PREFERENCES AND WILLINGNESS TO USE INSECT-BASED LIVESTOCK FEED AMONG SMALLHOLDER DAIRY FARMERS IN MURANG'A COUNTY, KENYA

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Preferences and Willingness to Use Insect-Based Livestock Feed Among Smallholder Dairy Farmers in Murang'a County, Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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DEDICATION

This thesis is dedicated to my parents, spouse and siblings for their prayers, constant encouragement and unceasing support throughout my study period.

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LIST OF ACRONYMS

AEZ	Agro-ecological zone
ANOVA	Analysis of variance
ASC	Alternative specific constant
ATT	Attitude
BI	Behavioural control
BSF	Black Soldier Fly
CP	Crude protein
FAO	Food and Agriculture Organization
FGD	Focus group discussion
FIES	Food Insecurity Experience Scale
FM	Fish meal
GDP	Gross Domestic Product
HC	House cricket
HMM	Housefly Maggot meal
ICIPE	International Centre of Insect Physiology and Ecology
IFAD	International Fund for Agricultural Development
IGAD	Intergovernmental Authority on Development
IIA	Independent of irrelevant alternatives
KES	Kenya shillings
KII	Key informant interview
LFSES	Livestock Feed Security Experience Score
LM	Locust meal
MC	Mormon cricket
MoALD	Ministry of Agriculture and Livestock Development
MW	Meal worm
MWTP	Marginal willingness to pay
PBC	Perceived behavioural control
PCA	Principal Component Analysis

SM	Soy meal
SN	Subjective norm
SP	Silkworm pupae
SPD	Silkworm pupae defatted
SSA	Sub-Saharan Africa
TPB	Theory of planned behaviour
TRA	Theory of reasoned action
UM1	Upper midland 1
UM2	Upper midland 2
UM3	Upper midland 3
UNICEF	United Nations Children's Fund
WFP	World Food Programme
WHO	World Health Organization
WTP	Willingness to pay

ABSTRACT

Limited access to good quality and adequate feeds presents a severe constraint to livestock production across developing countries. To address this challenge, researchers, policymakers and practitioners are encouraging the use of non-conventional feed sources rich in protein. Insects have been promoted as an alternative source of protein to feed livestock. However, its production and utilization are still limited among sub-Saharan African feed manufacturers and livestock producers. Understanding smallholder livestock farmers' preferences and uptake of alternative feed sources is necessary to inform policymakers and feed manufacturers in scaling up and commercializing insect-based livestock feed. The study characterized the livestock feed systems. It also assessed farmers' willingness to use insect-based livestock feed and their preferences for livestock feed attributes. The study was carried out in three agro-ecological zones in Murang'a County in Kenya. The study used a multistage sampling design to draw a random sample of 378 respondents. A structured questionnaire, a choice experiment tool, key informant interviews and focus group discussions were used for data collection. Descriptive statistics were used to characterize the feed systems. A hetprobit model was used to assess farmers' willingness to use insect-based livestock feed. While a mixed logit model was used to assess farmers' preferences for livestock feed attributes. The study results indicated that the common feed types utilized in the dairy systems were nappier grass, crop residues and concentrate feeds. However, the protein concentrates were utilized by a small proportion of farmers. Significant challenges to dairy farming were high cost and unreliable quality of commercial concentrate feeds and limited access to good quality forage during the dry season. Results of the hetprobit model revealed that attitudes, subjective norms, perceived behavioural control, age, access to extension service, herd size and wealth status were positively associated with farmers' willingness to use insect-based feed. While farming experience and gender (being a male-headed household) negatively influenced farmers' willingness to use insect-based feed. The mixed logit results revealed farmers' positive preferences for lower-priced and branded feed products, and the potential of feed products to increase milk yield. In contrast, farmers had negative preferences for source of energy from cassava and source of protein from insects. The model analysis further indicated that household size, income and group membership significantly determined farmers' preferences for livestock feed attributes. The study concluded that the sampled dairy farmers were interested in the uptake of insects as an alternative source of livestock feed. The study recommends training to farmers on the benefits of using insect-based feed in livestock production; provision of incentives to minimize feed costs and improve feed quality for livestock farmers; need to strengthen service providers such as extension, and build capacity of farmer groups to facilitate mass training and information access on the utilization of insect-based feeds.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The livestock sector makes an essential contribution to the economies of most Sub-Saharan African (SSA) countries (Baltenweck *et al*., 2020). In Kenya, the livestock sector accounts for approximately 12 percent of the national Gross Domestic Product (GDP) and about 40 percent of the agricultural GDP (Republic of Kenya, 2020). The sector also employs about 50 percent of the agricultural labour force in the country. For most rural resource-poor farmers, livestock production is an essential source of food, income, collateral for credit, draught power and manure for crop production (Njarui *et al*., 2016a). In addition, the sector plays a vital role in addressing the rising need for animal proteins owing to rapid population growth and urbanization (Balehegn *et al*., 2020).

