fathoni *et al.,* 2022; Mbuthia *et al.,* 2021).

Ticks are important both as direct blood-feeding parasites and also as vectors of a range of production limiting pathogens with negative economic and welfare impacts on dairy production, relating to animal mortality and reduced production and reproduction (de Vries, 2019; Lihou *et al.,* 2020). In this case, improvement in dairy cattle productivity would be achieved through well-structured crossbreeding programmes to attain resilient animals, implementing appropriate animal health management practices and designing conducive cowsheds allowing adequate floor spacing for cow comfort. These husbandry practices can minimise disease infections associated with tick-borne and non-tick-borne diseases, improve tolerance to heat load stresses, and subsequently improve reproduction and milk production in dairy herds (Fathoni *et al.,* 2022). Provision of inadequate floor spacing per animal has been associated with increased disease prevalence in animals (Duguma, 2020). In these sample farms, provision of better-quality housing and allowing for adequate larger floor spacing per animal in the zero-grazing stall units had been observed in positive deviant farms. It can thus be argued that with effective animal health management, positive deviant farms attained better animal health status (Alvåsen *et al.,* 2012; Campbell *et al.,* 2021; Swai & Karimuribo, 2011).

5.5 Conclusions

This study estimated animal disease prevalence, cumulative disease incidence, case-fatality rate and mortality density in positive deviant and typical farms in two prominent milksheds in Tanzania. The two milkshed were representative of low- and high-stress dairy-production environments. The results show that compared to typical farms, positive deviant farms consistently attained ($p<0.05$) lower animal disease infections and subsequent deaths, regardless of the level of environmental stress that the animals were exposed to. The implication is that positive deviant farms deployed animal husbandry practices that effectively minimised animal disease infections and deaths, and therefore could maintain animals in better health and welfare status.

CHAPTER SIX

ASSESSING LACTATION CURVE CHARACTERISTICS OF DAIRY COWS MANAGED UNDER CONTRASTING HUSBANDRY PRACTICES AND STRESSFUL ENVIRONMENTS IN TANZANIA

Abstract

The ability of smallholder dairy farming systems (SHDFs) to achieve desirable lactation-curve characteristics is constrained or reduced by environmental stresses. Under stressful production environments in the tropics, the better lactation-curve characteristics in smallholder dairy farms are a result of improved dairy genetics and husbandry practices. Better husbandry practices improve animal health and welfare status, which is important to sustain SHDFs in the tropics where dairy cattle are constantly exposed to multiple range of environmental stresses of feed scarcity, disease infections and heat load. In this case, lactating cows in smallholder dairy farms labelled positive deviants are expected to express lactation curve characteristics differently from typical farms, regardless of the stress levels confronted. Thus, this study tested this hypothesis with Holstein-Friesian and Ayrshire cows in two milksheds in Tanzania classified into low-and high-stress environments. A two-factor nested research design was used, with farm (positive deviant and typical) nested within the environment. Positive deviant farms were farms that performed above the population average, attaining ≥0.35 Mcal NE_L/d energy balance, ≥6.32 L/cow/day milk yield, ≤1153.28 days age at first calving, ≤633.68 days calving interval and ≤12.75 per 100 animal-years at risk disease-incidence density. In this study, a total of 3,262 test-day milk production records from 524 complete lactations of 397 cows in 332 farms were fitted to Jenkins and Ferrell model to estimate lactation curve parameters. In turn, the outcome parameters *a* and *k* were used to estimate lactation curve characteristics. The lactation curve characteristics estimates proved the study hypothesis. Regardless of the stress levels, cows in positive deviant farms expressed lactation curve characteristics differently from cows managed in typical farms. The scale (*a*) and shape (*k*) parameters together with peak yield and time to peak yield indicated higher lactation performance in positive deviant farms than in typical farms under low- and high-stress ($p<0.05$). Lactation persistency was higher in positive deviants than typical farms by 14.37 g/day and 2.33 g/day for Holstein-Friesian cows and by 9.91 g/day and 2.16 g/day for Ayrshire cows in low- and high-stress. Compared to cows managed in typical farms, cows in positive deviant farms attained higher lactation performance under low- and high-stress respectively, Holstein-Friesian produced 50.2% and 36.2% more milk while Ayrshire produced 52.4% and 46.0% more milk. The higher milk productivity in

positive deviant farms can be associated with deployment of husbandry practices that more effectively ameliorated feed scarcity, heat load and disease infections stresses, which are prevalent in tropical smallholder dairy farms.

6.1 Introduction

Lactation curve characteristics are important in revealing the influence of genetic and environmental factors in a dairy herd. Under tropical conditions, smallholder dairy herds perform sub-optimally when under persistent exposure to environmental stresses of heat load, nutritional scarcity and disease infections. Such environmental stresses disrupts the physiology as well as the reproductive and productive performance of dairy cows (Mbuthia *et al.,* 2021; Sekaran *et al.,* 2021). These disruptions, in Tanzania smallholder dairy farms operating low-input-low-yield production systems, are such that production performance is sub-optimal. The average production is less than 9 litres of milk per cow per day (Ekine-Dzivenu *et al.,* 2019; Mrode *et al.,* 2021; Ojango *et al.,* 2019). This sub-optimal production performance is a widespread observation that can be detected in the expression of lactation curve characteristics.

Despite persistent exposure to environmental stresses, some farms labelled positive deviant farms manage to attain higher production performance than their comparable contemporaries labelled typical farms (Chawala *et al.,* 2019). This outperformance in production observed in positive deviant farms can be associated with deployment of more effective amelioration of the environmental stresses. Studies of positive deviance have shown that positive deviant farmers are remarkably successful when confronting same and similar environmental stresses than typical farmers (Albanna *et al.*, 2022). For example, Migose (2020) observed that successful positive deviant farmers tended to have larger herds, yielding higher milk production per cow compared to average performing dairy farms. Positive deviant farmers used inputs (level, quality and cost management), knowledge, skills, and financial stability to improve dairy husbandry practices (feeding, breeding and healthcare services) and attained higher lactation performance.

Analysing the differences in lactation curve characteristics between positive deviants and typical managed dairy cows can inform on husbandry practices suited to local production circumstance for improving farm productivity. This has been articulated by in several studies of the positive deviance behaviour observed in ecology, agriculture and livestock (Adelhart Toorop *et al.,* 2020; Albanna *et al.,* 2022; Modernel *et al.,* 2018; Steinke *et al.,* 2019). These studies have revealed that locally determined successful management strategies can be scaled in extension message to enhance husbandry practices among smallholder farmers to be able to raise agricultural and animal productivity. For instance, positive deviants may accelerate local adoption of more environmentally friendly fodder production that address feed scarcity and improve animal production performance (Albanna *et al.,* 2022; Modernel *et al.,* 2018). This presents opportunity to use positive deviance approach to bring about change in lactation performance of dairy cattle through the processes of analysing and then communicating the underlying management practices.

The differences observed in production performance between positive deviants and typical farms reflect differences in husbandry practices, and those husbandry practices can ameliorate the environmental stresses considerably. This minimizes the levels of disrupted physiology, reproductive and productive performance of the dairy cows, which in Tanzania are predominantly crossbreds of Holstein-Friesian and Ayrshire dairy breeds. Therefore, cows of same breed but under low- or high-level husbandry would express lactation curve characteristics differently.

The lactation curve parameters of dairy crossbreeds in the tropics have been adequately modelled to generate standardized lactation curves using a wide variety of empirical linear and nonlinear parametric functions (Ali & Schaeffer, 1987; Dijkstra *et al.,* 1997; Grossman *et al.,* 1986; Jenkins & Ferrell, 1984; Pollott, 2000; Wood, 1967). However, some functions may be more appropriate than others because these functions vary in their mathematical properties, processing, number of parameters, relevance to a typical lactation cycle and ability to fit a larger range of curves (Pizarro Inostroza *et al.,* 2020). For this issue, some studies have assessed models that can accurately predict values for the scale and shape parameters, daily average milk supply, peak day, peak yield and lactation milk yield.

Models that accurately estimate lactation curve parameters and lactation milk yield are relevant for genetic evaluation, herd management and breeding decisions for dairy cattle maintained in varied production conditions with different environmental stress levels. The Wood equation (Wood, 1967), the Dijkstra equation (Dijkstra *et al.,* 1997), Pollott model (Pollott, 2000), and the MilkBot model (Ehrlich, 2011) are all noteworthy examples of models in this area. The modified Wood's equation, as specified by Jenkins and Ferrell (JF) (Jenkins & Ferrell, 1984), has the advantage of having been designed for crossbred cattle in the tropics. The JF model has been successfully used to assess lactation performance of cattle in smallholder dairy farming systems (SHDFs) in the tropics (Migose, 2020; Rodrigues *et al.,* 2014). This model uses only two instead of three parameters to estimate lactation curves with minimal lactation data points (Landete-Castillejos & Gallego, 2000). The JF model is suited to differentiating lactation curve characteristics between cows managed in positive deviants and typical farms where large variation in milk records and breed compositions prevails (Jenkins *et al.*, 2000; Mbuthia *et al.*, 2021; Rodrigues *et al.*, 2014).

Consistent recording is time-consuming and expensive, thus farmers' recollections of past events are sometimes used in addition to cross-sectional studies (Migose, 2020). Because of these capacity challenges, relatively few records exist in smallholder farms to enable accurate assessment of the lactation curve characteristics. One record per lactation can be collected in cross-sectional studies. But, for accurate assessment of lactation curve characteristics, longitudinal studies typically provide relatively larger number of records per lactation (Migose, 2020). However, whether with access to cross-sectional or longitudinal lactation data, previous lactation curve modelling studies did not differentiate between varying levels of dairy husbadry practices nor similar husbandry practices under same and disimilar environmental stresses. This is important to improving the informativeness of the parameter estimates obtained for designing effective amelioration of heat load, feed scarcity and disease infections stresses that limit and reduce productivity in dairy cattle in the tropics (Lee *et al.*, 2020; Marshall, 2014; Marshall *et al.*, 2019; Marshall *et al.*, 2020; Quist *et al.*, 2007). Using data-powered positive deviance approach has shown that positive deviant farms deploy relatively more effective husbandry practices that minimise cow exposure to environmental stresses of feed scarcity, disease infections and heat load. Building on this observation, this study tested the hypothesis that Holstein-Friesian and Ayrshire cows, and their crossbreds managed in positive deviants and typical farms express lactation curve characteristics differently, regardless of the stress levels they confront. The underlying assumption was that cows managed in positive deviant farms are in high level of husbandry practices that minimise cow exposure to environmental stresses of feed scarcity, disease infections and heat load stress.

6.2 Materials and Methods

6.2.1 The Data Source

Detailed information of the data source, study area, data collection and objective identification process of positive deviants and typical farms in a large population are described in section 3.2.1, 3.2.2, 3.3 and 3.4 of Chapter Three, respectively. A brief description and objective specific information is presented in this Chapter with details of the data collection on lactation milk production.

Test-day milk yield data was available from October 2016 through July 2020 period in the ILRI database (https://www.adgg.ilri.org/uat/auth/auth/login). ILR granted access to the database as part of support to this study. This data was screened for individual animal information (date of birth, genotype, parity, calving date, milking and drying-off dates) for Holstein-Friesian and Ayrshire, and their crossbreds cattle in individual farms and production environment. These dairy cattle breeds are the most popular with smallholder farms in Tanzania. Test-day milk yield data for individual cow conformed to the standard recording procedure (ICAR, 2017). This requires milk being recorded on the 4th evening and the 5th morning after calving, and thereafter on the 14th evening and the 15th morning of the month, until drying-off. Test-day milk yield data for the specified monthly recording dates for the evening of the 14th and the morning of the 15th was not always available. In such cases, data was edited to remove test-day records that were collected earlier than five days after calving, in which case the subsequent TD milk yield record was considered the first test-day record. Further, where recording was more than once in a month, milk production records were removed in favour of records closest to the 14th and 15th days of recording.

After screening, the available test-day milk production data for Holstein-Friesian and Ayrshire cows was 3,262 records of 524 complete lactations for 397 cows in 332 farms. Following screening of individual records, the structure of the dataset for the farms and test-day records that proceeded to estimation of lactation curve parameters is summarised in Table 6.1 and 6.2.

Table 6.1: The number of dairy farms, Holstein-Friesian cows, lactations and monthly test-day (TD) milk yield records available for analysis of lactation curve characteristics.

Factor	Stress levels	Holstein-Friesian cows and their crossbreeds			
		Number of farms	Number of cows	Number of lactations	TD records
Environment					
	Low-stress	76	92	117	564
	High-stress	187	235	311	2174
Farm (Environment)					
	Low-stress				
	Positive deviants	3	5	6	36
	Typical	73	87	111	528
	High-stress				
	Positive deviants	7	9	14	105
	Typical	180	226	297	2069
	TOTAL	263	327	428	2738

Table 6.2: The number of dairy farms, Ayrshire cows, lactations and monthly test-day (TD) milk production records available for analysis of lactation curve characteristics.

Factor	Stress levels	Ayrshire cows and their crossbreeds			
		Number of farms	Number of cows	Number of lactations	TD records
Environment					
	Low-stress	33	33	45	192
	High-stress	36	37	51	332
Farm(Environment)					
	Low-stress				
	Positive deviants	3	3	6	15
	Typical	30	30	39	177
	High-stress				
	Positive deviants	1	1	1	5
	Typical	35	36	50	327
	TOTAL	69	70	96	524

6.2.2. Research Design

The study implemented a two factor nested design, with farm (positive deviants and typical) nested within the environment (low- and high-stress). The environment was a fixed effect while the farm nested within the environment was a random effect. Figure 6.1 represent a two-factor nested research design model. The experimental units were the individual farms, each with a herd of cows (Tempelman, 2009).

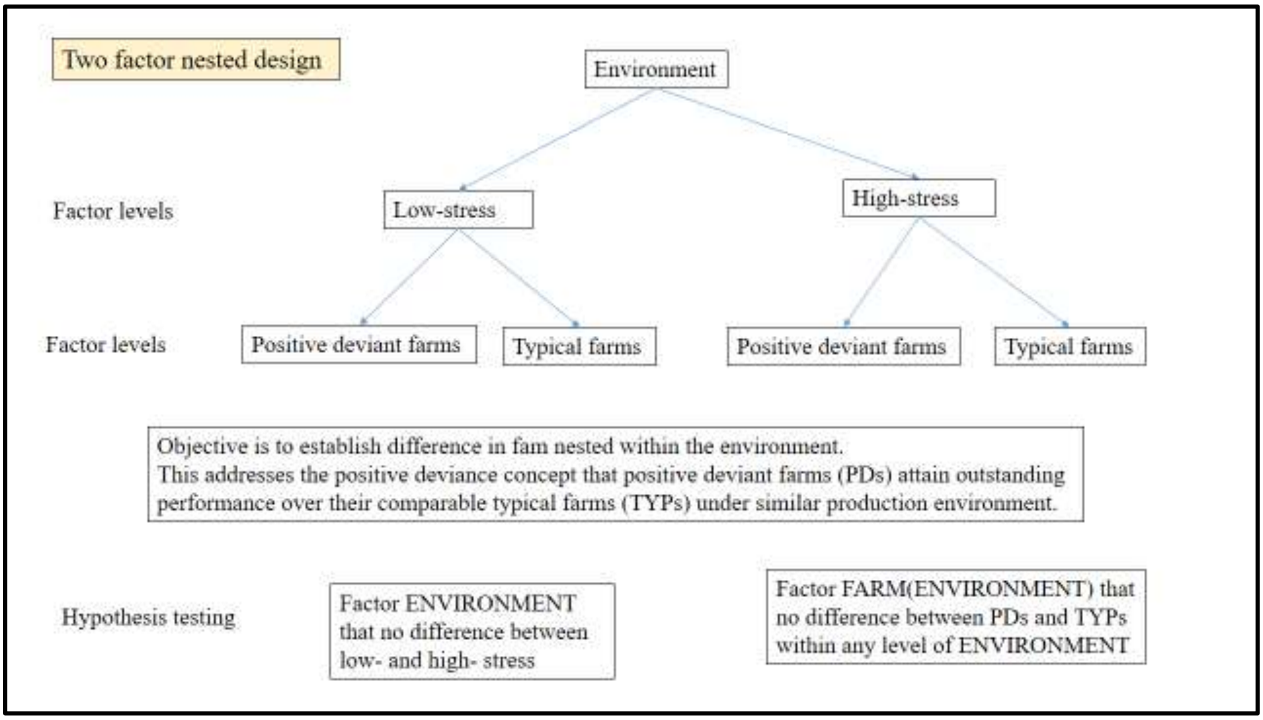

Figure 6.1: Schematic representation of a two factor nested research design model.

6.2.3 Estimating Lactation Curve Parameters and Lactation Milk Production

Lactation curve parameters were estimated with the modified Wood‘s equation as specified by Jenkins and Ferrell (Jenkins & Ferrell, 1984; Jenkins & Ferrell, 1992). The choice of this model was on the basis that the model accommodates two parameters (Equation 6.1), and can estimate lactation milk production with at least three data points, sparsely distributed (Landete-Castillejos & Gallego, 2000). The model is suited to dairy cattle genotypes in the tropics, which dominated in the sample. The JF model fitted to estimate the lactation curve parameters was in the form:

$$Y_{(n)} = \frac{n}{a \times e^{k \times n}} \qquad (6.1)$$

where Y(n) is the milk production observed on the n^{th} week after calving, *n* is weeks in lactation after calving, *a* is a curve scale parameter, and *k* is a curve shape parameter, indicating lactation persistence while *e* is the exponential function (a Euler’s number which is the root of natural logarithms, approximately 2.718). The scale and shape parameters were estimated using

Marquardt method with starting values of 0.270 and 0.127 for *a* and *k* obtained for Jersey × (Angus or Hereford) that were previously reported (Jenkins & Ferrell, 1984). In turn, the outcome parameters *a* and *k* were used to calculate parameter characteristics of a lactation curve defined by JF (Jenkins & Ferrell, 1984).

The lactation curve characteristics estimated included time to peak lactation (peak week), peak milk yield attained (peak yield), and total lactation milk production truncated to a standard of 305-days (LMP305). In this case, LMP305 is considered equivalent to an integral area of the fitted lactation curve from calving up to 305-d lactation period. Computation of LMP305 using equation 6.4 specified 43.57 being the number of weeks for a 305-days lactation period for a standard lactation period and derived characteristics of the lactation curves with the following equations:

$$\text{Peak week} = \frac{1}{\mathrm{k}} \tag{6.2}$$

$$\text{Peak yield} = \frac{1}{\mathrm{a} * \mathrm{k} * \mathrm{e}} \tag{6.3}$$

$$\text{LMP305} = -\frac{7}{\mathrm{a} * \mathrm{k}} \times \left(43.57 * \mathrm{e}^{-\mathrm{k}43.57} + \frac{1}{\mathrm{k}} * \mathrm{e}^{-\mathrm{k}43.57} - \frac{1}{\mathrm{k}}\right) \tag{6.4}$$

Also, computed was persistency to measure the ability of lactating cows to sustain higher levels of milk production from the time of peak lactation to the last day of milking. This is the linear average daily change in milk production (g/d) between peak lactation and drying-off (Jenkins *et al.*, 2000; Rodrigues *et al.*, 2014):

$$\text{Persistency, g/d} = \left(\frac{\text{yield last day lactation measured} - \text{yield at peak lactation}}{\text{days from peak lactation to last day lactation measured}}\right) * 1000 \tag{6.5}$$

As defined in the present study, larger negative estimates for persistency indicate a more rapid loss in daily milk production from time of peak lactation to the end of the lactation period (Jenkins *et al.*, 2000).

6.2.4. Statistical Analysis

This study assessed lactation curve parameters (scale and shape parameters), observed milk yield, predicted milk yield, time to peak yield, peak yield, lactation persistency and total lactation milk production (LMP) of Holstein-Friesian and Ayrshire, and their crossbreeds raised in positive deviants and typical farms nested within low- and high-stress environments. Estimates of the curve parameters *a* and *k* and the derived curve characteristics were analysed with Linear Mixed Model to test for lactation performance differences between the environments and between positive deviants and typical farms within a low- and high-stress environments. The two factor nested design model fitted was in the form:

$$Y_{(i)jk} = \mu + PE_i + FT(PE)_{j(i)} + e_{ijk} \qquad (6.6)$$

where, Y_{ijk} is any of the lactation performance variable. These included daily milk yield, model predicted milk yield, scale and shape parameters, *a* and *k*, time to reach peak week, peak yield, persistency and LMP305. μ is the overall mean, PE_i is a fixed effect of production environment, $FT(PE)_{j(i)}$ is the random effect of farm nested within the environment and $e_{kj(i)}$ is the random error. A mixed model analysis of variance of this model was performed in SAS Statistics software (SAS Institute Inc, 2013). Differences in least square means were tested using Fisher's least significant difference, with PDIFF option (Meier, 2006). Next, least square means for scale and shape parameters (*a* and *k*) were used in the computation to generate lactation curves.

6.3 Results

The lactation curve parameters for Holstein-Friesian breed are presented in Table 6.3 and 6.4, and those for Ayrshire breed are presented in Table 6.5 and 6.6 for cattle managed in positive deviants and typical farms under low- and high-stress environments. Both observed and predicted lactation parameters reveal that lactation performance was consistently better ($P<0.05$) in positive deviant farms than in typical farms and in low-stress than in high-stress level environment. Non-significance ($P>0.05$) were observed in days to peak milk yield of Holstein-Friesian under low-stress environment and in peak milk yield of Ayrshire under high-stress environment. While Holstein-Friesian consistently attained better lactation performance (Table 6.3 and 6.4) under low-stress than under high-stress environment ($P<0.05$), Ayrshire consistently did not ($P>0.05$) under low- and high-stress environments (Table 6.5 and 6.6). Compared to typical farms, positive deviants realised 1,339 litres more milk in 305-d lactation (4,008 vs 2,669 litres) and 5.6 litres more daily milk yield (14.3 vs 8.7 litres/cow/day) under low-stress environment. Under high-stress environment, positive deviants realised 871 litres more milk in 305-d lactation (3,275 vs 2,604 litres) and 3.0 litres more daily milk yield (11.0 vs 8.0 litres/cow/day).

Cows managed in positive deviant farms attained higher observed daily milk yield (MPt) than those managed in typical farms ($P<0.05$). Evidence of this is Holstein-Friesian in positive deviant farms that produced 5.83 litres more milk in low-stress environment and 3.24 litres more milk in high-stress environment (Table 6.3) and Ayrshire breed that produced 4.41

litres more milk in low-stress environment and 3.48 litres higher in high-stress environment (Table 6.5). The model prediction minimised bias (observed – predicted) to between 5 and 7% for Holstein-Friesian cows (Table 6.3 and 6.4) and to between 4 and 8.5% for Ayrshire cows (Table 6.5 and 6.6) in both positive deviant and typical farms.

Cows managed in positive deviant farms attained higher peak milk yields than those managed in typical farms. This is observed in Holstein-Friesian cows attaining 6 litres more in low-stress environment and 3.4 litres more in high-stress environment (Table 6.4) whereas Ayrshire attained 4 litres more in low-stress environment and 2.9 litres more in high-stress environment (Table 6.6). Regardless of the stress levels, cows managed in positive deviant farms consistently attained peak milk yield 0.5 to 5.7 weeks later than those managed in typical farms. For Holstein-Friesian, peak milk yield was attained 15.2 to 15.4 weeks in positive deviant farms compared to 14.1 to 14.9 weeks in typical farms (Table 6.4). For the Ayrshire (Table 6.6), the peak milk yield was attained 17.5 to 19.3 weeks in positive deviant farms compared to 12.7 to 13.6 weeks in typical farms.

Figures 6.2 and 6.3 are lactation curves of Holstein-Friesian and Ayrshire cattle breeds managed in positive deviants and typical farms under low- and high-stress environments. Lactation curves indicated that milk production was higher under low-stress compared to high-stress environment for both Holstein-Friesian and Ayrshire cattle breeds (Figure 6.2) and consistently milk production was higher in positive deviant farms than in typical farms for both Holstein-Friesian and Ayrshire cattle breeds (Figure 6.3). This is further observed in the low scale and shape parameters indicating that both Holstein-Friesian and Ayrshire cows were more productive in positive deviants than in typical farms under both low- and high-stress environments (Figure 6.3).

Table 6.3: Means (LSMEANS ± SE) of lactation curve parameters for Holstein–Friesian cows managed in positive deviants and typical farms nested within low- and high-stress production environments.

Factor	**Stress levels**	**MPt**	***a***	***k***
Environment				
	Low-stress	12.08±0.33	0.4475±0.0234	0.0699±0.0015
	High-stress	10.19±0.19	0.4616±0.0136	0.0703±0.0009
	Mean difference	1.89***	-0.0141 NS	-0.0003 NS
Farm(Environment)				
	Low-stress			
	Positive deviants	15.00±0.65	0.3616±0.0452	0.0673±0.0029
	Typical	9.17±0.19	0.5333±0.0118	0.0726±0.0008
	Mean difference	5.83***	-0.1718 ***	-0.0053 NS
	High-stress			
	Positive deviants	11.81±0.38	0.3961±0.0265	0.0664±0.0017
	Typical	8.57±0.09	0.5271±0.0059	0.0741±0.0004
	Mean difference	3.24***	-0.1310 ***	-0.0077 ***

MPt observed daily milk yield measured in litres per cow per day; *a* is a scale parameter of lactation curve; *k* is a shape parameter of lactation curve; ***<0.001; NS>0.05.

Table 6.4: Means (LSMEANS ± SE) of predicted milk yield, peak time, peak yield and LMP305 for Holstein–Friesian cows managed in positive deviants and typical farms nested within low- and high-stress production environments.

Factor	Stress levels	ModelMPt	Peak week	Peak yield	LMP305
Environment					
	Low-stress	11.50±0.34	15.14±0.27	15.25±0.35	3338.62±79.81
	High-stress	9.52±0.20	14.66±0.15	12.89±0.20	2840.03±46.35
	Mean difference	1.98***	0.48NS	2.36***	498.58***
Farm(Environment)					
	Low-stress				
	Positive deviants	14.30±0.66	15.37±0.51	18.26±0.68	4008.19±154.45
	Typical	8.69±0.17	14.91±0.13	12.24±0.18	2669.05±40.33
	Mean difference	5.61***	0.46NS	6.02***	1339.14***
	High-stress				
	Positive deviants	10.99±0.39	15.21±0.30	14.59±0.40	3275.79±90.44
	Typical	8.05±0.09	14.10±0.07	11.20±0.09	2404.28±20.37
	Mean difference	2.95***	1.11***	3.40***	871.51***

ModelMPt is a model predicted daily milk yield at animal level measured in litres per cow per day; Peak week is the time taken to reach peak lactation (weeks); Peak yield is the maximum milk yield attained at peak day measured in litres per cow per day; LMP305 is a total lactation milk production for a 305-d lactation period measured in litres per cow per lactation; ***<0.001; NS>0.05.

Table 6.5: Means (LSMEANS ± SE) of lactation curve parameters for Ayrshire cows managed in positive deviants and typical farms nested within low- and high-stress production environments.

Factor	**Stress levels**	**MPt**	***a***	***k***
Environment				
	Low-stress	10.39±0.53	0.4398 ± 0.0339	0.0740 ± 0.0035
	High-stress	9.46±0.89	0.5715 ± 0.0568	0.0643 ± 0.0059
	Mean difference	0.93^{NS}	-0.1318^{*}	0.0098^{NS}
Farm(Environment)				
	Low-stress			
	Positive deviants	12.60±1.02	0.4223 ± 0.0651	0.0607 ± 0.0067
	Typical	8.19±0.30	0.4572 ± 0.0189	0.0873 ± 0.0020
	Mean difference	4.41^{***}	-0.0350^{NS}	-0.0266^{***}
	High-stress			
	Positive deviants	11.20±1.76	0.5473 ± 0.1127	0.0518 ± 0.0117
	Typical	7.72±0.22	0.5958 ± 0.0139	0.0767 ± 0.0014
	Mean difference	3.48^{*}	-0.0485^{NS}	-0.0249^{*}

MPt represent daily milk yield measured in litres per cow per day; *a* is a scale parameter of lactation curve; *k* is a shape parameter of lactation curve; *<0.05; ***<0.001; ^{NS}>0.05

Table 6.6: Means (LSMEANS ± SE) of predicted milk yield, peak time, peak yield and LMP305 for Ayrshire cows managed in positive deviants and typical farms nested within low- and high-stress production environments.

Factor	**Stress levels**	**ModelMPt**	**Peak week**	**Peak yield**	**LMP305**
Environment					
	Low-stress	9.96±0.54	15.09±0.42	13.46±0.57	2931.09±132.11
	High-stress	9.17±0.90	16.48±0.70	11.53±0.96	2646.72±221.37
	Mean difference	0.79^{NS}	-1.38^{NS}	1.94^{NS}	284.36^{NS}
Farm(Environment)					
	Low-stress				
	Positive deviants	12.13±1.04	17.50±0.81	15.48±1.10	3539.64±253.68
	Typical	7.80±0.30	12.69±0.23	11.44±0.32	2322.53±73.85
	Mean difference	4.33***	4.81***	4.04***	1217.11***
	High-stress				
	Positive deviants	11.16±1.79	19.31±1.39	12.98±1.90	3141.66±439.39
	Typical	7.18±0.22	13.65±0.17	10.07±0.23	2151.79±54.33
	Mean difference	3.98*	5.66***	2.90^{NS}	989.87*

ModelMPt is a model predicted daily milk yield at animal level measured in litres per cow per day; Peak week is the time taken to reach peak lactation (weeks); Peak yield is the maximum milk yield attained at peak day measured in litres per cow per day; LMP305 is a total lactation milk production for a 305-d lactation period measured in litres per cow per lactation; *<0.05; ***<0.001; ^{NS}>0.05.

Estimated lactation length and persistency are presented in Table 6.7. Larger negative value for lactation persistency indicate a more rapid decline in daily milk yield from the time of peak lactation until the last day of lactation. In contrast, a positive or even a smaller negetaive value indicates a slow descending rate, and this is desirable for optimising total lactation milk production because of higher daily milk yield from peak to the day of drying-off. Results show that lactation persistency was consistently slower descending (smaller negative values) in positive deviant farms compared to those in typical farms under low- and high-stress production environment though were not significantly different ($p>0.05$). It is further observed that lactation persistency was slow descending rate in positive deviant farms than in typical farms for both Holstein-Friesian and for Ayrshire cows regardless of the environmental stress levels. In positive deviant farms, lactation persistency of Holstein-Friesian cows was 14.37 g/day and 2.33 g/day lower decline in low- and high-stress environments, respectively whereas for Ayrshire cows it was 9.91 g/day and 2.16 g/day lower decline in low- and high-stress environments, respectively. The lactation persistency with slow descending rate means a lower decrease in milk yield in positive deviants compared to those in typical farms under low- and high-stress production environment.

The overall lactation length (Table 6.7) in this study was 453.76 days for Holstein-Friesian and 471.93 days for Ayrshire dairy cattle, revealing a practice of extended milking of cows beyond the standard lactation of 305-days. However, lactation lengths were somewhat shorter in positive deviant farms (range 428-457 days) than in typical farms (range 450-509 days). However, a marked exception was observed in typical farms for Ayrshire cattle managed under high-stress environment where lactation length was about 10 days longer in positive deviant farms.

Table 6.7: Means (LSMEANS±SE) of lactation length and persistency for Holstein-Friesian and Ayrshire cows managed in positive deviants and typical farms nested within low- and high-stress production environments

Factor	Stress levels	Lactation length, days		Persistency, g/day	
		Holstein-Friesian	Ayrshire	Holstein-Friesian	Ayrshire
Environment					
	Low-stress	439.40±31.71	469.28±45.30	-23.15±4.93	-23.26±4.79
	High-stress	442.48±21.28	452.12±76.02	-25.13±3.31	-21.49±8.03
	Mean difference	-3.08^{NS}	17.16^{NS}	1.98^{NS}	-1.77^{NS}
Farm(Environment)					
	Low-stress				
	Positive deviants	428.20±61.95	429.00±86.84	-15.97±9.63	-18.31±9.18
	Typical	450.59±13.52	509.56±25.80	-30.34±2.10	-28.22±2.73
	Mean difference	-22.39^{NS}	-80.56^{NS}	14.37^{NS}	9.91^{NS}
	High-stress				
	Positive deviants	428.64±41.77	457.00±150.42	-23.97±6.49	-20.41±15.10
	Typical	456.32±8.16	447.24±22.18	-26.29±1.27	-22.57±2.34
	Mean difference	-27.69^{NS}	9.76^{NS}	2.33^{NS}	2.16^{NS}

^{NS}>0.05.

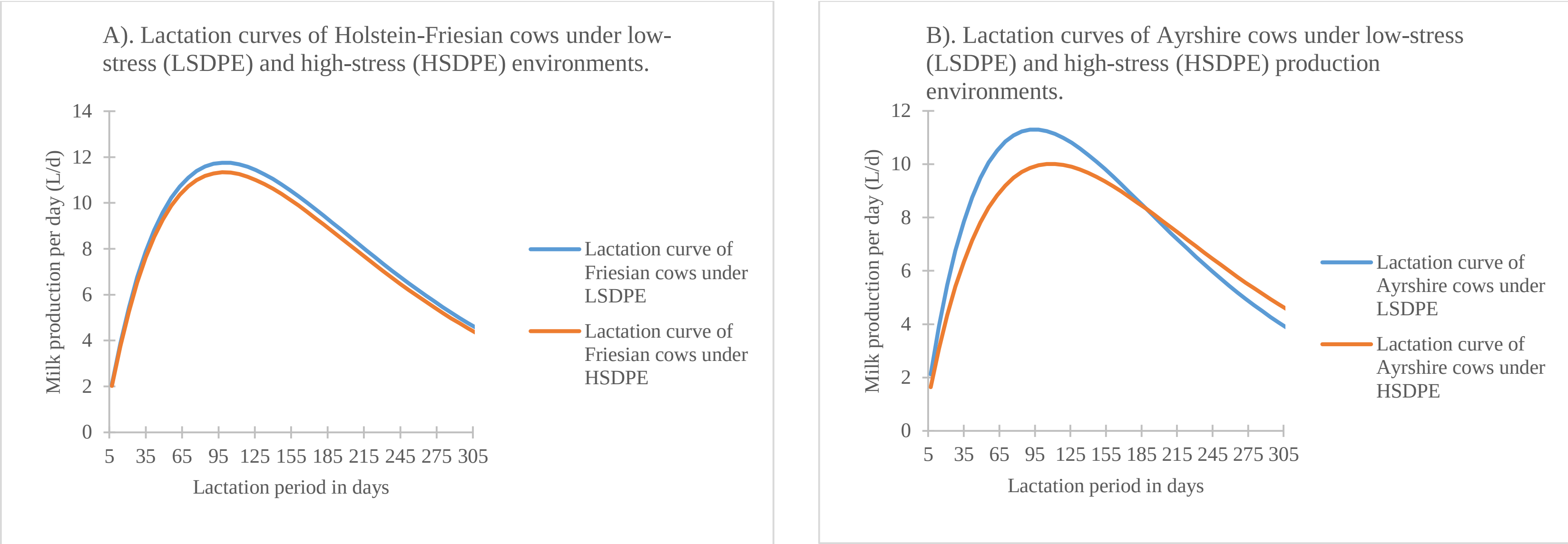

Figure 6.2: Lactation curves of dairy cows managed under low- and high-stress production environments: A). Friesian cows and B). Ayrshire cows.

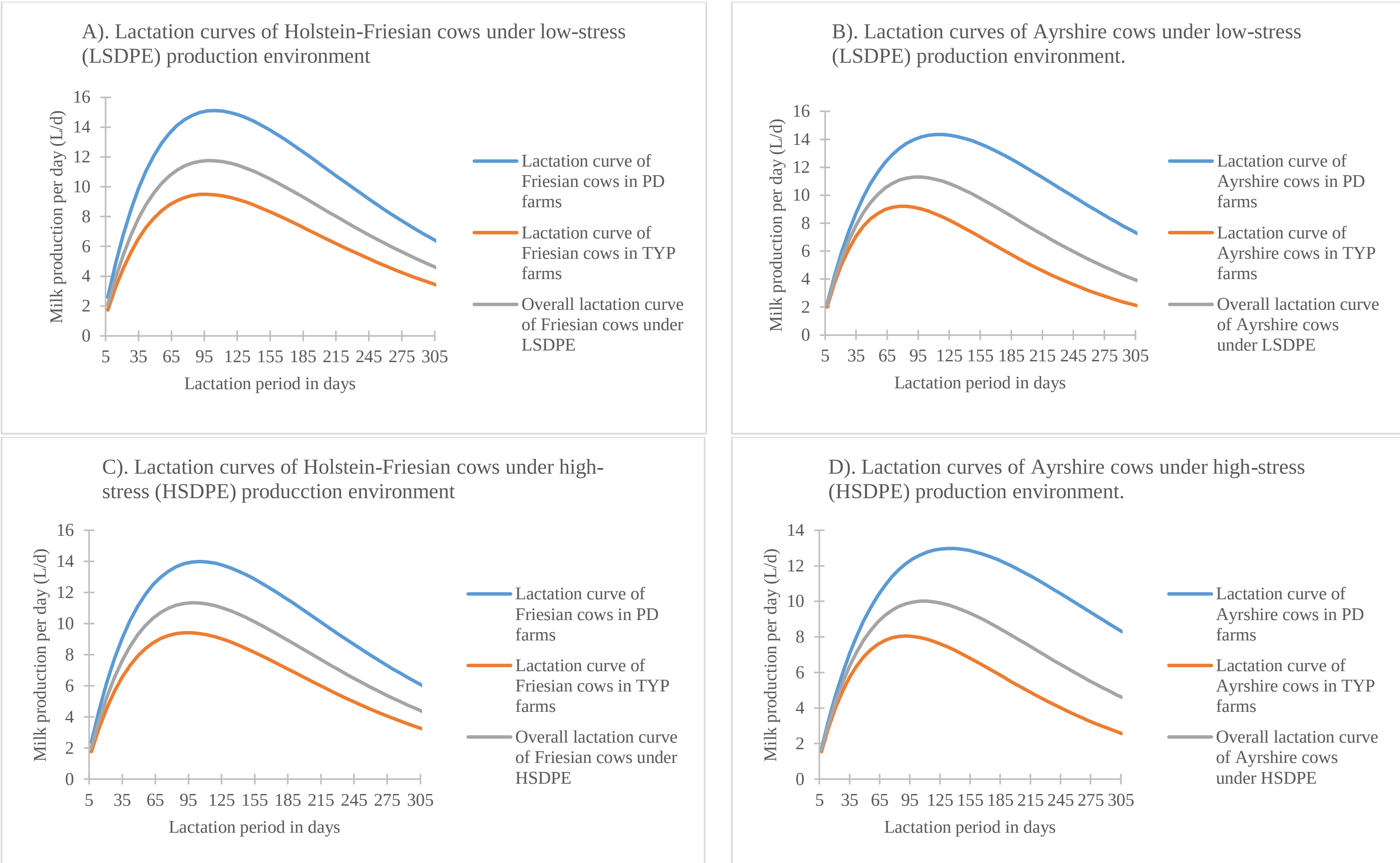

Figure 6.3: Lactation curves of dairy cows managed in positive deviants (PD) and typical (TYP) farms nested within low- and high-stress production environments: A and C). Holstein-Friesian cows and B and D). Ayrshire cows.

6.4 Discussion

The popularity of Holstein-Friesian and Ayrshire, and their crossbreeds cattle with smallholder farmers has been associated with their commercial attributes for high milk yield potential, suited to supplying household with quality nutrition and income where milk market price is on volume basis (Bebe *et al.,* 2003b; Mbuthia *et al.,* 2021). The fitted JF model produced typical lactation curves from the milk yield test-day data of Holstein-Friesian and Ayrshire cows managed in positive deviants and typical farms under low- and high-stress environments. The model prediction minimised bias (observed – predicted) to between 4 and 8.5% for Holstein-Friesian (Table 6.3 and 6.4) and Ayrshire (Table 6.5 and 6.6) cows managed in both positive deviants and typical farms under low- and high-stress environments. These further provides evidence of the suitability and capability of the JF model to predicting milk yield with good accuracy for cows in smallholder dairy farms in the tropics.