However, the livestock sector's productivity in Kenya faces several constraints that hinder it from realizing its full potential. These constraints include limited access to quality and adequate feeds, limited access to input and output markets, diseases, unstable climatic conditions, low productivity, poor genetic potential, weak policies and institutional environment, among others (African Union- Inter-African Bureau for Animal Resources (AU-IBAR), 2015; Republic of Kenya, 2020). Of these constraints, limited access to quality and adequate feeds represents the most significant constraint faced by smallholder livestock farmers in the country (Paul *et al*., 2020; Tegemeo Institute of Agricultural Policy and Development, 2021).

In Kenya, the primary livestock feed resources for the ruminant stock include natural pastures, cultivated forages, crop residues and concentrate feeds (which are used to supplement the pastures and forages) (Kiptot *et al*., 2015; Republic of Kenya, 2020). Among the feed resources, pastures and forages account for a more considerable

proportion of the livestock feed and dominate most intensive and semi-intensive ruminant production systems (Alaru *et al*., 2023; Jimma *et al*., 2016). However, these feeds are characterized by significant variability in quality, availability and seasonality due to their reliance on rainfall and other agro-ecological factors that differ on a regional basis (Jimma *et al*., 2016; Njarui *et al*., 2016b). The fluctuation in quality and quantity results in feed deficits mainly during the dry seasons (feed available during the dry season is often low in protein besides insufficient nutrients) (Njarui *et al*., 2016b). This underlines the importance of supplementation to meet the production and reproduction of nutrient demands (Umutoni *et al*., 2015).

Concentrate feeds have been used to supply nutrients during pastures and forage scarcity. Soybean meal, cotton seed, fish meal and sunflower seeds are used to provide protein, while grains- maize, wheat and barley- supply energy in the supplemental diets (Republic of Kenya, 2020). Currently, soybean and fish meal are the main protein feeds that supplement the livestock diet (van Huis, 2022), with global estimates indicating that about 10 per cent of the world's soybean production and 85 per cent of fisheries are processed into livestock feed (Ssepuuya *et al*., 2017; van Huis, 2022).

However, availability of these protein and energy feed supplements is challenging in the face of competition with other human and industrial use. As an example, marine overexploitation of fish stocks for direct human consumption continues to negatively impact the availability of the small pelagic forage fish (such as silver cyprinid *Rastrineobola argentea*, in Kenya, commonly referred to as "omena') from which fishmeal is derived (Mutisya *et al*., 2021). While the availability of land for soybean cultivation is diminishing globally due to competition with human food production (Onsongo *et al*., 2018; van Huis, 2022). Similarly, the sustainability of cereal grains production as critical sources of energy feed supplements is questionable, considering their high demand for human consumption and as raw material for various industrial uses (Gachuiri and Lukuyu, 2021; Morgan and Choct, 2016).

The growing scarcity of livestock feed ingredients is reflected in their erratic supply and high market prices, leading to high production costs for most smallholder livestock farming systems (Balehegn *et al*., 2020; Ssepuuya *et al*., 2017). This is in addition to the high competition with humans, which has been identified as a concern that increases food insecurity (Dicke, 2018). According to Chia *et al*. (2020) and Ssepuuya *et al*. (2017), feed costs alone account for up to 80 per cent of the total cost of livestock production. Furthermore, this situation is exacerbated by a weak regulatory environment which contributes to the presence of highly-priced commercial feeds of poor quality in the feed market (AU-IBAR, 2015).