The choice of JF-model was because the model is suited to the production circumstance in the tropics where data scarcity and missing values is frequent in smallholder dairy farms. The JF model has an added advantage of computing lactation milk yield standardised to 305-days thus allowing to discount for cases of either shorter or protracted lactation lengths. In this study, lactation lengths were generally long, with averages varying from 428 to 509 days, depending on the levels of dairy husbandry standards and stress levels in the production environment. Long lactation lengths reflected the practice to extend milking cows which to smallholders is a livelihood strategy of assuring a steady supply of milk for household nutrition and income (Bebe *et al.*, 2003b; Mbuthia *et al.*, 2021). For this, smallholder dairy farming practices extended lactations to optimise the output of high-yielding cows (Borman *et al.*, 2004). Improved dairy cows can maintain high milk yields for longer proportion of lactation, though these animals can be affected by extended period of negative energy balance. Some studies have shown that effective feeding management practices are necessary if extended lactation system is to yield a desired levels of milk production (Borman *et al.*, 2004). Following extended lactation management strategy, some benefits such as more spread of income across the year can be realized by farmers. In addition, extended lactation strategy enhances animal welfare by minimising stresses associated with the higher prevalence of reproductive and productive diseases (Niozas *et al.,* 2019). Some researchers contend that the adoption of extended lactation presents an alternative strategy for resolving these issues (Knight, 2005). However, the suitability of extended lactation strategy will depend on a number of factors such as the potentiality of a cow for milk production, herd size and the ability of farmers to supply sufficient quantities and well-balanced feeds for lactating cows.

Dairy cows in positive deviant farms expressed lactation curve characteristics differently from those cows managed in typical farms under similar level of environmental stresses. The scale (*a*) and shape (*k*) parameters for both Holstein-Friesian and Ayrshire cows indicated that lactating cows were more productive in positive deviant farms than those in typical farms under both low- and high-stress environments. For the 305-day total lactation milk production, positive deviant farms attained higher milk yield than typical farms ($P<0.05$), meaning more improved animal genetics and nutrition enhanced dairy productivity in positive deviants as compared to typical farms (Niozas *et al.,* 2019). For example, Holstein-Friesian produced 50.2% more milk in low-stress environment and 36.2% more milk in high-stress environment (Table 6.3 and 6.4) whereas Ayrshire produced 52.4% more milk in low-stress environment and 46% more milk in high-stress environment (Table 6.5 and 6.6; Figure 6.3). These findings are in line with the results of other researchers working in SHDFs. For example, pure Holstein cows at higher THI were observed to have a reduced daily milk yield and peak milk yield in a rate of 23.8% and 12.9% compared to those in lower THI conditions in Egypt (El-Tarabany *et al.,* 2016). This is because dairy cows have less chances to fight off heat stress during lactation period, so it has the greatest impact on milk production especially during the first lactation phase. In addition, a negative energy balance in dairy cows at the start of lactation can be exacerbated by the creation and emission of a greater quantity of thermal energy during a period when animals consume less feeds (Mahyari *et al.,* 2022). For this reason, greater sensitivity of Holstein-Friesian and Ayrshire genotypes to heat stress caused a reduced productivity of cows in high-stress environment than those in low-stress environment as observed in this study.

Holstein-Friesian and Ayrshire cattle breeds had consistent lactation persistency indicating a slower decline in milk yield after reaching peak yield in positive deviant farms compared to those cows managed in typical farms and under low-stress environment compared to high-stress environment. Higher production performance in positive deviant farms would suggest differences in dairy cattle husbandry between positive deviants and typical farms (Alvåsen *et al.,* 2012). In contrast, higher production performance under low-stress environment would suggest greater production limitation resulting from exposure to high-level environmental stresses of heat load and disease infections found in the dairy-production environment classified a high-stress (King *et al.,* 2006), which was the Tanga coastal lowlands of Tanzania.

Management practices mostly deployed to ameliorate environmental stresses include selection of tolerant genotype that matches with the production environment, feeding, housing and regular animal health services (King *et al.,* 2006; Macciotta *et al.,* 2008; Mbuthia *et al.,* 2021; Marshall, 2014). For example, as observed in this study, the higher milk yield, peak yield and lactation milk production estimates with smaller negative lactation persistency in low-stress environment could be associated with relatively better feeding practices, adequate spacing per animal to allow air movement in the cowshed and frequently sourcing professional animal health services. In contrast, the higher THI (77.29 THI units) and disease incidence rate (9.55 per 100 animal-years at risk) as observed earlier in the high-stress environment could be related with the reduction in production performance, especially for Holstein-Friesian cattle breeds. Persistent exposure of dairy cattle to heat load and disease infections stresses are the causes of a reduction of milk production performance in dairy cattle (King *et al.,* 2006; Mbuthia *et al.,* 2021). The higher THI is associated with poor milk production because of elevated blood insulin and protein catabolism (Wang *et al.,* 2020). Elevated blood insulin and protein catabolism negatively affect milk synthesis. Glucose uptake by different tissues and organs is triggered through the acceleration of blood insulin, but central nervous and immune systems take a high priority of sufficient supply than other tissues. This change in the order of utilising glucose reduces the allocation to the mammary gland. This leads to an accelerated protein catabolism in the mammary gland for more energy substrate. These changes in the physiology and following energy metabolism subsequently tends to be adaptive strategies used to prioritise the maintenance for cows under heat stress and these are responsible for reduced milk synthesis. Further, persistent exposure to heat load and disease incidence lowers natural immunity making animals more vulnerable to disease infections. Disease infections disrupt the physiology and lactation performance of dairy cows by interfering cell proliferation responsible for milk synthesis which defines the lactation curves. This is especially an important aspect for consideration in high-stress environment where dairy cattle are constantly exposed to the level of mild to moderate heat stress (77.29 THI units). With exposure of a lactating dairy cattle to such THI range, the prevailing level of heat load stress is sufficient to cause depressed feed intake, even during the periods of very high wind speed in the coastal zone (King *et al.,* 2006). Depressed feed intake caused by heat stress cannot support higher daily milk yield, peak yield as well as total lactation milk production of dairy cattle in high-stress environment compared to those in low-stress environment.

The higher milk yields attained from dairy cattle managed in low-stress environment than those in high-stress environment corroborate with research findings previously observed in SHDFs in Indonesia. The study reported lower milk yields (8.3 kg/cow/day) for cows managed in lowland farms than that of the highland farms (13.5 kg/cow/day) (Moran & Doyle, 2015). However, the study only made a simple comparison between the lowland and highland farms without taking into account the effects of other confounding variables such as the random effect of farm nested within production environment. Thus, the observed differences in lactation curve characteristics of the current study reflect the great influence of production environments and animal husbandry practices to which dairy cattle are persistently exposed to. This brings to fore the necessity to implement appropriate management and breeding strategies to optimise the benefit of maternal ability within the breeding system. The results of this study provide some evidence that improved performance of dairy cows in low-stress than in high-stress production environments can be associated with effective ameliorative management practices.

Effective ameliorative management practices that were observed in the study areas include better feeding practices, floor spacing per animal that create suitable microclimate in the cowshed and high-quality animal health services. In addition, the variation in climatic conditions (for example, temperature, humidity and rainfall) between production environments affects the availability and quality of forages. It follows that dairy cattle reared under the low-stress environment could easily meet their nutritional requirement being in a favourable climate for high productivity and quality forage. For farms in high-stress environment, it becomes necessary to invest more in management practices that minimise the effects of environmental stresses affecting animal welfare and lactation performance.

The lactation curve characteristics obtained in this study indicated higher lactation performance of cows in positive deviant farms compared to typical farms. The higher lactation performance means that a lower milk yield gap realised in positive deviant farms compared to typical farms. This lower yield gap was attained with deploying better animal husbandry practices including feeding, health, watering and housing. Good animal husbandry ameliorates the environmental stresses to enable dairy cows express their genetic potentiality to a greater degree (Pant & Odame, 2009).

The findings of the current study agree with the earlier results obtained from different dairy cattle genotypes where positive deviant farms consistently attained higher milk yield than typical farms. For example, typical dairy farmers who adopt challenge feeding strategy among their high yielding cows do also increase peak milk yield, realise a slow descending milk yield after peak yield and subsequently higher lactation milk production (Jenkins & Ferrell, 1992). This is because dairy cows have higher feed demands during lactation period to meet nutrients requirements for maintenance and production (Humer *et al.*, 2018). Thus, effective management practice that meet these higher nutritional requirements for energy and metabolisable protein would be the adoption of challenge feeding. In implementation, challenge feeding is feeding large quantities of well-balanced diet through a combination of locally available forage with concentrates supplementation to support milk synthesis, particularly during early- and mid-lactation periods to attain optimum milk yields. These observations position positive deviant farms as local role models or pioneers in innovation and supporting up-scaling to improve dairy cattle farming. Thus, the results of the current study highlight the significance of bottom-up policy developments for transforming the food system in a way that supports food sovereignty and boosts smallholder farmers' incomes.

Previous studies have reported that when energy availability increases, the rate of increase in lactation milk yield increases as well (Armstrong, 1994; Jenkins & Ferrell, 1992; King *et al.,* 2006). This is an indication of a strong relationship between feeding management practices and milk production. Also, well fed cows on a positive total energy balance at calving period tend to resume oestrous earlier and therefore significantly improve both milk and calf-crop production per life-time. It thus follows that farmers need good knowledge of dairy feeding to offer a ration with crude protein content between 14 and 16%, and 10 MJ/kg DM as the minimum metabolisable energy that cows require for production and maintenance (National Academies of Sciences, Engineering, and Medicine, 2021). This is a responsibility that extension service can offer to farmers through capacity building in forage production and ration formulation to ensure that dairy cattle are fed with a well-balanced diet that can meet nutritional requirement for growth, maintenance and production.

Persistency which is a measure of the average rate of decline in milk yield from peak time was consistently slower descending in positive deviants compared to those in typical farms under low- and high-stress production environments. In lactation milk yield, a slow descending persistency indicates a slow rate of decline. This is in contrast to a larger negative value that indicates a rapid rate of decline (Jenkins *et al.,* 2000; Val-Arreola *et al.,* 2004). That cows in positive deviant farms had a slower descending rate of persistency implies that cows had greater lactation persistency, were reaching peak time later and thus realised greater peak yield. This is relative to cows in typical farms, though the observed differences were not statistical significant.

The observed lactation performance in this study were better in comparison to earlier observed mean peak yield between 7 and 9 kg/day which occurred earlier in 6 weeks postcalving with lactation persistency of –52 to –41 g/day (Jenkins *et al.,* 2000). In the present sample, lactation persistency was of slower rate, ranging from -30.34 to -15.97 g/day for dairy cows in typical farms and positive deviant farms. This suggest better lactation performance because a slower descending rate imply higher daily milk yield from peak to the day of drying-off (Jenkins *et al.,* 2000; Val-Arreola *et al.,* 2004).

Lactation persistency parameters are related to the balance of mammary epithelial cell (MEC) proliferation and apoptosis as well as the exfoliation of MEC from the mammary epithelium into milk (Herve *et al.,* 2019). These processes can be influenced by production environment and management practices such as feeding regime in a farm. Among the farms, animal feeding, watering and health and housing were comparatively better in positive deviant farms than in typical farms (Chapter Four). What this demonstrates is that dairy cattle breeds will attain higher production potential when under improved husbandry practices (McClearn *et al.,* 2020).

Consistently better lactation performance observed for Holstein-Friesian and Ayrshire cattle breeds in positive deviants compared to those in typical farms can be linked to investing more in improved feeding, housing and animal health, aggregately bettering the animal welfare (Twine *et al.,* 2018). Better animal welfare contributes to lowering stress levels on lactating cows, allowing them to overcome reduced production performance related to stress and diseases (Bang *et al.,* 2021; Gustafson *et al.,* 2015; Mbuthia *et al.,* 2021). This is based on the fact that availability of more feeds, good quality housing with adequate floor spacing per animal and more sourcing for professional animal health service providers was observed in positive deviant farms (Chapter Four). In case of financial crisis such as the lack of funds which can be used to purchase forage or pay for private health services, smallholder farmers can select appropriate genotypes, set aside a proportion of land for growing improved pasture and practice feed conservation (Figure 6.4, 6.5 and 6.6), join cooperative as well as consulting government extension workers or animal health service providers for healthcare management to effectively minimise production constraints. Forage production may include growing improved pasture such as *Pennisetum purpureum* (Napier grass) and *Tripsacum laxum* (Guatemala grass) or a mixture of *Chloris gayana* (Rhodes grass) and Desmodium species or Lablab legume. These strategies contributed to higher productivity levels in positive deviants compared to typical farms and in low-stress environment compared to high-stress environment.

Mixed dairy cattle genotypes in a typical farm.

Holstein-Friesian genotypes in a positive deviant farm.

Figure 6.4: Improved dairy cattle genotypes in a typical farm and positive deviant farm.

Pennisetum purpureum (Napier grass)

Tripsacum laxum (Guatemala grass)

Figure 6.5: Improved forage production in smallholder dairy cattle farming systems.

Housing and feed conservation in a typical farm.

Feed conservation in a positive devinat farm.

Figure 6.6: Feed conservation practices in smallholder dairy cattle farming systems.

In addition, farms with limited resources may be more susceptible to disease infections and loss of livestock assets because of an increased mortality density (Chapter Three, Four and Five). In light of this, public infrastructure investments by increasing the budgets dedicated to SHDFs are therefore necessary to support research, extension service and farmers' organisations in establishing co-innovative solutions adapted to local contexts and needs such as structured crossbreeding, forage production and effective delivery of veterinary services. Crossbred animals outperform purebred animals in a number of significant traits under different stressful production environments. For instance, crossing parents from different strains or breeds frequently produces offspring that are stronger, have better growth, fertility, and production. Therefore, the development and management of smallholder dairy breeding programs should be comprehensive, directed toward existing production systems, and also focusing on enhancing husbandry practices such as feeding, watering and housing.

Further, the period around lactation peak is important for the health of cows and later reproductive efficiency. A commonly reported consequence is the increase of average lactation length and lactation milk yield observed in some studies, with more than 50% of cows exceeding the 305-days period (Cole *et al.*, 2009; Macciotta *et al.*, 2011). For the current study, high producing cows managed in positive deviant farms tended to have higher lactation peaks and also attained their peak yield later than those in typical farms. The findings show that both Holstein-Friesian and Ayrshire dairy cattle breeds took about 14.1 to 15.4 and 12.7 to 19.3 weeks to reach peak milk yield. This is about 3 months or 90 days above normal expectation of 40 to 60 days (8 weeks) or 7.6 to 11.1 weeks observed from various production environments and cattle breeds (Jenkins & Ferrell, 1984; Jenkins & Ferrell, 1992). Other studies have reported a peak milk yield occurring from around 58 to 78 days on average (Ben Abdelkrim *et al.*, 2021), indicating that different models, genotypes and husbandry practices may affect peak days and lactation milk yield.

The results of the present study corroborate with the findings of other studies which characterised lactation curves of different dairy cattle breeds. For example, time at peak yield for dairy cattle of different genotypes from different production environments and management practices estimated with various models tended to vary from around 38 to 144 days in lactation (Dematawewa *et al.*, 2007; Lee *et al.*, 2020; Macciotta *et al.*, 2011; Val-Arreola *et al.*, 2004). Results of these studies indicate higher lactation yield and persistency for cows reaching peak milk yield at later periods than cows attaining their peak milk yield earlier in their lactation cycle. Such results support the current findings in which dairy cows in positive deviant farms under low- and high-stress environments attained higher peak milk yield at later periods in lactation compared to those in typical farms.

The results of this study indicate that better lactation curve characteristics observed in positive deviant farms can be associated with more effective management practices deployed to ameliorate multiple pervasive environmental stresses. For example, the adoption of feed technology utilization combined with other improved dairy technologies has been related with the success in smallholder dairy cattle farming. Previous studies have demonstrated that the quantity and quality of animal feeds, household networking, membership in dairy related cooperatives, level of training, willingness to invest more in dairy technologies and larger herd size significantly influenced the success of dairy production in positive deviant farms (Birhanu *et al.,* 2017; Gellynck & Kühne, 2010; Migose, 2020; Savikurki, 2013). This supports the need to strengthen dairy cooperatives to allow smallholder farmers access high quality production inputs and services to ameliorate nutritional deficit and disease infection stresses (McClearn *et al.,* 2020; Schumacher, 2020; Sumner *et al.,* 2018; Thapa Shrestha *et al.,* 2020).

6.5 Conclusion

Results of the study show that Holstein-Friesian and Ayrshire dairy cattle breeds managed in positive deviant farms consistently expressed lactation curve characteristics indicating higher lactation performance than those managed in typical farms. The observed higher lactation performance of dairy cows can be associated with deployment of suitable management practices that ameliorated feed scarcity, heat load and disease infections stresses. These are prevalent environmental stresses in tropical smallholder dairy farms, those in Tanzania included. Lactation curve characteristics indicating higher lactation performance in positive deviant farms demonstrate that deployment of management practices has influential effect on dairy productivity. This is a success factor to consider whenever planning dairy interventions targeted to smallholder farmers. Also, lactation curve characteristics indicating higher lactation performance of dairy cattle under low-stress environment reveal that production environment is a factor to consider when promoting dairy production for smallholder livelihood interventions.

CHAPTER SEVEN

ASSESSING GROWTH-CURVE CHARACTERISTICS OF DAIRY CATTLE HEIFERS MANAGED UNDER CONTRASTING HUSBANDRY PRACTICES AND STRESSFUL ENVIRONMENTS IN SMALLHOLDER FARMS IN TANZANIA

Abstract

In smallholder farming systems, dairy cattle typically attain suboptimal growth due to several environmental stresses. However, animal growth performance in some farms exposed to similar environmental stresses might be optimal when farmers exhibit positive deviance behaviour, outperforming their peers with typical behaviour. The observed difference in performance is attributable to deployment of husbandry practices that ameliorate environmental stresses of heat load, nutritional scarcity and disease infections. This study assessed the extent to which mature body weight, time-scale parameter, maturing rate and average lifetime absolute growth rate of heifers differs between those reared in positive deviants and typical farms under low- and high-stress dairy-production environments in Tanzania. Positive deviant farms had been isolated on the criteria of performing above the population average, set at ≥0.35 Mcal $NE_{L/d}$ (1.464 MJ NE_L/d) energy balance, ≤12.75 per 100 animal-years at risk disease-incidence density, ≥6.32 L/cow/day milk yield, ≤1153.28 days age at first calving, and ≤633.68 days calving interval. A two-factor nested research design was adopted in which farm was nested within contrasting stressful environments (low- and high-stress). Body weights of dairy heifers were estimated based on heart-girth measurements. Weight-age-data on a total of 199 heifers reared in 158 smallholder dairy farms was fitted to Brody model to estimate growth curve characteristics. Results showed that dairy cattle in low-stress and positive deviant farms had significantly larger body weights compared to those in high-stress and typical farms ($p<0.05$). Results revealed that heifers in positive deviant farms had consistently heavier observed and predicted body weights as well as mature body weight than those in typical farms under low- and high-stress environments. Heifers in low-stress environment attained heavier mature body weight (396.10±11.08 vs. 354.68±17.13 kg) with lower maturing rates and average lifetime absolute growth rates (0.071±0.009 vs. 0.144±0.013 kg/d) than those in high-stress environment. The low maturing rates for heifers in positive deviant farms indicates that heifers were maturing later than were those in typical farms and can be associated with higher blood levels of exotic dairy cattle genotypes. Results reflect better

feeding and healthcare husbandry practices in positive deviant farms compared to typical farms in both low- and high-stress dairy-production environments.