In recognition of the challenges mentioned, the government of Kenya, through the Ministry of Agriculture and Livestock Development (MoALD), has formulated several policies, including the National Livestock Policy of 2020. The policy recognizes the economic importance of improved access to quality and adequate feed and encourages diversification into alternative feed sources (Republic of Kenya, 2020). The utilization of alternative protein and energy sources of feed to replace conventional feed sources such as soybean, fish meal, and cereal grains in livestock production is gaining increased recognition, as noted from an analysis of existing literature.

For example, studies by Ssepuuya *et al*. (2017), Khan (2018) and van Huis (2022) have reported using insects such as black soldier fly, housefly, mealworm, grasshopper, cricket, silkworm, cockroach and termite as potential alternative protein sources to soy and fish meal in livestock diets. These studies noted that using insects as feed is more beneficial than conventional protein sources (soy and fish meal). First, insects grow and reproduce quickly, utilizing less feed, land, water and capital. Insects also utilize organic waste, which has been identified as a public health hazard (Ssepuuya *et al*., 2017). Thirdly, insects are rich sources of proteins, and in some instances, their protein content is higher than that of soy and fish meal (Khan, 2018). Table 1.1 presents different insects' crude protein (CP) content compared to fish and soy meal.

Table 1.1: Crude protein in insect meals vis-a-vis fish and soy meal

	Source[1]									
Constituent	BSF	HMM	MW	LM	HC	MC	SP	SPD	FM	SM
Crude protein (% DM)	42.1 (56.9)	50.4 (62.1)	52.8 (82.6)	57.3 (62.6)	63.3 (76.5)	59.8 (69.0)	60.7 (81.7)	75.6	70.6	51.8

Source[1]: Insects meals as animal feed (Alfiko *et al*., 2022; Makkar *et al*., 2014): Values in parentheses are calculated values of the defatted meals; BSF; Black Soldier Fly, HMM; Housefly Maggot meal, MW; Meal worm, LM; Locust meal, HC; House cricket, MC; Mormon cricket, SP; Silkworm pupae, SPD; Silkworm pupae defatted FM; Fish meal, SM; Soy meal

Table 1.1 shows that the CP content of insects is high and ranges from 42 to 63 per cent, comparable to the CP of soy meal though slightly lower than that of fish meal. However, the CP in the defatted meal is higher than the CP in both soy and fish meal and could replace soy and fish meal as a rich source of protein in livestock diets (Alfiko *et al*., 2022; Makkar *et al*., 2014).

Despite policy acknowledgement for diversification into potential alternative feed sources, including insect-based livestock feed, there needs to be more effort directed towards their commercialization in Kenya. Generally, the production and utilization of livestock feed formulated with insects is still at an experimental scale among farmers and local feed producers (Chia *et al*., 2020; Okello *et al*., 2021; Ssepuuya *et al*., 2017). Additionally, livestock feed formulation with insects has paid much attention to the black soldier fly with little focus on crickets (van Huis, 2022), which is the focus of the present study. Therefore, there is a need to support the scaling up and commercialization of potential alternative protein and energy feed sources. For this to be successful, it requires understanding the existing feed systems in terms of (production systems, types of feed resources, sourcing arrangements, seasonality of feed, expenditure on feed and livestock feed security), including the preferences and trade-offs livestock farmers make when choosing feed products.

This study was carried out to determine smallholder dairy farmers' willingness to use insect-based livestock feed, as well as their preferences for livestock feed attributes (source of protein, source of energy, brand of feed product, effect of product on yield and price) using Murang'a County in Kenya as a case study. The findings would inform

various stakeholders, including the private sector concerning willingness of farmers to substitute existing feeds with alternatives.

1.2 Statement of the problem

Livestock is critical to incomes, nutrition, food security and sustainable livelihoods in smallholder production systems in Kenya (Republic of Kenya, 2020). However, the potential of livestock as a driver for economic growth in Kenya is hindered by various constraints, of which limited access and high cost of good quality livestock feed is the most critical constraint to improving livestock productivity in the country (AU-IBAR, 2015; Paul *et al*., 2020). In smallholder production systems across Kenya, feeds and feeding related problems are often cited as the most important constraints to livestock production (Balehegn *et al*., 2020; Kiptot *et al*., 2015). This is the case that much of the existing feed sources or ingredients rely on the shifts in weather patterns and have competing uses with humans for food production, and industries for raw materials (Dicke, 2018; Republic of Kenya, 2020).