7.1 Introduction

Optimal growth performance in airy cattle is important as it impacts on the productivity of the animal and profitability of the dairy enterprise in terms of income of the farmers with milk, more offspring, meat and manure to improve soil fertility. Remuneration from smallholder dairy farming is a rationale that the Tanzanian government prioritises in the national development agenda. Working with the government of Tanzania, African Dairy Genetic Gains (ADGG), a multi-partner dairy project implemented in Tanzania has been building on this agenda since November 2015 in partnership of International Livestock Research Institute (ILRI) and Tanzania Livestock Research Institute (TALIRI) (ILRI, 2019). The overall goal of ADGG is to improve productivity and profitability of dairy farmers through innovative use of information communication technology (ICT) and genomics in the country. The ADGG project has digitized animal performance data by capturing milk yield, reproduction and growth. Growth is a production trait of economic importance that has significant influence on livelihood benefits for farmers keeping dairy cattle (Arbel *et al.,* 2001; Bertilsson *et al.,* 1997; Hansson & Öhlmér, 2008; Knob *et al.,* 2018). Thus, growth-curves in dairy cattle is an important tool that allows for monitoring the development of animals and assessing if growth is occurring within the anticipated range of the specific breed or group of animals under consideration.

Dairy cattle attain suboptimal growth performance when they are persistently exposed to environmental stresses, of which excessive heat load, nutritional scarcity and disease infections are prevalent in smallholder dairy farming systems (Adjassin *et al.,* 2022; Heikkilä *et al.,* 2008). But even when exposed to similar environmental stresses in a given production environment, some farms are able to cope better and show positive deviance behaviour by outperforming their peers who generally exhibit typical behaviour. The positive deviance behaviour is an observed phenomenon among groups or communities which has been attributed to a few individuals that deploy management practices, technologies or innovations differently to achieve better solutions to local problems under similar challenges and barriers compared to those deploying typical behaviour (Albanna & Heeks, 2019; Pascale *et al.,* 2010). This would imply that positive deviant farms more effectively ameliorate environmental stresses with better husbandry practices to attain higher animal growth performance than the typical farms do (Duan *et al.,* 2021). There are different options to assess husbandry practices on smallholders in relation to animal performance. One strategy is to view the composition and structure of the herd, labour management, feeding and healthcare issues as the key determinants of dairy performance (Somda *et al.,* 2004; Waters-Bayer, 1988). Another strategy focuses on the assessment of bio-technical attributes like growth performance, age at first calving, calving intervals, lactation length and milk yield (Bulale, 2000; Kiwuwa *et al.,* 1983). Growth performance is a production trait that is dependent on the degree of husbandry practices deployed in a given environment. In this case, bio-technical factors provide fundamental information to explicitly describe the types of dairy production systems. Consequently, dairy cattle raised in positive deviant farms exposed to better husbandry practices are expected to express growth-curve characteristics differently from those animals reared in typical farms.

Growth functions have been used to describe growth-curve characteristics from which adequacy of husbandry practices can be revealed. Growth-curve characteristics include asymptotic mature body weight, time-scale parameter and maturity rate. These growth-curve parameters are biologically meaningful information that do reveal differences in growth characteristics between animals reared under different exposures to environmental stresses and varying husbandry practices (Crispim *et al.,* 2015). Therefore, it is possible that the different levels of growth traits in dairy cattle managed in positive deviants and typical farms under stressful production environments may be achieved through appropriate ameliorative management practices.

Growth-curve characteristics of dairy cattle have been described using different nonlinear models fitted to longitudinal growth data to estimate biologically meaningful information (Duan *et al.,* 2021; Ning *et al.,* 2018; Yin & König, 2020). Generally, there is no consensus on which nonlinear model is appropriate across production environments to estimate growth-curve parameters. In this context, the choice of which model can be applied depends on the nature of the study and the intended application of the findings (Busanello *et al.,* 2022). For instance, Brody and Gompertz growth-curve models can be applied to estimate various growth-curve characteristics in dairy animals (France & Kebreab, 2008). Thus, modelling growth-curves with these growth functions makes it possible to relate growth curve characteristics with the husbandry levels deployed on the farm. Because positive deviance behaviour is a phenomenon that reveal differences in management practices, growth curves of the animals reared in positive deviant farms could be related to the level of husbandry practices deployed. However, empirical evidence remains scanty in highly fragmented smallholder dairy cattle farming systems where heterogeneity in management practices and performance is huge. This study assessed the extent to which mature body weight, time-scale parameter, maturing rate and average lifetime absolute growth rate of heifers differs between those reared in positive deviants and typical farms under low- and high-stress dairy-production environments in Tanzania.

7.2 Materials and Methods

7.2.1 Data Source

Detailed information of the data source, study area, data collection and objective identification process of positive deviants and typical farms in a large population are described in section 3.2.1, 3.2.2 and 3.3 of Chapter Three, respectively. A brief description and objective specific information is presented in this Chapter with details of data collection on growth performance.

7.2.2 Data Collection and Processing

Animal growth data in the sample farms was obtained from ADGG project database (https://www.adgg.ilri.org/uat/auth/auth/login). The database had individual animal growth data captured at the time of milk recording using a heart girth tape. Milk production was the summation of the morning and evening milking. Each farm was visited once or twice a month during which measurements of all the animals in the farm were taken. Heart girth (in cm) taken by tape was circled right behind the shoulder at the fourth ribs posterior to the front leg and height at withers. Care was taken to ensure that the animals were standing on a level surface with the correct posture for measurements. Heart girth measurements used in this study were of heifers managed in smallholder dairy farms in Tanzania.

The heart girth measures were converted to body weight using formulas for crossbred Holstein-Zebu dairy heifers (Oliveira *et al.,* 2013). The conversion of metric tape is one of the most accurate indirect methods for measuring body weight in dairy cattle (Busanello *et al.,* 2022; Dingwell *et al.,* 2006). Live body weights were predicted from heart girth measurements fitting the model in the form of:

$$Body\ weight\ (kg) = 0.00058 \times (heartgirth)^{2.6135} \qquad (7.1)$$

This was a preference model applied after the formulas (live weight = 4.277×heartgirth - 393.13) published earlier (Lukuyu *et al.,* 2016) for smallholder dairy cattle tended to give unrealistic and negative body weight for heart girth less than 110 cm. Birth- and weight-dates were provided for all the animals. However, estimates of growth parameters can be affected by the number of weight recordings (Perotto *et al.,* 1994). In this case, only data from dairy heifers with three records or more were included in the analysis (Brody, 1945). After cleaning, a total of 1480 weight-age records of 199 dairy cattle heifers reared in 158 smallholder dairy farms were available for subsequent statistical analysis. The weight-age taken beyond 36 months of age was excluded in the estimation of the growth parameters because it could be inflated by possible pregnancy status of such animals (Perotto *et al.*, 1994). Table 7.1 provides a summary of farms, animals and weight-age records distributed in low- and high-stress dairy-production environments.

Table 7.1: A summary indicating the distribution of farms, animals and data points in low- and high-stress dairy-production environments in Tanzania.

Factor	**Level of stress**	**Number of farms**	**Number of heifers**	**Data points**
Production environment				
	Low-stress	113	149	1161
	High-stress	45	50	319
	Total	158	199	1480
Farm(environment)				
	Low-stress			
	Positive deviants	7	10	69
	Typical farms	106	139	1092
	Total	113	149	1161
	High-stress			
	Positive deviants	4	5	30
	Typical farms	41	45	289
	Total	45	50	319
Farm				
	Positive deviants	11	15	99
	Typical farms	147	184	1381
	Total	158	199	1480

7.2.3 Estimation of Growth-Curve Parameters

Data on body weight was processed for estimating asymptotic mature body weight, maturity rate and time-scale parameter. In turn, these parameters were used to estimate average lifetime absolute growth rate (AGR). Since there is no consensus on which nonlinear model is the best in all circumstances, the choice of growth model depends on the nature of the study and the intended use of the results (Busanello *et al.,* 2022). For this, the study aimed to use a versatile model for heifers reared in smallholder cattle farming systems under stressful dairy-production environments. Therefore, the Brody model which is a three parameters nonlinear function was fitted to the weight-age data to estimate growth parameters. In addition, Brody model was most preferred in this study because it had previously produced better results from dairy cattle reared in smallholders under contrasting stressful dairy-production environments in Tanzania (Ekine *et al.,* 2020). Therefore, the growth parameters were estimated using the nonlinear least squares functions in SAS software (SAS Institute Inc, 2013), fitted with Brody function:

$$y_t = A(1 - b \times Exp^{-Kt}) \quad (7.2)$$

Biological interpretation of growth curve parameters adopted the description of Fitzhugh (1976). In the mathematical expression, y_t represents body weight of the animal at a given age (*t*); parameter *A* is the asymptotic mature body weight (MW), if $t \to \infty$; when the adult weight of the animal is not reached, this reflects an estimate of the weight of the last weighing. This means the ultimate body weight of an individual animal maintained independently of short-term fluctuations. The *b* is the time-scale parameter (integration parameter), and indicates the proportion of the MW to be gained after birth (has no relevant biological interpretation) or means the time for an individual to reach its maximum growth rate. Additionally, this is a constant without biological interpretation, but it is important to model the sigmoidal format of the growth curve from birth (t= 0) until the adult age of the animal ($t \to \infty$). *K* is the maturity rate (MR) or index, which expresses the ratio of the maximum growth rate in relation to mature body weight, where lower MR values indicate delayed maturities and higher MR values indicate accelerated maturity. In this study, *t* is the growth time; and *e* is the exponential function (an Euler's number which is the root of natural base logarithm, approximately 2.718). In this study, parameters estimation was an interactive Marquardt process and used starting values of 384.60, 0.9192 and 0.0022 for *A, b* and *K* in the model previously reported for Nellore cows (Marinho *et al.,* 2013).

Further, average lifetime absolute growth rate (AGR) was derived after growth curve parameters were determined. The AGR estimates the increase in weight of the animal for each time unit *t*. This was computed from the fitted model:

$$AGR = \left(\frac{\partial \mathrm{yt}}{\partial \mathrm{t}} = \mathrm{AbK} \times \mathrm{Exp}(-\mathrm{Kt})\right) \qquad (7.3)$$

where parameter *A* is the asymptotic mature body weight, *b* is the time-scale parameter, *K* is the maturing rate/index and *t* is the time unit (Freitas, 2005; Marinho *et al.*, 2013; Perotto *et al.*, 1994).

7.2.4 Statistical Analyses

Statistical analysis was to test the hypothesis that growth curve characteristics differs between positive deviants and typical farms whether under low- or high-stress dairy-production environments. All statistical analyses were performed in SAS software (SAS Institute Inc, 2013), fitting linear mixed model to account for variables that could be correlated or with non-constant variability. Means separation was achieved with least significant difference for direct pairwise comparisons between means. The fitted statistical model was in the form:

$$\mathrm{Y}_{(\mathrm{i})\mathrm{jk}} = \mu + \mathrm{PE}_{\mathrm{i}} + \mathrm{FT(PE)}_{\mathrm{j(i)}} + e_{\mathrm{ijk}} \qquad (7.4)$$

where, $\mathrm{Y}_{(\mathrm{i})\mathrm{jk}}$ is the dependent variable (heart girth, estimated and predicted body weight, asymptotic mature body weight, time-scale parameter, maturing rate and average lifetime absolute growth rate), μ is the overall mean, PE_{i} is the fixed effect of environment, $\mathrm{FT(PE)}_{\mathrm{j(i)}}$ is the random effect of farm (positive deviants and typical) nested within the environment (low- and high-stress) and e_{ijk} is the random error.

In addition, simple correlation was performed to determine the relationship between asymptotic mature body weight and maturing index/rate of dairy heifers managed in positive deviants and typical farms under low- and high-stress production environments.

7.3 Results

Table 7.2 shows the means for heart girth, estimated and predicted body weight, and model prediction bias of heifers reared in positive deviants and typical farms under low- and high-stress dairy-production environments. The overall heart girth was 131.58 cm translating to 214.39 kg for both the estimated and predicted body weight of heifers, respectively. The bias (estimated – predicted) of the prediction model was less than one percent (0.42%), suggesting that the Brody model predicted growth-curve characteristics with good accuracy for heifers in smallholder dairy farming systems. Further results reveal that heifers in positive deviant farms had larger heart girth, resulting to heavier estimated and predicted body weights ($p<0.05$) than those in typical farms under low- and high-stress dairy-production environments. Estimated and predicted body weight was heavier ($p<0.001$) in positive deviants compared to typical farms regardless of level of the environmental stress.

Table 7.2: Estimated means (LS-Means±SE) for growth performance characteristics of dairy cattle managed in positive deviants and typical farms nested within low- and high-stress dairy-production environments.

Factor	Level	Growth performance characteristics			
		Heart girth (cm)	**Estimated BW (kg)**	**Predicted BW (kg)**	**Bias (%)**
Environment					
	Low-stress (n=149)	138.66±1.49	240.56±5.60	240.59±5.58	0.24±0.62
	High-stress (n=50)	134.40±2.30	228.58±8.65	228.59±8.62	0.25±0.95
	Mean difference	4.26^{NS}	11.98^{NS}	11.99^{NS}	0.02^{NS}
Farm(environment)					
	Low-stress				
	Positive deviants (n=10)	146.38±2.89	269.78±10.86	269.86±10.82	0.01±1.20
	Typical farms (n=139)	130.94±0.73	211.33±2.73	211.32±2.72	0.46±0.30
	Mean difference	15.44***	58.45***	58.54***	0.45^{NS}
	High-stress				
	Positive deviants (n=5)	139.13±4.38	247.93±16.45	247.93±16.41	0.09±1.82
	Typical farms (n=45)	129.66±1.41	209.23±5.30	209.25±5.29	0.41±0.59
	Mean difference	9.48*	38.69*	38.68*	0.32^{NS}

$^{***}p<0.001$; $^{**}p<0.01$; $^{*}p<0.05$; $^{NS}p>0.05$; n = number of animals, overall mean heart girth = 131.58 cm, estimated body weight = 214.39 kg, predicted body weight = 214.39 kg, model prediction bias (estimated - predicted) = 0.42%.

Table 7.3 shows the estimated means for asymptotic mature body weight, time-scale parameter, maturing rate and average lifetime absolute growth rates (AGR) for heifers reared in positive deviants and typical smallholder farms under low- and high-stress environments. The overall mature body weight, time-scale parameter, maturing rates and average lifetime absolute growth rates was 347.83 kg, 0.87, 0.26×10^{-2} and 0.10 kg/day. These growth function parameters measures growth rates of heifers by comparing between those in the low- and high-stress environments. Results reveal that heifers reared in positive deviant farms had heavier ($p<0.05$) asymptotic mature body weight than those in typical farms under low- and high-stress environments. Regardless of the level of environmental stress, heifers in positive deviant farms showed lower maturing rate and AGR than those in typical farms, indicating that animals with heavier body weight expresses lower maturing rates and AGR (Table 7.3; Figure 7.1 and 7.2). Maturing rate means the rate at which an individual dairy animal approaches its mature body weight. The low maturing rate observed for heifers in positive deviant farms indicates delayed maturities of heifers compared to those in typical farms (Table 7.3; Figure 7.1 and 7.2). A bivariate correlation between asymptotic mature body weight and maturing index/rate of dairy heifers was negative and highly significant ($r = -0.5096$, $p<0.0001$), indicating that asymptotic mature body weight increased with decreasing maturing index.

Table 7.3: Estimated means (LS-Means±SE) for growth curve characteristics of dairy cattle managed in positive deviants and typical farms nested within low- and high-stress dairy-production environments.

Factor	Level	Growth curve characteristics			
		MW (kg)	**Time-scale (b)**	**MR ($\times10^{-2}$)**	**AGR (kg/d)**
Production environment					
	Low-stress (n=149)	396.10±11.08	0.65±0.06	0. 22±0. 02	0.07±0.01
	High-stress (n=50)	354.68±17.13	0.76±0.09	0. 30±0. 03	0.14±0.01
	Mean difference	41.42*	0.11NS	0. 08*	0.07***
Farm(environment)					
	Low-stress				
	Positive deviants (n=10)	443.82±21.50	0.39±0.11	0. 18±0. 03	0.05±0.02
	Typical (n=139)	348.38±5.40	0.91±0.03	0. 25±0. 01	0.09±0.00
	Mean difference	95.44***	0.52***	0. 07*	0.05**
	High-stress				
	Positive deviants (n=5)	391.00±32.61	0.64±0.16	0. 27±0. 05	0.14±0.03
	Typical (n=45)	318.35±10.51	0.88±0.05	0. 32±0. 02	0.14±0.01
	Mean difference	72.65*	0.24NS	0. 05NS	0.00NS

***$p<0.001$; **$p<0.01$; *$p<0.05$; NS$p>0.05$; n = number of animals, overall mature body weight (MW) = 347.83 kg, time-scale (b) = 0.87, maturity rate (MR) = 0.26×10^{-2}, average lifetime absolute growth rate (AGR) = 0.10 kg/day.

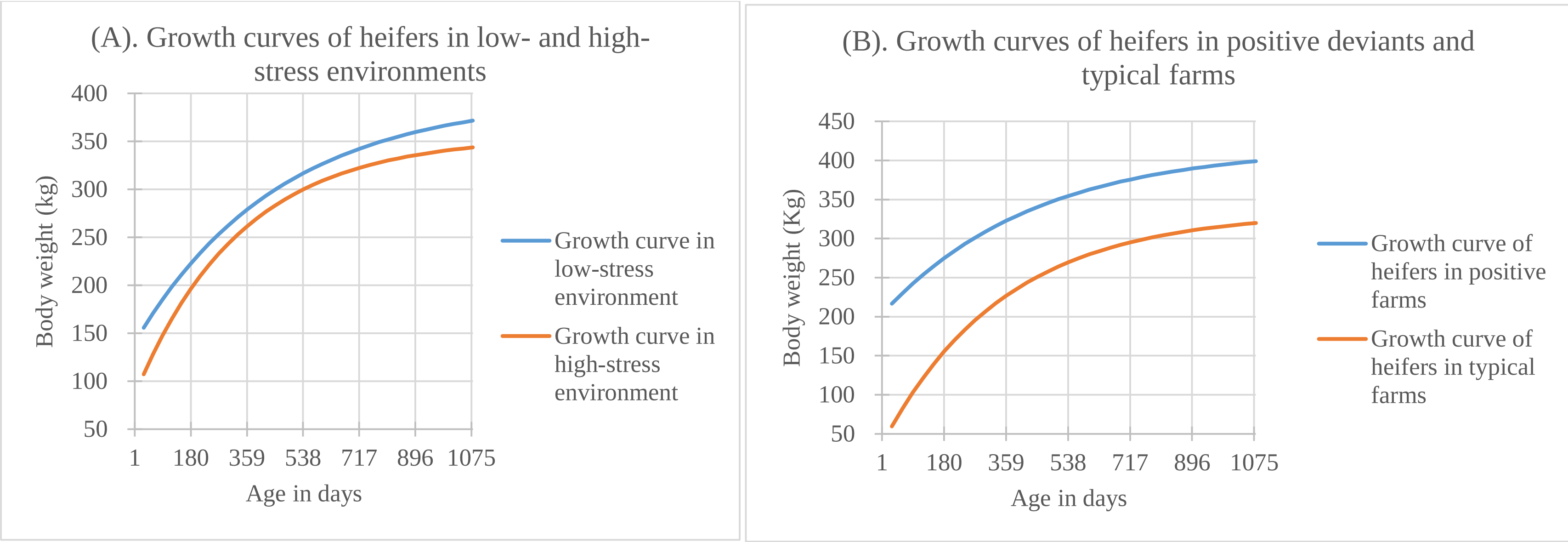

Figure 7.1: Growth curves of heifers in (A) low- and high-stress dairy-production environments (B) positive deviants and typical smallholder dairy farms.