As a result, the country through the MoALD is promoting diversification of the livestock feed base and research on alternative sources of feed to address the feed challenges (Republic of Kenya, 2020). Utilization of alternative sources of feed is extensively gaining increased recognition in literature (Chia *et al*., 2020; Mutisya *et al*., 2021; Okello *et al*., 2021; Ssepuuya *et al*., 2017; van Huis, 2022). These studies (Chia *et al*., 2020; Mutisya *et al*., 2021; Okello *et al*., 2021; Ssepuuya *et al*., 2017; van Huis, 2022) recognize the use of insects as an alternative source of feed rich in proteins in livestock diets.

In Kenya, efforts seeking to support commercialization of insects as an alternative source of livestock feed are being effected (Chia *et al*., 2020; Okello *et al*., 2021). These efforts are mainly driven by research institutions (International Centre of Insect Physiology and Ecology (ICIPE) and higher-learning institutions) and have largely focused on growth performance of livestock fed on insects, profitability of using insects

as livestock feed and farmers' acceptance of insect-based livestock feeds (Chia *et al*., 2020; Kinyuru and Kipkoech, 2018; Mutisya *et al*., 2021; Okello *et al*., 2021; Onsongo *et al*., 2018; Sebatta *et al*., 2018). While there are efforts to support commercialization of insects as an alternative source of feed in Kenya, its production and uptake as a source of livestock feed is still very low among feed manufacturers and livestock producers.

This would require a further understanding of the existing livestock feed systems more so in establishing whether farmers would be willing to substitute conventional feed sources with non-conventional ones such as insect-based feed. It would also require knowledge of farmers' preferences and the trade-offs livestock farmers make when selecting various feed products. Previous studies that have assessed preferences for livestock feeds comprise Kiptot *et al*. (2015); Najim *et al*. (2015); Njenga *et al*. (2013); and acceptance of insect-based livestock feed consist of Okello *et al*. (2021); Sebatta *et al*. (2018); Chia *et al*. (2020). However, these studies present limited understanding of farmers' preferences for specific feed attributes and the trade-offs they make when selecting feed products. Equally, the studies have not taken into account the farmers' willingness to pay for specific feed attributes, which is necessary to inform feed formulation decisions.

The current study contributes to the existing literature by assessing preferences for livestock feed attributes using a choice experiment framework for accounting for farmers' trade-offs when selecting various feed products. It also assesses farmers' willingness to use insect-based livestock feed in smallholder dairy farming systems in Kenya, and the findings are discussed relative to the theory of planned behaviour. It is anticipated that understanding the preferences for livestock feed attributes and willingness to use insect-based livestock feed from the point of view of dairy farmers is essential to inform interventions for enhancing the uptake of non-conventional feed sources.

1.3 Objectives of the study

The study's overall objective was to assess preferences and willingness to use insect-based livestock feed among smallholder dairy farmers in Murang'a County of Kenya. This information would be crucial in the commercialization of insect-based livestock feed. Utilizing these non-conventional feed sources would ensure high-quality or low-cost livestock feeds for increasing livestock production and profitability. The specific objectives of the study were:

1. To characterize the livestock feed systems among smallholder dairy farmers in Murang'a county
2. To assess willingness to use insect-based livestock feed among smallholder dairy farmers in Murang'a county
3. To assess the preferences for livestock feed attributes among smallholder dairy farmers in Murang'a county

1.4 Research hypotheses

The study sought to test the following null hypotheses:

1. There are no significant variations in livestock feed systems characteristics based on agro-ecological zones of smallholder dairy farmers in Murang'a county
2. Attitudes, subjective norms, perceived behavioural control and socioeconomic characteristics have no significant influence on willingness to use insect-based livestock feed among smallholder dairy farmers in Murang'a county
3. There are no significant preferences for livestock feed attributes among smallholder dairy farmers in Murang'a county

1.5 Significance of the study

This study sought to characterize the livestock feed systems, assess farmers' willingness to use insect-based livestock feed and preferences for livestock feed attributes in Kenya. The information generated will provide an understanding to feed manufacturers of the feeds farmers need and their preferences for various feed product attributes. This could

enable scaling up the production of non-conventional feed sources to meet the needs of smallholder livestock farmers. Additionally, research scientists can evaluate the viability of the processes involved in formulating insect-based feed. Furthermore, the study's findings will provide insights to policymakers, feed manufacturers and other livestock stakeholders on interventions to enhance the uptake of non-conventional feed sources in Kenya.