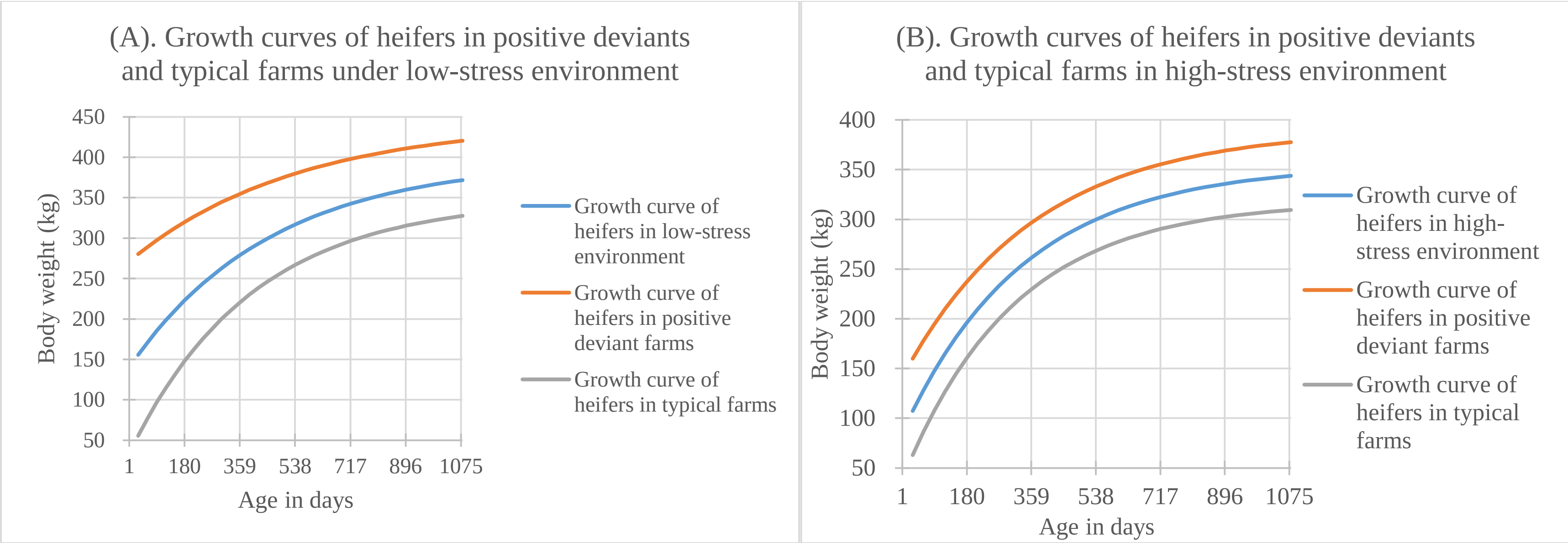

Figure 7.2: Growth curves of heifers in positive deviants and typical farms under (A) low-stress and (B) high-stress dairy-production environments.

7.4 Discussion

Body weight measurements are of importance in dairy cattle farming systems to inform on nutritional requirements, breeding, health and reproductive management of replacement heifers (Busanello *et al.,* 2022; Oliveira *et al.,* 2013). In order to better manage dairy animals, it is vital to quantify and understand how they interact with their production environments through the assessment of husbandry practices in relation to animal performance (Abdelkrim *et al.*, 2021), such as growth-curve characteristics of dairy animals. Thus, this study assessed growth-curve parameters for heifers reared in positive deviants and typical smallholder dairy farms in low- and high-stress dairy-production environments. Growth parameters included heart girth, estimated and predicted body weight, asymptotic mature body weight (MW), time-scale parameter (*b*), maturity rate (MR) and average lifetime absolute growth rate (AGR). With nested model, the observed differences in growth-curve parameters at the farm level reflects varying husbandry practices while differences at the environment level reflects the extent to which the stresses have been ameliorated.

In the present study, weight-age records were taken on monthly basis and the formula developed for Holstein-Zebu crossbred was used to estimate live body weights (Oliveira *et al.,* 2013). Intervals between weight-time points varied among study animals, and this variation can also affect the final growth-curve parameter estimates. This is because weight can increase or decline sharply with time as a result of environmental or physiological stresses acting on the animal. In this case, all data was thoroughly checked and those presenting irregularities were excluded from further analysis. Thus, only weight-age records from heifers with three data points or more were included in the analysis (Table 7.1). Further, the different levels of farm management practices in the smallholder dairy cattle farming systems can play a great role in the predictive ability of the growth models. The small model prediction bias of less than one percent shows that the Brody model fitted to the weight-age data achieved higher predictive ability (Table 7.2), indicating the capability of the Brody model to accurately estimate growth function parameters of the dataset used in this study. This was achieved partly by screening and cleaning the dataset for obvious errors due to the enormous range of data points and breed compositions.

A stressful environment is a significant factor that can have a negative impact on both growth performance, milk production and health traits of dairy cattle (El-Tarabany *et al.,* 2016). The results proved this hypothesis that the estimated weight, predicted weight and mature body weight of heifers in low-stress environment exceeded ($p<0.01$) those in high-stress environment. This larger body weights observed in low-stress environment is a reflection in the variation of animal husbandry practices and breed compositions, which was dominated by Holstein-Friesian crossbred heifers. It is consistent with the recent study which revealed higher levels of more upgraded dairy cattle genotypes which are more sensitive to environmental stresses in high-stress environment than was in low-stress environment. This earlier study reported that in both high-stress (76% vs. 61.7%) and low-stress conditions (14.3% vs. 8.4%), cattle upgraded to higher grade levels (75% exotic breed) made up a bigger percentage of the herd on positive deviant farms than on typical farms. Higher grade (about 75% exotic breed) cattle made up a greater share of the herd overall in high-stress than in low-stress production environments (62.3% vs. 8.8%). Therefore, the lower growth performance of animals managed under high-stress environment compared to those in low-stress environment might be associated with the negative impact of higher disease incidence-density (9.55 vs. 6.25 per 100 animal-years at risk) and heat load stresses measured in terms of THI (77.29 vs. 68.20 THI units). Higher-grade of dairy cattle are more vulnerable to disease infections, heat loads, and demand higher nutritional requirements to achieve potentially high growth performance levels. This information shows that high-grade dairy cattle managed under high disease infections rates, heat load stress combined with nutritional deficiency tend to show a lower growth performance partly because of a disruption in the animal's homeostasis and a loss of adaptability (Carabaño *et al.,* 2022).

Previous studies described that variation in mature body weight can be associated with different levels of husbandry practices and dairy cattle upgrading (Busanello *et al.,* 2022; Jenkins *et al.,* 1993). In addition, the estimates of AGR values (Table 7.3) appears to agree reasonably well with equivalent estimates from Holstein and crossbred females data reported earlier by other workers in the tropics (Marinho *et al.,* 2013; Perotto *et al.,* 1994). Therefore, improving growth performance of heifers through genetic selection and deployment of viable ameliorative strategies is important in smallholder dairy cattle farming systems operating under stressful production environments in the tropics. For example, heat stress has been reported as one of the major issues in many dairy production systems (Carabaño *et al.,* 2022), both in hot and more temperate regions as a result of the rise in temperatures due to climate change (Arias *et al.,* 2021).

The differences in heart girth, estimated, predicted and mature body weights, maturity rate and average lifetime absolute growth rates reflect the variable levels of husbandry practices deployed in smallholder dairy farms in low- and high-stress environments. The actual weight, predicted weight and mature body weight were higher for heifers in positive deviant farms than those in typical farms both in low- and high-stress environments. Estimated mature body weight of heifers in positive deviant farms was higher by 95.44 kg and by 72.65 kg than those in typical farms in low- and high-stress environments. The findings demonstrate better performance of dairy cattle managed in positive deviant farms than those in typical farms. The observed variation can be explained by the differences in the ameliorative husbandry practices implemented in positive deviants and typical farms. In positive deviant farms, a combination of greater investment in feeding, watering, higher genetic proportion of exotic breed, housing and better animal healthcare have been associated with better amelioration of feed scarcity, heat load stress and disease infections. These husbandry practices are supportive to better growth performance results (Singh, 2015).

Mature body weight observed in this study fell within the range of dairy cattle genotypes raised in the tropics under various levels of environmental stresses (Chawala *et al.,* 2021). The findings of this study suggest that dairy cattle reared in positive deviant farms express different growth-curve characteristics compared to those in typical farms under similar stressful dairy-production environment. A higher genetic proportion of high-grade dairy cattle in positive deviant farms was associated with larger heart-girth and heavier body weight than those in typical farms. This was expected because large body size often have heavier asymptotic mature body weight. Compared to previous studies, the current findings ranging from 318.35 kg in typical farms to 443.82 kg in positive deviants farms under high- and low-stress environments are lower than the mature body weight of Vietnamese smallholder dairy cows (392 to 623 kg) (Bang *et al.,* 2022), and pure breeds of Jersey (408 to 454 kg), Holsteins (590–680 kg) and Brown Swiss (509–537 kg) (Capper & Cady, 2012; Piccand *et al.,* 2013). The reported differences are logical for pure dairy breed in USA and New Zealand, and mixed breeds and their crossbreds on smallholders under stressful environments. The genetic makeup of the Vietnamese smallholder dairy cows is mostly composed of Holsteins (85.0%), Jersey (6.0%), Brown Swiss (5.3%), and Zebu (4.5%) (Bang *et al.,* 2021). Thus, dairy cattle in positive deviant farms could be a good genetic base for selecting high milk-producing cows with better growth-curve characteristics comprising some degree of adaptation to stressful environmental conditions in the tropics.

Under smallholder dairy farming, it is important to maintain heavier productive cows with higher mature body weight accompanied with high milk yield potential within shorter calving interval. This productivity translates into more total livelihood benefits generated from dairy cattle farming. Furthermore, the results of this study corroborate with previous studies which have reported that animals with lower mature body weight tend to have a higher maturity rates than those with higher mature body weight (Busanello *et al.,* 2022; Hafiz *et al.,* 2014;

Jenkins *et al.,* 1993; MacDonald *et al.,* 2007). Maturing rate refers to the rate at which an animal attains its mature body weight (Jenkins *et al.,* 1993). It is an important index because dairy cattle with higher maturing rate tend to attain puberty and sexual maturity earlier which is also desirable for breeding objectives. The parameter indicates the animal's growth rate to reach asymptotic mature body weight. The lower maturing rate observed for dairy cattle in positive deviant farms than those in typical farms is a reflection of negative correlation between asymptotic mature body weight and maturing rate (Hafiz *et al.,* 2014), indicating that the animals with smaller body weight have higher maturing rates and are able to attain mature weight earlier than heavier animals with lower maturing rates. For example, a study conducted to compare growth curves of three dairy cattle genotypes reared under similar environmental conditions in Ireland observed a lower maturing rates for heavier than lighter animals. The average maturing rates for heavier Holstein-Friesian genotype (591 kg) selected for high milk production but with greater emphasis on functional non-production traits was more slower than that of the Holstein-Friesian genotype selected for high milk production (566 kg) or the New Zealand Holstein-Friesian females of high genetic potential for profitability (543 kg) strain (Berry *et al.,* 2005).

Results of this study reveal that better performance of dairy heifers depends on the type of management practices deployed to ameliorate persistent environmental stresses in smallholder cattle farming systems. For instance, some studies have shown that Holstein-Friesian crosses produced under suitable management practices in the tropics can offer the best advantage for production attributes including growth performance and milk yield (Chawala *et al.,* 2021; Singh, 2015). The results of this study suggest that positive deviant farmers were able to identify appropriate genotypes and management options that suit for their production environment and breeding goals through assistance from professional dairy service providers. This is in agreement with the breeding objective of smallholders in adopting dairy cattle with higher levels of improved genetic materials to improve growth performance and milk production for cash needs and provision of high-value food (Marshall *et al.,* 2020; Singh, 2015; Vercillo *et al.,* 2015). The findings of this study would be useful at providing reliable and valuable pathways for identifying sires expected to produce heifers with younger age at first calving to optimise lifetime productivity in smallholder farming systems.

The better performance of heifers in positive deviant farms suggest that ameliorative husbandry practices deployed to overcome environmental stresses in those farms are more effective compared to typical farms. In this study, positive deviant farms had larger herds of more high-grade dairy cattle housed in better quality zero-grazing stall units. In addition, positive deviant farms invested more on feeds, water especially during dry seasons and also frequently sourced professional animal health services for their dairy cattle (Chapter Four). These management practices can be associated with amelioration of feed scarcity, disease infections and heat load stresses to improve animal welfare and growth-curve characteristics. This corroborates a phenomenon of positive deviance behaviour observed in other studies applying positive deviance concept (Adelhart Toorop *et al.,* 2020; Albanna *et al.,* 2022; Birhanu *et al.,* 2017; Duru *et al.,* 2015; Mertens *et al.,* 2016), that positive deviant farms stand out in performance than their peers confronting similar production constraints. The findings suggest an overall amelioration of environmental stresses in growth-curve characteristics of dairy cattle managed in positive deviants in comparison to their contemporaries in typical farms.

Results of this study provide evidence that positive deviant farms achieved better growth performance of heifers than typical farms, consistent with earlier observation that they outperform typical farms in addressing feed scarcity indicated by higher total energy balance, addressing disease infections indicated by lower disease incidence density, and attaining greater productivity indicated by attaining higher milk yield, earlier age at first calving and shorter calving interval (Chapter Three). This evidence of positive deviants outperforming in addressing feed scarcity and disease infections subsequently attaining higher productivity than their contemporary typical farms is valuable and informative in extension services to learn from them about effective husbandry practices to improve dairy performance for better livelihood benefits to farmers. Thus, the reasons for lower growth performance of heifers raised in typical farms could partly be attributed by various factors prevailing in smallholder farming systems. Like any other agricultural systems, smallholder farming are multidimensional and complex systems where many factors such as weather conditions, housing systems, feeding and watering practices, animal healthcare and genotype, simultaneously influence growth performance of dairy cattle (Bang *et al.,* 2022). Raising improved high-producing dairy cows in high-stress environments is challenging due to the hot and humid weather conditions. Therefore, the results of this study suggest that combining different viable ameliorative management practices that exist among smallholder farms could be of great value for improving growth performance of dairy cattle in typical farms under stressful production environments.

The low quality of forage and by-product types commonly used by farmers like *Pennisetum purpureum* known as Napier grass or crop residues and simple farm diet formulation such as roughage with concentrates, does not supply enough or an appropriate balance of nutrients for dairy cattle (Bang *et al.,* 2022). In this context, the lower growth performance of dairy cattle managed in typical farms could partly be associated with the lower production of improved forage required to provide sufficient nutrients for growth and maintenance (National Academies of Sciences, Engineering, and Medicine, 2021). Although forage production is a golden alternative to the dependency for natural and communal grazing pasture, it is hindered by insufficient investment and a scarcity of affordable and high-quality seeds (Ng'hily, 2022). This is an organizational and institutional factor which limits the adoption to produce more improved forage for feeding high-grade dairy cattle in smallholders operating under contrasting stressful environments. Furthermore, the animals were also probably uncomfortable in the poorly designed cowsheds, which could amplify the negative effects of environmental stresses and result in lower growth performance on typical farms (Bang *et al.,* 2022). These issues can be addressed through the application of technical innovations that enhance ameliorative management strategies of genetic quality, nutrition and animal health to improve productivity and sustainable utilisation of dairy cattle in smallholder farming systems. In addition, the findings of the study suggest the need for prioritising husbandry practices for improved animal welfare. Therefore, organizational and institutional innovations, which include access to credit at reasonable rates are required to improve the efficiency of the dairy supply chain. Founding farmers' cooperatives to supply inputs such as animal feeds, artificial insemination and health services aiming to improve dairy production performance is recommended in this study to overcome environmental stresses. Enhanced community-based crossbreeding initiative could benefit smallholder farms to improve the productivity of dairy cattle through crossbreeding. The approaches suggested in this study would be useful in providing valuable information for defining suitable and accurate amelioration strategies to sustain dairy cattle production.

7.5 Conclusions

Results show that heifers managed in positive deviant farms attained better growth-curve characteristics than those in typical farms, suggesting that positive deviant farms implemented more effective husbandry practices to ameliorate environmental stresses experienced in their farms. The results provide evidence-based solutions from successful positive deviant farmers for extension services to learn how husbandry practices such as crossbreeding, feeding and housing can be deployed differently to improve growth performance of dairy cattle. Since all herds are likely to benefit in terms of production efficiency, dairy herds with poor growth performance would greatly benefit from effective ameliorative husbandry practices like feeding and well-organized crossbreeding with more improved dairy cattle genotypes.

CHAPTER EIGHT

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

8.1 General Discussion

Around the world, smallholder dairy farms generate a significant amount of food and other essentials for livelihood benefits. Dairy farming is crucial to the survival of these farmers and their families because of the reliable income and nutritional security it provides. Despite the fact that environmental stresses are recognized as the key factors that limit and reduce dairy cattle productivity, effective management practices plays important roles in dairy cattle performance. This is due to the fact that dairy cattle genotypes typically used by smallholders are particularly vulnerable to heat load, nutritional scarcity, and diseases that are so common in stressful dairy-production environments. Chronic exposure to these environmental factors causes discomfort in dairy cattle, which leads to decreased feed intake, compromised immunity and an increased risk of diseases. Farmers that keep dairy cattle for economic reasons experience a decline in their standard of living and marketability as a result of the repressed production capacity, which manifests as low productivity, huge yield gaps and the loss of livelihood advantages. Finding the outliers labelled positive deviant farmers who achieve exceptional results in smallholder dairy cattle farming can guide more strategic changes in typical, comparable farms facing similar environmental constraints. In most cases, positive deviants are discovered by a purely subjective process, which introduces bias and prevents broad generalization of the findings. This section discusses the identification of positive deviant farms within a large group of smallholder dairy farms by employing multi-objective criteria, and to assess the management practices that most likely have the greatest impact on animal health status, lactation and growth performance.

8.1.1 Research Issues Addressed in the Study

Environmental constraints such as heat load, nutritional deficiency and disease infections can limit or reduce dairy cattle productivity and, consequently, the potential livelihood gains from dairying in smallholder dairy farms. Dairy cattle on smallholdings are unable to express their full genetic potential for milk production because of low fertility, slow growth and development, increased disease prevalence, and higher mortality densities. However, a small percentage of smallholders, known as positive deviants, are able to reduce the pressures of environmental stresses and hence achieve noticeably higher livelihood advantages from dairy cattle while still experiencing similar levels of environmental constraints. Understanding how positive deviant farms successfully ameliorate environmental stresses thereby improving performance of their animals might help with management strategy selection (Albanna *et al.,* 2022; Hammond *et al.,* 2017; Savikurki, 2013). Learning from such successful smallholder dairy farmers experiencing similar constraints should provide guidance on how to reduce environmental pressures to increase dairy cattle productivity. Positive deviance concept is a useful approach for finding and promoting practical solutions to production challenges facing dairy farmers, especially in the tropics. Innovations that address local environmental stresses to improve dairy productivity are likely to be successful, accepted by the community and sustainable (Albanna & Heeks, 2019; Hammond *et al.,* 2017; Jaramillo *et al.,* 2008). In this context, positive deviance concept is a restricted learning process, nonetheless, that teaches how to creatively alleviate constraints that prevent typical farmers from fully exploiting the full production potential of their dairy cattle in a sustainable manner. Therefore, the objective of the study was to contribute to improved productivity and sustainable utilisation of dairy cattle on smallholder dairy farms through learning from positive deviants in contrasting stressful production environments of proven amelioration strategies to promote to other smallholders. The specific objectives of the study were:

i. To identify positive deviance farms using Pareto-optimality ranking technique in a sample of smallholder dairy farms under contrasting stressful environments in Tanzania and estimate productivity, yield gap and livelihood benefits attained.
ii. To characterise management practices that positive deviant farms deploy differently from typical farms to ameliorate local prevalent environmental stresses under contrasting dairy-production environments in Tanzania.
iii. To assess animal disease prevalence and mortality in smallholder dairy farms under contrasting management practices and stressful environments in Tanzania.
iv. To assess lactation curve characteristics of Holstein-Friesian and Ayrshire dairy cows managed under contrasting husbandry practices and stressful environments in Tanzania.
v. To assess growth-curve characteristics of dairy cattle heifers managed under contrasting husbandry practices and stressful environments in smallholder farms in Tanzania.

The research questions were:

i. Do the positive deviant farms significantly outperform typical farms in productivity, yield gap and total livelihood benefits under contrasting stressful environments in Tanzania?

ii. Do the positive deviant farms deploy management practices differently from typical farms to ameliorate prevalent environmental stresses under contrasting stressful environments?
iii. Do the animals managed in positive deviants and typical farms suffer different levels of disease infections and mortality, whether under low- or high-stressful environments?
iv. Do the cows in positive deviants and typical farms express lactation curve characteristics differently, regardless of the stress levels exposure in low- and high-stress environments?
v. Do the growth curve characteristics of heifers in smallholder dairy farms differs significantly under contrasting husbandry practices and stressful production environments?