1.6 Scope of the study

The research focused on smallholder dairy farmers in Murang'a county of Kenya. The county was selected because it is one of the leading dairy production areas in Kenya (Orwa and Oyoo, 2020). The county is also characterized by various agro-ecological zones which enabled the study to compare characteristics of livestock feed systems (production systems, types of feed resources, sourcing arrangements, seasonality of feed, expenditure on feed and livestock feed security) across different agro-ecological zones. The study employed both qualitative and quantitative approaches to collect data from the dairy farming households. These included key informant interviews, focus group discussions, choice experiment cards and household survey questionnaires.

1.7 Organization of the thesis

The thesis is organized in five chapters. Chapter one presents the study's background, statement of the problem, objectives, research hypotheses, significance and scope of the study. Chapter two comprises theoretical and empirical literature relevant to the study. Chapter three provides the research methodology employed in the study, theoretical and empirical framework, description and measurement of variables, study area, sampling procedure, data collection and analysis. Chapter four covers the research findings and discussions. Finally, chapter five provides the study's summary, conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of literature relevant to the study. The chapter is structured into three sections. The first section (section 2.2) discusses the theoretical literature. The second section (section 2.3) reviews past empirical studies and finally, the last section of the chapter (section 2.4) concludes with an overview of the literature and research gaps.

2.2 Theoretical literature

The theoretical literature reviewed in this study involves; approaches for assessing livestock feed security and theories that present the basis for understanding smallholder dairy farmers' decisions concerning utilization of livestock feeds. Additionally, the section reviews the theories for assessing willingness to use insect-based livestock feed and approaches for estimating preferences for livestock feed attributes.

2.2.1 Approaches for assessing livestock feed security

Past discussions on characterization of the livestock feed systems have focused on assessment of existing livestock feed resources and feeding practices, constraints linked to livestock production and feed, feed management practices and preferences for feed types and practices (Jimma *et al*., 2016; Kiptot *et al*., 2015; Najim *et al*., 2015; Njenga *et al*., 2013; Umutoni *et al*., 2015). Currently, there is an increasing interest that characterization of the livestock feed systems would also comprise the assessment of livestock feed security (Cordeiro *et al*., 2022; FAO and IGAD, 2019). In this study, livestock feed security refers to availability of, accessibility to and steady supply of sufficient, good quality and affordable feed among livestock farming households all year round, following drought and normal periods (FAO and IGAD, 2019; Makkar *et al*., 2020). Livestock feed security is made up of three key components; feed availability, accessibility and quality, which are all critical to the efficiency of livestock production

and reproduction, livestock wellbeing, human health and sustainable livelihoods in both the developed and developing world (Cordeiro *et al*., 2022; Makkar *et al*., 2020).

Two approaches for assessing the state of livestock feed security in East Africa, Kenya included have been developed by the FAO and IGAD (FAO and IGAD, 2019). The first approach is for assessment of livestock feed security at a community level, whereas the second approach is for the assessment at household level (Makkar *et al*., 2020). Both approaches incorporate pictorial evaluation tool for assessments of grazing biomass and animal body condition. However, the household level approach (when combined with other approaches that provide information on household livelihood and nutrition), can be used to understand the relationship between feed availability, livestock source food production, human nutrition, food security and livelihood (Makkar *et al*., 2020). Thus, drawing from the Food Insecurity Experience Scale (FIES), an experience-based approach used to measure household food security (FAO, IFAD, UNICEF, WFP and WHO, 2022), the study developed a scale for the measurement of livestock feed security at the household level.