The study outputs provided empirical evidence to inform smallholder dairy farmers and livestock extension agents that it is possible to ameliorate persistent environmental stresses through effective deployment of management practices differently from typical farms to attain higher productivity levels and sustainable utilisation of dairy cattle genotypes for quality food and income security.

8.1.2 Methodological Issues

The ADGG has created a genetic gains platform for identifying and validating superior crossbred bulls and heifers to facilitate artificial insemination services and planned natural mating by combining on-farm performance data with fundamental genomic data. This project helps farmers gain access to high-quality dairy crossbred heifers, enhanced bulls, and artificial insemination services. Herd size range from as few as one to as many as thirty, with the average being four to seven dairy cattle and a mode of two cattle per herd. Dairy cattle breeds in the herd may include Holstein-Friesian, Ayrshire, and Jersey cattle, as well as any offspring of these breeds that have been crossed with indigenous Tanzanian Shorthorn Zebu cattle. Recent estimates indicate that on average milk yield stands at 6.40 litres per cow per day in typical farms to 11.32 litres per cow per day in positive deviant farms, which translates to a lactation milk production of less than 2600 litres (Chapter Three).

The research project faced some methodological issues during its implementation. The first concern was the classification of contrasting stressful dairy-production environments in Tanzania with a high concentration of dairy cattle based on the temperature-humidity index (THI). This is because heat stress in dairy cattle is associated with a decrease in feed intake, growth performance, milk yield and may cause reproduction problems (Bang *et al.,* 2022; Polsky & von Keyserlingk, 2017). In this study, the target was to classify two contrasting stressful dairy-production environments using THI at the farm level. Infrared temperature (IRT) as a non-invasive approach to assessing heat stress in dairy cows has recently been applied in smallholder farming systems in the tropics (Bang *et al.,* 2022). Another alternative could be the application of heat load index (HLI) measured inside the cowsheds. Heat load index is an indicator of environmental heat load calculated from ambient temperature, humidity and wind speed to measure the levels of heat stress in animals inside the cowsheds (Bang *et al.,* 2021; Bang *et al.,* 2022). These advanced technological options would be more objective and reliable technique to quantify THI at farm level. However, the use of these advanced technological tools that could be used to collect temperature and humidity data at specific times of a day within the cowshed at the farm level was not readily available. Confronted with such limitation in modelling the effects of heat stress on milk production in dairy cattle, Mbuthia *et al.* (2021) utilised grid-interpolated solar and meteorological data from the National Aeronautics and Space Administration/Prediction of Worldwide Energy Resources (NASA/POWER) to compute THI. Further, THI computed by using air temperature and relative humidity obtained from meteorological stations has been used to quantify heat load stresses in farm animals such as dairy sheep. The usefulness of meteorological data from weather stations near the farms was demonstrated by producing heat load estimates that were comparable to those recorded inside the animal shed (Carabaño *et al.,* 2022). Under similar circumstances, this study resorted to THI computed using monthly averages of air temperature (°C) and relative humidity (%) data which were obtained from meteorological database sources (Chapter Three). In turn, THI computed on the basis of meteorological data as an indicator for heat stress was used to classify the two contrasting study areas into low- and high-stress dairy-production environments (Dikmen & Hansen, 2009; Zimbelman *et al.,* 2009).

The second issue concerned the number of production performance indicator variables to be included in the process of identifying positive deviant farms. The target was to involve six performance indicators variables: average body weight gain, energy balance, milk yield, age at first calving, calving interval and disease-incidence density with possible maximum number of smallholder dairy farms from Hai and Tanga City districts. After cleaning all data, a total of 794 smallholder dairy farms each with a complete set of five production performance indicator variables of energy balance, milk yield, age at first calving, calving interval and disease-incidence density were available for statistical analysis. This was in addition of Moshi Rural district in low-stress and Muheza district in high-stress environments. Both Moshi Rural and Muheza districts in low- and high-stress environments were added to increase the number of study farms based on the criteria of having high concentration of dairy cattle and also were beneficiaries of the ADGG Project (Chapter Three). Average body weight gain was excluded at this stage because of having less number of smallholder dairy farms with complete dataset of this variable.

The third issue was the choice of an appropriate technique for objectively identifying positive deviant farms in a population of smallholder dairy farms in low- and high-stress dairy-production environments. Previous studies have relied on subjective methods to identify positive deviants, such as peer and expert knowledge exchanges, participatory rating and snowball sampling technique. In this case, cross-sectional survey data, expert knowledge and peer judgement approaches are integrated to identify positive deviant farms. In addition, outperformance of subjectively identified positive deviants in a population was mostly conducted on the criterion of a single performance indicator variable which introduces biasness. In contrast, objective approaches for identifying positive deviants have applied multivariate statistics including principal component analysis with cluster analysis using a set of selected performance variables to differentiate farm types. The use of multivariate statistics has the advantage of reproducibility (Musafiri *et al.*, 2020). But, the usage of many performance-indicator variables raises serious issues with multi-collinearity.

Therefore, this study deviated from such a problem through the application of an objective and quantitative Pareto-Optimality ranking technique using longitudinal data to identify truly positive deviant farms in a sample population. Pareto-Optimality ranking technique is not sensitive to multi-collinearity and avoids biasness in the identification of positive deviants (Chapter Three). However, Pareto-optimality ranking identifies a wide range of Pareto-optimal solutions including extreme cases. Solutions that perform exceptionally well for one indicator variable but poorly for other variables (Adelhart Toorop *et al.*, 2020). Confronted with such issue, Modernel *et al.* (2018) turned to expert knowledge to rule out the win-lose and lose-win farms to define the win-win farms amongst Pareto-optimal solutions. This study used individual average farm performance compared to threshold points to identify those farms that simultaneously attained above average performance in all five indicator variables from rank 1 (Chapter Three). These were labelled true positive deviant farms. To increase the number of isolated truly positive deviant farms for subsequent analysis, all farms that scored rank 2 and 3 with all other criteria held constant were selected (Table 8.1).

Table 8.1: Pareto rankings, number of observations, ranges of standardised **(Zscore)** variables per rank, positive deviants and the percentages of positive deviant farms in the population.

		Milk yield		**Energy balance**		**Age at first calving**		**Calving interval**		**Disease incidence**		**PDs**	
Rank	**Number**	Min (Zscore)	Max (Zscore)	Min (Zscore)	Max (Zscore)	Min (Zscore)	Max (Zscore)	Min (Zscore)	Max (Zscore)	Min (Zscore)	Max (Zscore)	**#**	**(%)**
1	105	-1.95519	3.84772	-4.70286	8.54042	-2.61124	1.97145	-1.63458	2.38474	-0.95088	2.92694	17	2.14
2	141	-1.83528	3.0302	-4.79304	4.22391	-2.57235	2.67365	-1.40592	3.02499	-0.95088	2.07251	5	0.63
3	166	-1.62782	2.68957	-3.80105	1.50361	-1.87231	2.88107	-1.3297	3.213	-0.95088	2.4795	5	0.63
4	149	-1.95519	2.3165	-4.49474	0.95319	-1.64544	2.89836	-1.15693	4.55447	-0.95088	1.88055	-	-
5	105	-1.70337	1.64783	-4.39721	0.21938	-1.25869	2.99775	-1.06039	3.57885	-0.95088	2.61672	-	-
6	84	-1.72274	1.25857	-2.71851	0.11756	-0.85681	2.72119	-0.76567	4.71707	-0.95088	1.92621	-	-
7	36	-1.74534	0.25527	-3.20053	-0.01902	-0.49383	2.94157	-0.49636	2.42031	-0.95088	1.67235	-	-
8	8	-1.61943	-0.10848	-2.04062	-0.34683	0.49574	2.35388	-0.24992	2.0443	-0.95088	2.23447	-	-
Total	**794**											**27**	**3.4**

Number representing the number smallholder dairy farms; PDs represent positive deviant smallholder dairy farms; Min refers to minimum; Max refers to maximum; *Z-scores* means standardized residuals (residuals divided by an estimate of their standard deviation), # means number of PDs

The design of an adequate structural framework for the research that fits the type and nature of the components or factors included in the study was the fourth issue. Study designs may involve hierarchical or cross-classifications of a number of factors each at various levels. These include the Latin square, split plot and the more general factorial designs which reflect the flexibility of analysis of variance. Detailed description of each design can be found in books such as Statistics for Veterinary and Animal Science (Petrie & Watson, 2013). Many studies have been affected by random-noise sources that naturally fall into a hierarchy such as farms and the biological variation among animals or technical variation like measurement error (Krzywinski *et al.,* 2014). However, nesting research designs allow for an evaluation of the variation introduced at each hierarchy tier in comparison to the layer below it, based on the type and nature of the data.

Nested design is a multilevel research design in which levels of one factor (farm) is hierarchically subsumed nested within levels of another factor (environment). This type of a model can be used to analyse data that have a hierarchical structure. This is because the data frequently occurs in a form of hierarchical (Field, 2009; Krzywinski *et al.,* 2014), which indicate that some variables are nested within others. Because of these reasons, this study utilised a two-stage nested research design (Chapter Three to Seven). The factors were production environment (fixed) and farm nested within production environment (random). This design suited to the objectives of this study because positive deviant farms under low-stress environment are not the same positive deviant farms under high-stress environment. This holds true for typical farms in both low- and high-stress environments. The study objectives were testing the hypothesis that positive deviant farms consistently outperform typical farms in production performance variables and deploy management practices differently from typical farms when nested within low- and high-stress environments to ameliorate local prevalent environmental stresses. Therefore, the nested research design was used to account for sources of variability in the hierarchical layers (Field, 2009; Krzywinski *et al.,* 2014).

The fifth issue was on how to deal with unbalanced sample size of positive deviants and typical smallholder dairy farms in low- and high-stress dairy-production environments. This is because the number of farms varied in positive deviants and typical farms as well as in low-stress and high-stress environments. To address this issue generalized linear mixed procedure was implemented with a nested design to handle unbalanced sample of farms in SAS software (SAS Institute Inc, 2013). This procedure also accounted for variables that could be correlated or with non-constant variability (Chapter Three to Seven) (Casals *et al.,* 2014). In this research project, study units were individual farms. This approach was consistent with earlier studies which have treated farms as their experimental units instead of individual animals (Duguma, 2020; Tempelman, 2009). For example, Duguma (2020) treated dairy farms as experimental units in the study aimed to investigate management practices and major diseases of dairy cattle in smallholdings in Ethiopian environments. Smallholder dairy farmers who owned one or more breeds of cattle were the experimental units in the study instead of animals.

The sixth issue concerned the transformation of heart girth metrics into weight-age growth measurements. Body weight of dairy cattle can be indirectly measured with a high degree of accuracy by the use of precise heart girth measurements (Busanello *et al.,* 2022; Dingwell *et al.,* 2006). However, some irregularities were noticeable with the use of formulas previously developed by Lukuyu *et al.* (2016). In this case, the formula was giving apparent unrealistic and negative body weights of heifers. For this, the study resorted to the formulas developed for Holstein-Zebu crossbred to estimate live body weights of heifers (Oliveira *et al.,* 2013).

8.1.3 Data Collection

The information about temperature and humidity levels was obtained from meteorological database that had information for local stations located in both milksheds at the regional level. Trained livestock field officers, also known as Performance Recording Agents (PRAs) equipped with Open Data Kit installed on Android tablets collected animal performance data from each farm on monthly basis. These agents collected data using a structured questionnaire that was designed to obtain information on production performance and management practices. The management practices covered animal healthcare, feeding, watering, housing, and housing construction materials, as well as dairy cattle breeds and breed compositions. Breeds and breed composition were declared by farmers, and verified by inspecting all breeding records and physical observation of each individual animal in the herd. For the purpose of computing the livelihood benefits of dairy cattle farming, additional market data on product pricing were collected from government offices as well as from published literature (Alary *et al.,* 2011; Lekasi *et al.,* 2001; Weiler *et al.,* 2014).

8.1.4 Statistical Procedures

Data analysis employed different analytical methods depending on the research question and the nature of data. This was to enable in-depth data mining for better understanding and reporting the performance of dairy cattle managed in positive deviants and typical farms under low- and high-stress dairy-production environments in Tanzania. Categorical data was cross-tabulated to generate frequencies and differences in management practices and association between factors tested with Chi-square test statistics for dairy-production environments (low- and high-stress environments) and farms (positive deviants and typical farms) (Chapter Four). For example, the correlation between watering cost and distance from the farm to reach main source of water during the dry season was tested using Pearson's correlation. Analysis of variance with mixed linear model procedure was used to estimate the mean differences for scale production performance variables (Chapter Three to Seven).

8.1.5 Identifying Positive Deviant Farms Using Pareto-Optimality Ranking Technique to Assess Productivity and Livelihood Benefits in Smallholder Dairy Farming under Contrasting Stressful Environments in Tanzania

According to temperature-humidity index (THI), dairy cattle in high-stress environment experienced mild-to-moderate heat stress than those in low-stress environment ($p<0.05$). Because THI was higher than the 72-point threshold at which dairy cattle begin to experience heat stress, the data suggest that heat stress interventions were needed to protect dairy cattle in high-stress environment. There are a variety of methods available to farmers for ameliorating heat stress in dairy cattle. These interventions include genetic selection, improved diet and watering, and environmental improvements to create microclimate inside the cow barn through adequate floor spacing per animal (Edwards-Callaway *et al.,* 2021). Study findings indicate that these techniques more benefited positive deviant farms with heat-sensitive Holstein-Friesian cattle, especially in high-stress dairy-production environment.

To objectively identify positive deviant farms operating in low- and high-stress environments, this study employed Pareto-optimality ranking technique to isolate 3.4% of positive deviants in a population that consistently outperformed typical farms despite being subjected to the same environmental pressures. When using a single performance indicator variable as the criterion, positive deviant farms make up to around 10% of the sample farms (Mayberry *et al.,* 2017), but when using multiple performance indicators, this number drops to 5% or less (Chapter Three). When Pareto-optimality ranking was applied with several performance measures supplemented with expert knowledge resulted into 1.79 percent of positive deviants (Modernel *et al.,* 2018). Farms that appear as positive deviants with several indicator variables are a better reflection of their cumulative excellent performance outcome that they effectively ameliorate environmental stresses using effective management strategies.

Dairy cattle in positive deviant farms outperformed those in typical farms in terms of production and functional traits while facing similar environmental pressures. This would imply that positive deviant farms and typical farms use management strategies to counteract environmental pressures differently. For example, a diet of balanced feed, suitably supplemented with concentrates, might be provided more to ameliorate nutritional deficit in positive deviant farms to improve productivity. Similarly, positive deviant farms had a lower disease-incidence density than their peers, suggesting that these farms were better at mitigating disease infections through effective animal-health measures. These results are consistent with those found in other studies that used THI, total energy balance, and morbidity density to evaluate environmental pressures on dairy cattle production (Ammer *et al.,* 2018).

Extended age at first calving and calving intervals observed for dairy cattle in typical farms could partly be influenced by feed scarcity and higher heat load stress in the high-stress environment. This is because for half of all standing oestrus cycles in heat stress and poor nutrition goes unnoticed, which can prolong the age at first calving and calving intervals (Nyman *et al.,* 2016). Positive deviant farms are more likely to alleviate environmental stresses, as indicated by their earlier age at first calving, shorter calving intervals, higher daily milk yields and total livelihood benefits (Chapter Three). In this context, positive deviant farms appear to implement management practices differently, thus it is vital to describe the exact measures they use to alleviate heat load, nutritional scarcity and disease infections. Reduced age at first calving to 25 months would reduce production and maintenance requirements because heifers would spend less time in the non-productive period before joining lactating herd.

8.1.6 Characterizing Management Practices in High and Average Performing Smallholder Dairy Farms under Contrasting Environmental Stresses in Tanzania

There are a number of environmental stresses that smallholder dairy farmers in the tropics must contend with. The most significant factors which directly affects dairy cattle production include feed scarcity, disease infections and heat load stresses. The livelihood benefits of dairy farming to a household becomes negatively affected as a result of these environmental challenges that limit or lower dairy cattle productivity (van der Linden *et al.,* 2015; VanLeeuwen *et al.,* 2012). The objective of this study was therefore to characterise management practices that effectively ameliorate environmental stresses of heat load, feed scarcity and disease infections in dairy cattle managed in positive deviants and typical farms under contrasting stressful dairy-production environments in Tanzania. The findings of the study showed that positive deviant farms had greater land size, larger herds of more improved dairy cattle housed in higher standard zero-grazing stall units and more space per animal than typical farms. Positive deviant farms invested significantly more on feed and water, as well as on professional animal health service (Chapter Four). Results of the study showed that these management practices distinguished positive deviants from typical farms. Positive deviant farms used these practices to reduce feed shortages, heat load pressures and disease infections, thereby improving animal welfare and productivity. These farms may be related to those that have adopted precision livestock farming systems in modern dairy cattle farming through the modification of management approaches by incorporating technological innovations that minimises animal stress and maintain higher productivity and farm sustainability (Simitzis *et al.,* 2021).

However, any modification aiming to improve productivity in smallholder dairy cattle farming systems should be planned with the total-farm perspective in cooperation with farmers for sustainability. Dogliotti *et al.* (2014) argued that the dominant transfer of technology strategy from top-down has failed to promote learning for technical innovations in most farming systems. The introduction of crop rotations, cover crops, manure applications, and beef-cattle production, for instance, was found to be a more effective approach to increase farm output with direct involvement of farmers in a model-aided project (Dogliotti *et al.,* 2014). To adapt to such complex shifts, both typical and positive deviant farmers have to be engaged in repeated cycles of learning process (Fazey *et al.,* 2018; Ruggia *et al.,* 2021). Therefore, the involvement of experienced positive deviant farmers' participation in on-farm training to promote effective ameliorative management practices could strengthen the learning cycles and the sustainability of the outcomes through a phenomenon called anchoring (Elzen *et al.,* 2012).

To facilitate dairy development in smallholder cattle farming systems, co-innovation has been shown to be an effective strategy in agricultural development programmes (Rossing *et al.,* 2021; Ruggia *et al.,* 2021). The technique conceptually merges social learning, farm monitoring for learning and complex adaptive systems theory (Ruggia *et al.,* 2021). Therefore, there are opportunities to improve smallholder dairy farms, especially the typical farms sustainability by using the co-innovation approach to change or improve management practices and adopt new technological methods (Albicette *et al.,* 2017). It is hypothesized that increased productivity and long-term viability of using improved dairy cattle genotypes in low- and high-stress production environments can be achieved through a farm-level co-innovation process involving both farmers and scientists with expertise in dairy production and farm management. In this context, extension service agents should no longer serve solely as advisers for operational-tactical decisions but rather as advocates for the entire farm planning and evaluation process to improve dairy cattle productivity in smallholder farming systems (Dogliotti *et al.*, 2014). Figure 8.1 shows a schematic diagram for identifying positive deviant farms, effective ameliorative management practices and farming content prototype for improving productivity and sustainable utilisation of dairy cattle genotypes in smallholder farming systems under stressful production environments. Boxes in the right indicate methods used in the corresponding steps from data collection through dissemination and promotion of locally identified viable ameliorative management practices for environmental stresses to improve dairy cattle productivity in smallholders.

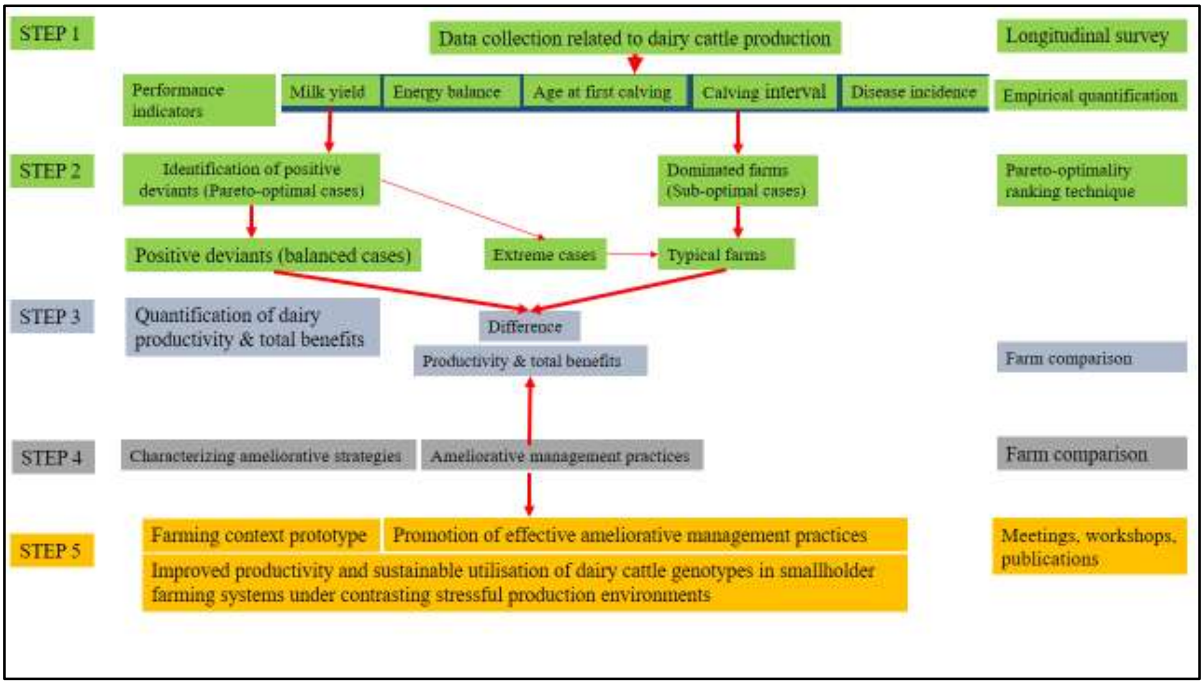

Figure 8.1: Schematic diagram followed in finding and promoting practical amelioration strategies for environmental stresses on smallholder farming systems.

The positive deviance approach and smallholder dairy cattle farming systems could be improved with the support of a follow-up study to farmers who adopt outstanding management strategies. It is hoped that further information, such as specifics on dairy management and the farming context, would be gleaned from subsequent studies, which will in turn make the sustainable prototype more usable in smallholder dairy farming systems. Potentially, the nested positive deviance strategy as applied in this study might be implemented in other significant livestock systems worldwide where a variety of sustainability issues are now being faced. Multiple-objective indicators of positive deviants might be chosen in light of the specifics of a certain community. The sustainability of dairy cattle farming systems around the world might be greatly enhanced with a more widespread implementation of the positive deviance concept, as a means that contribute towards the achievement of the United Nation's Sustainable Development Goals (Basu & Galiè, 2021).

8.1.7 Assessing Disease Prevalence and Mortality of Dairy Cattle in Smallholder Farms under Contrasting Management Practices and Stressful Environments in Tanzania

Compared to positive deviant farms, where professional animal health service providers were regularly sought, it is believed that the higher disease prevalence and cumulative incidences in typical farms can be connected with the reliance on fellow farmers for provision of animal health services (Chapter Four). This is consistent with the observations reported earlier on smallholder farmers in India who relied on untrained fellow farmers to provide veterinary services (Singh *et al.,* 2020). Farmers rarely have enough training in providing veterinary services, therefore this practice may result in drug abuse or incorrect disease diagnoses which may end up with higher mortality densities in dairy cattle.

The mortality density per 100 animal-years at risk was lower by 15.06 and 2.58 in positive deviants in low- and high-stress environments, respectively, when compared to typical farms. These results show that the use of good animal husbandry practices in positive deviant farms reduced the spread of disease and the loss of dairy animals compared to typical farms. It is clear from the lower animal mortality density in positive deviant farms in both low- and high-stress environments that the probability of death from disease-related causes was reduced in these farms, regardless of the environment. This suggests that positive deviant farms used animal husbandry techniques that more effectively reduced the probability of death to their animals, even in the case of disease infections (Alvåsen *et al.,* 2012). This was realized in positive deviant farms with closer monitoring of animal status as a result of their regular access to top-notch, skilled professional animal health services (Chapter Four).

However, positive deviance behaviour can be associated with more resources than typical farms (Chapter Four), which is vital for promoting animal health and welfare (Derks *et al.,* 2014; Ries *et al.,* 2022a). This has implications for developing animal health service system that prioritizes the needs of the poor. This is because in the event of a disease outbreak or a death in the cattle population, farms with fewer resources may be at a greater risk of losing more livestock assets. Therefore, it is imperative that government invest on infrastructure that facilitate the timely and effective provision of veterinary services (FAO, 2020; Katjiuongua &

Nelgen, 2014). After installing the necessary infrastructure, it is important also to emphasize understanding of the legal and governance system awareness to preserve those resources. Group regulations could help and should be strictly enforced in order to maintain those facilities (Makokha *et al.,* 2019).

8.1.8 Assessing Lactation Curve Characteristics of Dairy Cows Managed In Positive Deviant and Typical Smallholder Farms under Contrasting Stressful Environments in Tanzania

Understanding the pattern of milk production during lactation with the help of a lactation curve is helpful. This is because milk production follows a predictable pattern that is in part dictated by the cow's biological efficiency. In addition, lactation persistency or the rate of drop in production after peak milk yield, has a significant impact on the cost of milk production (Jingar *et al.,* 2014). When milk production declines, the rate of reduction is slower when persistency is high and faster when persistency is low. Therefore, the objective of this study was to assess lactation-curve characteristics of dairy cattle genotypes managed in positive deviants and typical farms under contrasting stressful dairy-production environments in Tanzania. The findings of the study observed in positive deviant farms in low-stress environment corroborate with earlier estimates of 13 to 15 kg/cow/day (Vu *et al.,* 2016) but lower than 16.8 kg/cow/day (Bang *et al.,* 2022) reported for Vietnamese smallholder dairy cows.

Long lactation periods were observed in this study, with an average of 428 days on milk but varying widely depending on production environment and dairy husbandry practices. Extended lactation length, which is a livelihood strategy for smallholders by ensuring a steady supply of milk for household nutrition and income (Bebe *et al.,* 2003b; Mbuthia *et al.,* 2021), explains the long lactation lengths observed in this study. Dairy farming practices that maximize the output of high-yielding cows in relatively larger herds through the supplementation of pasture-based diets across longer lactations may become more appealing in smallholders (Borman *et al.,* 2004). This necessitates modelling extended lactations in dairy cows because the majority of the study animals in the current population had lactations periods that lasted longer than 305-days. This is because extended lactations can be beneficial for low-cost pasture-based systems since they alleviate the issues associated with frequent calving (Borman *et al.,* 2004; Niozas *et al.,* 2019). Additionally, it can be applied as a substitute management technique for cows that failed to conceive within the prescribed time frame (Butler *et al.,* 2010). Given that animals maintain a high level of persistency, prolonged lactations do not necessarily result in poorer productivity, even in intensive dairy production systems (Niozas *et al.,* 2019; Österman & Bertilsson, 2003).

The greater lactation performance in positive deviant farms than typical farms and under low-stress compared to high-stress environment suggest that animal husbandry practices and production environment are significant success variables to consider when promoting high-yielding dairy cattle in smallholder dairy farms. Positive deviant farms do apply more effective management practices that mitigate the negative effects of environmental stresses such feed scarcity, heat load and disease infections (Chapter Four). Additionally, tolerant genotype matching the production environment, feeding, housing and routine animal healthcare are the most common management strategies used by positive deviant farms to reduce the effects of environmental stresses (King *et al.,* 2006; Marshall, 2014; Mbuthia *et al.,* 2021). These management practices can be linked to the higher estimates of daily milk yield, peak yield and lactation milk production observed in positive deviants than typical farms in low- and high-stress environments. Effective management practices plays a major role in maintaining maximum secretion potential in milk synthesis. For example, greater milk yields can be predicted from metrics like peak yield, which is connected with maximum secretion potential and the genetic potential of the cow, and from lower values of proportionate reduction in cell counts, which is correlated with more durable lactations and higher overall milk production (Albarrán-Portillo & Pollott, 2011). Therefore, differences in lactation curve characteristics can be attributed to the substantial impact of production environments and management strategies on dairy cattle. This highlights the need for farmers to implement suitable management and breeding strategies to maximize the advantage of maternal capacity within the breeding system.

The success of smallholder dairy cattle production has been linked to the incorporation of feed technology usage with other enhanced dairy technologies. Therefore, the megahit of dairy production in positive deviant farms could be significantly influenced by factors such as the quantity and quality of animal feeds, household networking, membership in dairy related cooperatives, level of training, willingness to invest more in dairy technologies, and larger herd size (Birhanu *et al.,* 2017; Gellynck & Kühne, 2010; Migose, 2020; Savikurki, 2013). This lends credence to the argument that dairy cooperatives should be fortified so that farmers can gain access to high-quality production supplies and services in order to reduce the negative effects of dietary deficiencies and disease infections stresses (Kilelu *et al.,* 2017; McClearn *et al.,* 2020). In addition, co-innovation initiatives that shift management practices and implement novel technologies can improve productivity and the sustainability of dairy cattle production in smallholder farming systems under stressful environments.

8.1.9 Assessing Growth Characteristics of Dairy Cattle Managed in Smallholder Farms under Low- and High-Stress Production Environments in Tanzania

The findings are indicative of the superior husbandry strategies employed by positive deviant farms to ameliorate environmental stresses in dairy cattle. Heifers raised in a low-stress environment matured at a slower rate and had lower average lifetime absolute growth rates, although they weighed more overall ($p<0.05$). The superior growth-curve characteristics of heifers in positive deviant farms compared to those in typical smallholder farms in both low- and high-stress dairy production settings may be attributable to improved feeding and healthcare management practices as well as higher blood levels of exotic genotypes (Busanello *et al.*, 2022; Oliveira *et al.*, 2013). This is in line with the findings reported in Chapter Four which shows better housing, feeding and healthcare management with higher grade of dairy cattle genotypes in positive deviant farms compared to those in typical farms in low- and high-stress environments. Further research needs to target nutritional quality of the feeds to ascertain the influence of animal feeds on growth performance of dairy cattle managed in positive deviants and typical farms under stressful environments.

Figure 8.2 represent a schematic diagram summarizing the flow of events influencing dairy cattle productivity in smallholders under contrasting stressful environments. Information flow diagram indicate that multidisciplinary approaches including breeding, nutrition, housing and healthcare are required for reducing the adverse impact of environmental stresses on the performance outcomes and sustainable utilisation of dairy cattle on smallholders under stressful environments.

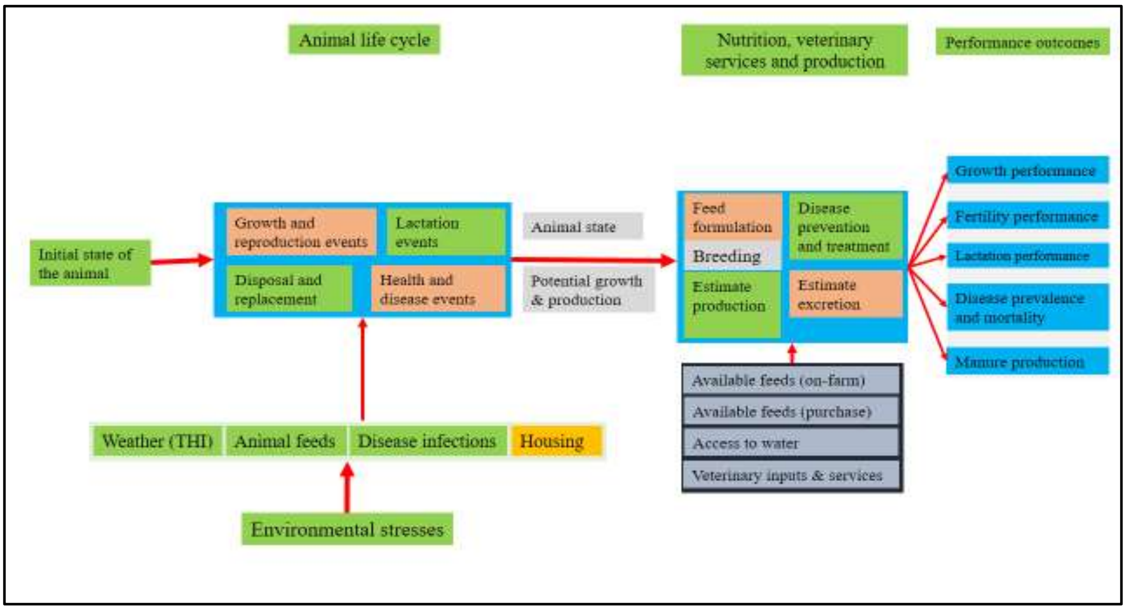

Figure 8.2: Schematic diagram of events/information flow influencing dairy cattle productivity on smallholders under contrasting stressful environments.

8.2 Conclusions

i. A few genuine positive deviant farms with higher productivity and livelihood benefits under low- and high-stress environments were discovered using the Pareto-Optimality ranking technique. Given the importance of addressing environmental stresses to dairy cattle productivity, the findings of the study suggest the need for investing more in management strategies, technologies and innovations, particularly in typical farms to improve dairy productivity levels.

ii. Cattle upgrading, larger floor spacing per animal, and increased investment in cattle housing, fodder, watering, and professional animal health services were the management strategies distinguishing positive deviants from typical farms. Better animal welfare is more often observed in positive deviant farms, and research has linked these practices to amelioration of feed scarcity, heat load strains and disease infections.

iii. Positive deviant farms had lower rates of animal health constraints than typical farms in low- and high-stress dairy-production environments. These results suggest that positive deviant farms deployed animal health management strategies more efficiently to lessen the impact of animal health constraints in dairy cattle. In this way, positive deviant farms are shown to be using management approaches differently to reduce the impact of animal disease infections stresses in their dairy herds.

iv. Higher lactation performance of dairy cattle in positive deviant farms compared to those in typical farms and in low-stress compared to high-stress environments reveals that management practices and production environment are critical aspects for increasing dairy output in smallholder farms. Positive deviant farms have adopted management measures to address feed scarcity, heat load and disease infection challenges, which led to improved lactation performance.

v. Heifers in positive deviant farms consistently exhibited heavier estimated, predicted and mature body weights than those in typical farms under low- and high-stress dairy-production environments. Improved feeding and healthcare management practices, as well as higher proportion levels of exotic dairy cattle genotypes, may account for the superior growth-curve characteristics of heifers in positive deviant farms compared to those in typical farms in both low- and high-stress dairy-production environments.

8.3 Recommendations

i. Typical farmers should learn from positive deviant farmers on how to apply husbandry practices effectively (breeding, housing, feeding and health services) to ameliorate feed scarcity, heat load stress and disease infections.
ii. Extension service departments should link typical farmers with positive deviant farmer to learn better husbandry practices.
iii. Scientists/researchers should identify positive deviant farmers objectively in order to learn from them how to apply husbandry practices effectively.
iv. Policy makers should integrate positive deviant farmers in extension services.
v. Also, policy makers should set annual budgets for strengthening cooperatives to provide affordable dairy inputs & quality extension service delivery.

8.4 Areas for Further Research

Areas that need to be prioritized for further researches are:

i. A study should be conducted to evaluate nutritive quality of animal feeds to ascertain whether investments made by positive deviant farmers in feeding is based in the quality of feeds.
ii. A study should be conducted to evaluate the benefits and consequences of extended lactations.
iii. A study should be conducted to examine the motivation of PDs in investing more in husbandry practices.

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APPENDICES

Appendix A: Clearance permit for conducting research in Tanzania

CLEARANCE PERMIT FOR CONDUCTING RESEARCH IN TANZANIA

UNITED REPUBLIC OF TANZANIA

MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGY.

SOKOINE UNIVERSITY OF AGRICULTURE
OFFICE OF THE VICE-CHANCELLOR

P.O Box 3000, CHUO KIKUU, MOROGORO, TANZANIA
Phone: +255 (023) 2640006/7/8/9, Direct Line: +255 (023) 2640015,
E-mail:vc@sua.ac.tz, Website: https://www.sua.ac.tz

Please refer to:
Our Ref: DPRTC/R.1/142/ VOL. I/109 **Date:** 5th August, 2021

The Regional Administrative Secretary,
Kilimanjaro Region,
P.O. Box 3070,
KILIMANJARO.

The Regional Administrative Secretary,
Tanga Region,
P.O. Box 5095,
TANGA.

RE: UNIVERSITY STAFF, STUDENTS AND RESEARCHERS CLEARANCE

The Sokoine University of Agriculture was established by University Act No. 7 of 2005 and SUA Charter, 2007 which became operational on 1st January 2007 repealing Act No. 6 of 1984. One of the mission objectives of the university is to generate and apply knowledge through research. For this reason, the staff and researchers undertake research activities from time to time.

2. To facilitate the research function, the Vice Chancellor of the Sokoine University of Agriculture (SUA) is empowered to issue research clearance to staff, students, research associate and researchers of SUA on behalf of the Tanzania Commission for Science and Technology.

3. The purpose of this letter is to introduce to you **Mr. Dismas Said Shija** who is a **PhD (Department of Animal Science)** student of the Egerton University, Kenya and a bonafide **Lecturer of the Sokoine University of Agriculture** (SUA). By this letter, **Mr.**

Page **1** of **2**

Dismas Said Shija has been granted clearance to conduct research in the country. The title of the research in question is "**Application of Positive Deviance Concept to asses amelioration strategies for environmental stresses on smallholder. dairy farms in Tanzania ".**

4. The period for which this permission has been granted is from **2nd August** 2021 to **30th June, 2022**. The research will be conducted in the Kilimanajro region, Hai District and Moshi Rural District and Muheza and Tanga City Districts in Tanga **region.**

5. Should some of these areas/institutions/offices be restricted, you are requested to kindly advice the researcher(s) on alternative areas/institutions/ offices which could be visited. In case you may require further information on the researcher please contact me.

6. We thank you in advance for your cooperation and facilitation of this research activity.

Yours sincerely,

VICE CHANCELLOR
SOKOINE UNIVERSITY OF AGRICULTURE
P. O. Box 3000
MOROGORO, TANZANIA

Prof. Maulid W. Mwatawala
FOR: VICE-CHANCELLOR

Copy to: Student – **Mr. Dismas Said Shija**

Appendix B: Ethical Clearance Certificate

FORM NO. 10

THE UNITED REPUBLIC OF TANZANIA
MINISTRY OF LIVESTOCK AND FISHERIES
TANZANIA LIVESTOCK RESEARCH INSTITUTE (TALIRI)

Director General, Tanzania Livestock Research Institute, Block No. 39,
P. O. Box, 834, Dodoma, Email:dg@taliri.go.tz or hq@taliri.go.tz

REF NO. TLRI/RCC.21/003

RESEARCH CLEARANCE CERTIFICATE

1. **This certificate is hereby presented to**
   DISMAS SAID SHIJA

   Title of the proposed research
   Application of Positive Deviance Concept to assess amelioration strategies for environmental stresses on Smallholder dairy Farms in Tanzania.

2. **General objective of the Research**
   To contribute to improved productivity and sustainable utilization of dairy cattle on smallholder dairy farms through learning from positive deviant farms (PDF) in contrasting stressful production environments of proven amelioration strategies to promote to other smallholders.

3. **Study area:**
   i. KILIMANJARO REGION: Hai and Moshi Rural district Councils
   ii. TANGA REGION: Muheza and Tanga City District Councils

4. **Starting date:** 2nd August 2021

5. **Ending date:** 30th August 2022

Signature of the Director General: [signature] Date: 2nd August 2021

DIRECTOR GENERAL
TALIRI

Appendix C: Identifying Positive Deviant Farms Using Pareto-Optimality Ranking Technique to Assess Productivity and Livelihood Benefits in Smallholder Dairy Farming under Contrasting Stressful Environments in Tanzania (ANOVA Tables)

Average milk yield (litre per cow per day) of dairy cows managed in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	6881.30	2293.77	168.84	<0.0001
Error	13556	184163.09	13.59		
Corrected Total	13559	191044.38			

Crude disease incidence density per 100 animal-years at risk in dairy cattle managed in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	11530.88	3843.63	23.04	<0.0001
Error	790	131782.58	166.81		
Corrected Total	793	143313.46			

Appendix D: Characterizing Management Practices in High and Average Performing Smallholder Dairy Farms under Contrasting Environmental Stresses in Tanzania (ANOVA Tables)

Stall floor spacing per animal (m^2/cow) in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	507.99	169.33	7.48	<0.0001
Error	333	7543.03	22.65		
Corrected Total	336	8051.02			

Land size (acres) in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	694.05	231.35	11.09	<0.0001
Error	333	6946.58	20.86		
Corrected Total	336	7640.63			

Appendix E: Assessing Animal Disease Prevalence and Mortality in Smallholder Dairy Farms under Contrasting Management Practices and Stressful Environments in Tanzania (ANOVA Tables)

Crude disease prevalence per 100 animal-years at risk in dairy cattle managed in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	141253.31	47084.44	23.04	<0.0001
Error	790	1614336.62	2043.46		
Corrected Total	793	1755589.93			

Cummulative disease incidence rate in dairy cattle managed in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	8711.27	2903.76	23.47	<0.0001
Error	790	97759.41	123.75		
Corrected Total	793	106470.68			

Appendix F: Assessing Lactation Curve Characteristics of Dairy Cows Managed Under Contrasting Husbandry Practices and Stressful Environments in Tanzania (ANOVA Tables)

Observed milk daily milk yield for Holstein-Friesian cows managed in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2496.92	832.31	55.51	<0.0001
Error	2734	40990.07	14.99		
Corrected Total	2737	43486.10			

Predicted milk daily milk yield for Holstein-Friesian cows managed in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2258.19	752.73	47.36	<0.0001
Error	2734	43457.53	15.90		
Corrected Total	2737	45715.72			

Total lactation milk production (305-days) for Holstein-Friesian cows managed in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	178861056	59620352	69.42	<0.0001
Error	2734	2347916817	858784		
Corrected Total	2737	2526777874			

Appendix G: Assessing Growth-Curve Characteristics of Dairy Cattle Heifers Managed In Smallholder Farming Systems under Contrasting Stressful Dairy-Production Environments in Tanzania (ANOVA Tables)

Observed body weight of dairy cattle in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	263321.61	87773.87	10.79	<0.0001
Error	1476	12003242.60	8132.28		
Corrected Total	1479	12266564.22			

Predicted body weight of dairy cattle in positive deviants and typical farms under contrasting environments obtained by fitting a two factor nested design model.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	263959.25	87986.42	10.90	<0.0001
Error	1476	11919588.05	8075.60		
Corrected Total	1479	12183547.31			

Appendix H: Abstract of published paper on objective one

world

MDPI

Article

Identifying Positive Deviant Farms Using Pareto-Optimality Ranking Technique to Assess Productivity and Livelihood Benefits in Smallholder Dairy Farming under Contrasting Stressful Environments in Tanzania

Dismas Said Shija [1], Okeyo A. Mwai [2], Perminus Karubiu Migwi [1], Daniel M. Komwihangilo [3] and Bockline Omedo Bebe [1,*]

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Abstract: In smallholder dairy-cattle farming, identifying positive deviants that attain outstanding performance can inform targeted improvements in typical, comparable farms under similar environmental stresses. Mostly, positive deviants are identified subjectively, introducing bias and limiting generalisation. The aim of the study was to objectively identify positive deviant farms using the Pareto-optimality ranking technique in a sample of smallholder dairy farms under contrasting stressful environments in Tanzania to test the hypothesis that positive deviant farms that simultaneously outperform typical farms in multiple performance indicators also outperform in yield gap, productivity and livelihood benefits. The selection criteria set five performance indicators: energy balance ≥ 0.35 Mcal NEL/d, disease-incidence density ≤ 12.75 per 100 animal-years at risk, daily milk yield ≥ 6.32 L/cow/day, age at first calving ≤ 1153.28 days and calving interval ≤ 633.68 days. Findings proved the hypothesis. A few farms (27: 3.4%) emerged as positive deviants, outperforming typical farms in yield gap, productivity and livelihood benefits. The estimated yield gap in typical farms was 76.88% under low-stress environments and 48.04% under high-stress environments. On average, total cash income, gross margins and total benefits in dairy farming were higher in positive deviants than in typical farms in both low- and high-stress environments. These results show that the Pareto-optimality ranking technique applied in a large population objectively identified a few positive deviant farms that attained higher productivity and livelihood benefits in both low- and high-stress environments. However, positive deviants invested more in inputs. With positive deviant farms objectively identified, it is possible to characterise management practices that they deploy differently from typical farms and learn lessons to inform the uptake of best practices and extension messages to be directed to improving dairy management.

Keywords: smallholder dairy; positive deviants; Pareto-optimality ranking; multiple indicators; yield gap; productivity; livelihood benefits

Citation: Shija, D.S.; Mwai, O.A.; Migwi, P.K.; Komwihangilo, D.M.; Bebe, B.O. Identifying Positive Deviant Farms Using Pareto-Optimality Ranking Technique to Assess Productivity and Livelihood Benefits in Smallholder Dairy Farming under Contrasting Stressful Environments in Tanzania. *World* **2022**, 3, 639–656. https://doi.org/10.3390/world3030035

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1. Introduction

Smallholder dairy farming has multifunctional livelihood roles and benefits in rural households. Smallholders integrate subsistence and market objectives in their production systems [1]. In Tanzania, for instance, dairy cattle provide nutrition and food security for household wellbeing, income for cash needs, and manure used in restoring soil fertility for crop production. Furthermore, cattle are live assets which households can liquidify in emergency or hold to accumulate wealth and gain the benefits of financing and insurance roles [2,3].

However, there are large variations in the extent to which households derive livelihood roles and benefits from dairy cattle farming. This is because dairy-cattle genotypes

World **2022**, 3, 639–656. https://doi.org/10.3390/world3030035 https://www.mdpi.com/journal/world

Appendix I: Abstract of published paper on objective two

world

MDPI

Article

Characterizing Management Practices in High- and Average-Performing Smallholder Dairy Farms under Contrasting Environmental Stresses in Tanzania

Dismas Said Shija [1,*], Okeyo A. Mwai [2], Perminus K. Migwi [1], Raphael Mrode [2] and Bockline Omedo Bebe [1]

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[*] Correspondence: dismas.shija@sua.ac.tz; Tel.: +255-786-444-700

Abstract: This study characterized breeding, housing, feeding and health management practices in positive deviants and typical average performing smallholder dairy farms in Tanzania. The objective was to distinguish management practices that positive deviant farms deploy differently from typical farms to ameliorate local prevalent environmental stresses. In a sample of 794 farms, positive deviants were classified on criteria of consistently outperforming typical farms ($p < 0.05$) in five production performance indicators: energy balance ≥ 0.35 Mcal NEL/d; disease-incidence density ≤ 12.75 per 100 animal-years at risk; daily milk yield ≥ 6.32 L/cow/day; age at first calving ≤ 1153.28 days; and calving interval ≤ 633.68 days. The study was a two-factor nested research design, with farms nested within the production environment, classified into low- and high-stress. Compared to typical farms, positive deviant farms had larger landholdings, as well as larger herds comprising more high-grade cattle housed in better quality zero-grazing stall units with larger floor spacing per animal. Positive deviants spent more on purchased fodder and water, and sourced professional veterinary services ($p < 0.001$) more frequently. These results show that management practices distinguishing positive deviants from typical farms were cattle upgrading, provision of larger animal floor spacing and investing more in cattle housing, fodder, watering, and professional veterinary services. These distinguishing practices can be associated with amelioration of feed scarcity, heat load stresses, and disease infections, as well as better animal welfare in positive deviant farms. Nutritional quality of the diet was not analyzed, for which research is recommended to ascertain whether the investments made by positive deviants are in quality of feeds.

Keywords: breeding practices; feed cost; healthcare cost; positive deviants; stressful production environment

Citation: Shija, D.S.; Mwai, O.A.; Migwi, P.K.; Mrode, R.; Bebe, B.O. Characterizing Management Practices in High- and Average-Performing Smallholder Dairy Farms under Contrasting Environmental Stresses in Tanzania. *World* **2022**, *3*, 821–839. https://doi.org/10.3390/world3040046

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1. Introduction

Smallholder dairy farming in the tropics is practiced under multiple and variable environmental stresses, of which prevalent are feed scarcity, disease infections and heat load stresses. These environmental stresses either limit or reduce dairy productivity [1,2], and subsequently impact on livelihood benefits of dairy farming to the households. For improving smallholder livelihoods, it becomes necessary to identify management practices that enable farmers to ameliorate prevalent environmental stresses and minimize the resultant limitation or reduction in dairy productivity. Development agencies have invested in identifying and scaling appropriate management practices, which smallholder farmers can deploy to ameliorate the prevalent environmental stresses [3]. Of importance are management practices that farmers can adopt or adapt in their local production systems to attain livelihood benefits from dairy farming [2,4,5].

Positive deviance is an approach gaining importance in identifying management practices deployed to ameliorate local prevalent environmental stresses under similar production circumstances. In a given population, success in ameliorating local environmental stresses is associated with a few farmers exhibiting positive deviant behavior. The positive

Appendix J: Abstract of published paper on objective three

Scientific Research Publishing

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Assessing Animal Disease Prevalence and Mortality in Smallholder Dairy Farms under Contrasting Management Practices and Stressful Environments in Tanzania

Dismas Said Shija[1*], Mwai A. Okeyo[2], Perminus K. Migwi[1], Neema Joseph Kelya[2], Bockline Omedo Bebe[1]

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Abstract

In dairy farming, deploying effective animal husbandry practices minimise disease infections and animal mortality. This improves animal health and welfare status, which is important in tropical smallholder dairy farming, where animals are persistently exposed to multiple environmental stresses. The hypothesis of this study was that animals managed in positive deviants and typical farms suffer different levels of disease infections and mortality, whether under low- or high-stress environments. The study adopted a two-factor nested design with farms contrasting in the level of animal husbandry (positive deviants and typical farms) nested within environments contrasting in the level of environmental stresses (low- and high-stress). A total of 1,999 animals were observed over 42 month period in the coastal lowlands and highlands of Tanzania. The disease prevalence was lower ($p < 0.05$) in positive deviant farms than in typical farms under low-stress (10.13 vs. 33.61 per 100 animal-years at risk) and high-stress (9.56 vs. 57.30 per 100 animal-years at risk). Cumulative disease incidence rate was also lower ($p < 0.05$) in positive deviant farms than in typical farms under low-stress (2.74% vs. 8.44%) and high-stress (2.58% vs. 14.34%). The probability of death for a disease infected dairy cattle was relatively lower in positive deviant farms compared to typical farms under low-stress (0.57% vs. 8.33%) and high-stress (0.60% vs. 6.99%). Per 100 animal-years at risk, the mortality density of cattle was lower ($p < 0.05$) in positive deviant farms compared to typical farms, 15.10 lower in low-stress and 2.60 lower in high-stress. These results show that compared to typical farms, positive deviant farms consistently attained (p

< 0.05) lower animal disease infections and subsequent deaths, regardless of the level of environmental stress that the animals were exposed to. This implies that positive deviant farms deployed animal husbandry practices that more effectively minimised animal disease infections and deaths and therefore could maintain their animals in better health and welfare status.

Keywords

Dairy Cattle, Disease Infections, Case-Fatality Rate, Animal Mortality Density, Positive Deviants, Tropics

1. Introduction

Disease prevalence and mortality rates are metrics relevant in monitoring the animal health status in a dairy herd. In addition, these metrics have an influence on animal well-being and farm profitability [1] [2]. Disease infections and mortality in a dairy herd can account for significant economic loss from losses in financial, wealth, nutrition, improved genetic materials and investment. Disease exposure and infections contribute to reduced productivity levels attainable in smallholder dairy cattle farming. In chronic and severe incidences, disease exposure and infections lead to huge yield gaps [3] [4] and subsequent loss of livelihood benefits to households [5].

Involuntary loss of heifer calves before calving increases the need for externally sourced heifer replacements to offset the loss of potential replacements [1]. In young stock, disease infections can lead to suboptimal performance in later adult age, including older age at first calving [6], but also increased risk of exiting the herd before first calving [7]. Disease infections causing mortality are variable between management practices that farmers deploy, production systems and production environments [8]. In dairy cattle, up to 31.0% morbidity rate and 58.4% mortality rate have been reported [9] and variations occur between production environments, depending on the magnitude of stress to animals [10] [11] [12].

The magnitude of economic loss value experienced in smallholder dairy farming can be substantial, with adverse impacts on the livelihood benefits [13]. This necessitates estimating disease prevalence rates and associated animal mortality rates to inform animal health interventions. Good animal health status is a determinant of productivity and livelihood benefits in a dairy herd [14]. However, keeping a herd in good health status comes with increased investments in quality housing, feeds and animal health services as has been observed by Shija *et al.* [15] and Schumacher [16].

In studying distinguishable management practices between positive deviants and typical farms, Shija *et al.* [15] observed that positive deviant farms deployed management practices differently from typical farms. The authors also observed that cattle were exposed to higher levels of heat stress in a high-stress environ-

Appendix K: Abstract of published paper on objective four

world

MDPI

Article

Assessing Lactation Curve Characteristics of Dairy Cows Managed under Contrasting Husbandry Practices and Stressful Environments in Tanzania

Dismas Said Shija [1,2,*], Okeyo A. Mwai [3], Julie M. K. Ojango [3], Daniel M. Komwihangilo [4] and Bockline Omedo Bebe [1]

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Abstract: The ability of smallholder dairy farming systems (SHDFS) to achieve desirable lactation-curve characteristics is constrained or reduced by environmental stresses. Under stressful production environments in the tropics, the better lactation-curve characteristics in smallholder dairy farms are a result of improved dairy genetics and husbandry practices. Better husbandry practices improve animal health and welfare status, which is important to sustain SHDFS in the tropics where dairy cattle are constantly exposed to multiple environmental stresses of feed scarcity, disease infections and heat load. In this case, lactating cows in smallholder dairy farms labelled positive deviants are expected to express lactation curve characteristics differently from typical farms, regardless of the stress levels confronted. Thus, this study tested this hypothesis with Holstein–Friesian and Ayrshire cows in two milksheds in Tanzania classified them into low-and high-stress environments. A two-factor nested research design was used, with farm (positive deviant and typical) nested within the environment. Positive deviant farms were farms that performed above the population average, attaining ≥0.35 Mcal NE_L/d energy balance, ≥6.32 L/cow/day milk yield, ≤1153.28 days age at first calving, ≤633.68 days calving interval and ≤12.75 per 100 animal-years at risk disease-incidence density. In this study, a total of 3262 test-day milk production records from 524 complete lactations of 397 cows in 332 farms were fitted to the Jenkins and Ferrell model to estimate lactation curve parameters. In turn, the outcome parameters *a* and *k* were used to estimate lactation curve characteristics. The lactation curve characteristic estimates proved the study hypothesis. Regardless of the stress levels, cows in positive deviant farms expressed lactation curve characteristics differently from cows managed in typical farms. The scale (*a*) and shape (*k*) parameters together with peak yield and time to peak yield indicated higher lactation performance in positive deviant farms than in typical farms under low- and high-stress environments ($p < 0.05$). Lactation persistency was higher in positive deviants than typical farms by 14.37 g/day and 2.33 g/day for Holstein–Friesian cows and by 9.91 g/day and 2.16 g/day for Ayrshire cows in low- and high-stress environments. Compared to cows managed in typical farms, cows in positive deviant farms attained higher lactation performance under low- and high-stress; Holstein–Friesian produced 50.2% and 36.2% more milk, respectively, while Ayrshire produced 52.4% and 46.0% more milk, respectively. The higher milk productivity in positive deviant farms can be associated with the deployment of husbandry practices that more effectively ameliorated feed scarcity, heat load and disease infections stresses, which are prevalent in tropical smallholder dairy farms.

Keywords: lactation curve parameters; productivity; positive deviants; production environment; smallholder dairy farming systems

check for updates

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Appendix L: Abstract on objective five accepted for the 8th All Africa Conference on Animal Agriculture

Dismas Said Shija <dismas.shija@sua.ac.tz>

AACAA8 2023 Abstract acceptance email

9 messages

Vetlink <support@vetlink.co.za> 5 June 2023 at 10:03
Reply-To: support@vetlink.co.za
To: dismas.shija@sua.ac.tz

Dear Shija, Dismas Said

We are pleased to inform you that your abstract entitled **Assessing growth-curve characteristics of dairy cattle heifers managed under contrasting husbandry practices and stressful environments in smallholder farms in Tanzania** has been accepted for the 8th All Africa Conference on Animal Agriculture.

Please note that the **format** of your presentation (Oral or Poster) will be confirmed no later than 30 June. Any withdrawals must be in writing and reach the committee by 30th June 2023

ACTION REQUIRED

Attend to the reviewer's comments and submit a final copy of the abstract within 7 days from the receipt of this mail. https://docs.google.com/document/d/1Lm66ztrL-Up46-saXOPuxD0L6hqkHSta/edit?usp=share_link&ouid=116869824295255161118&rtpof=true&sd=true

Register for the conference to confirm your participation by 26 June 2023 (close of early bird registration). For registration, please visit the conference website (https://aacaa8.com).

Complete your Speaker Agreement by 30 June 2023 -(https://vetlink.plutio.com/p/form/Mga9TfvxmCD6QKW5p)

IMPORTANT DATES
Abstract revision: As soon as possible
Registration and speaker agreement 26 June
Submission of Powerpoint: 1 September (instructions here: https://aacaa8.com/speaker-guidelines/)

On behalf of the Organising Committee and the Scientific Committee, I wish you a successful preparation and we look forward to seeing you in Gaborone in September.
Best regards,

AACAA8 Scientific Committee

Dismas Said Shija <dismas.shija@sua.ac.tz> 5 June 2023 at 14:22

Assessing growth-curve characteristics of dairy cattle heifers managed under contrasting husbandry practices and stressful environments in smallholder farms in Tanzania

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Abstract: In smallholder farming systems, dairy cattle typically attain suboptimal growth due to several environmental stresses. However, animal growth performance in some farms exposed to similar environmental stresses might be optimal when farmers exhibit positive deviance behaviour, thus outperforming their peers with typical behaviour. The observed difference in performance is attributable to deployment of husbandry practices that ameliorate environmental stresses of heat load, nutritional scarcity and disease infections. This study assessed the extent to which mature body weight, time-scale parameter, maturity rate and average lifetime absolute growth rate of heifers differs between those reared in positive deviants and typical farms under low- and high-stress dairy-production environments in Tanzania. Positive deviant farms had been isolated on the criteria of performing above the population average, set at ≥0.35 Mcal NE_L/d energy balance, ≤12.75 per 100 animal-years at risk disease-incidence density, ≥6.32 L/cow/day milk yield, ≤1153.28 days age at first calving, and ≤633.68 days calving interval. A two-factor nested research design was adopted in which farm was nested within contrasting stress environments (low- and high-stress). Body weights of dairy heifers were estimated based on heart-girth measurements. Weight-age-data on a total of 199 heifers reared in 158 smallholder dairy farms was fitted to Brody model to estimate growth curve characteristics. Results showed that heifers in low-stress and positive deviant farms had significantly larger body weights compared to those in high-stress and typical farms ($p<0.05$). Results revealed that heifers in positive deviant farms had consistently heavier mature body weight than those in typical farms (443.82±21.50 kg vs. 348.38±5.40 kg and 391.00±32.61 kg vs. 318.35±10.51 kg) under low- and high-stress environments. Heifers in low-stress environment attained heavier mature body weight ($p<0.05$) with lower maturity rates and average lifetime absolute growth rates than those in high-stress environment. Results of this study showed that heifers managed in positive deviant farms attained better growth-curve characteristics than those in typical farms under low- and high- stress environments, suggesting that positive deviant farms implemented more effective husbandry practices to ameliorate environmental stresses experienced in their farms. This provide evidence-based solutions from successful positive deviant farms for extension services to learn how husbandry practices can be deployed differently to improve growth performance for sustainable dairy production.

Keywords: high-stress environment, husbandry practices, low-stress environment, mature body weight, maturity rate, average lifetime absolute growth rate, smallholder dairy farms

Appendix M: Visiting smallholder dairy cattle farms under stressful environments

Holstein-Friesian genotype managed in a typical farm.

A typical farm keeping mixed dairy cattle genotypes.