The FIES comprises eight questions concerning individuals' access to quality and adequate food that are used to assess household food security level. These questions capture household experiences of uncertainty and anxiety concerning food access, compromising on quality and variety, reducing quantities of food consumed and skipping meals, and experiencing hunger (FAO, IFAD, UNICEF, WFP and WHO, 2022; Ville *et al*., 2019). Based on the responses to the questions, households can be categorized into four levels of food security, those that are food secure, mildly food insecure, moderately food insecure and severely food insecure (FAO, IFAD, UNICEF,WFP and WHO, 2019).

While the FIES approach has been applied by Mwangi *et al*. (2020) and Mucioki *et al*. (2018) to assess the level of household seed security in Kenya, this study applies and extends the FIES in the context of livestock feed security given the feed-food

interrelationship. This assessment is unique and the study is unaware of any study that has examined livestock feed security at the household level applying the FIES approach.

2.2.2 Theories for understanding smallholder dairy farmers' decisions on utilization of livestock feed

This study assesses smallholder dairy farmers' decisions concerning utilization of livestock feed applying the theory of the firm and utility maximization framework.

The theory of the firm

The neoclassical theory of the firm dates back to the work of Coase (1937) and Williamson (1981) on the nature of the firm and transaction costs (Lewin and Phelan, 1999). The theory assumes that the firm's primary objective, in this case, the livestock enterprise, is to maximize profits subject to a technological or production constraint (Jehle and Reny, 2011). Assuming that the firm, in this case, the livestock enterprise, produces only a single output using many inputs, it will choose that level of output and that combination of inputs that will maximize its profits such that:

$$\pi(p, w) = pf(x) - wx \qquad (2.1)$$

Where p is a vector of output prices; w is a vector of input prices; and x is a vector of inputs (feed, labour and capital).

From equation 2.1 the study can obtain the first order necessary condition that maximizes profit as;

$$p\frac{\partial f(x^*)}{\partial x_i} = w_i \qquad i = 1, \dots, n \qquad (2.2)$$

Equation 2.2 implies that the livestock enterprise will maximize its profit when the value of marginal product of each of the inputs including feed, labour and capital equals the price of each of the inputs. Thus, the solution of equation 2.2 yields the optimal input demand function as given in equation 2.3

$$x_i^* = x_i^*(p, w) \qquad (2.3)$$

Where x_i^* represents the optimal choice of inputs, p is a vector of output prices and w is a vector of input prices. Equation 2.3 can be applied to model livestock farmers' choices for various feed products.

However, equation 2.3 (the optimal input demand function) cannot be applied in the modelling of specific preferences for livestock feed attributes which is necessary in the characterization of feed products. To model the livestock feed attributes, the study will apply the utility maximization and Lancaster framework discussed in the subsequent section.

The utility maximization and Lancaster framework

The utility maximization framework assumes that the primary objective of a farm household is to maximize utility subject to its budget constraint (Jehle and Reny, 2011). The utility maximization framework is important for understanding the demand relationships for market goods such as livestock feed products. An extension of the utility maximization framework, Lancaster framework of 1966, considers an assessment of preferences for specific product attributes, in which an individual derives its utility from the characteristics or traits of a good rather than from the good itself (Lancaster, 1966). The framework is based on the concept that utility is provided by the attributes a good or product possess instead of the good per se (Hynes *et al*., 2011). Lancaster framework is ideal for this study as it considers the analysis of individuals' choices with regard to product attributes.

Previous studies have used the framework to: assess farmers' preferences for livestock genetic attributes (Duguma *et al*., 2011; Roessler *et al*., 2008); value livestock genetic resources (Omondi *et al*., 2008); assess preferences for disease-free zones (Otieno *et al*., 2011); investigate dairy farmers preferences to participate in pasture grazing programs (Danne and Musshoff, 2017); assess preferences for insect-fed fish among consumers (Ankamah-Yeboah *et al*., 2018); and investigate preferences for dairy cattle traits (Chawala *et al*., 2019). The study applies the framework to assess preferences for

livestock feed attributes among smallholder dairy farmers in Murang'a county of Kenya. The approaches for assessing preferences are presented in Section 2.2.4.

2.2.3 Theories for understanding smallholder dairy farmers' willingness to utilize insect-based livestock feed

The theory of planned behaviour (TPB) has been widely considered to be effective in predicting general behaviour changes in individuals with regard to adoption of new agricultural practices, farm innovations and products. The TPB is an advancement of Ajzen and Fishbein (1975) theory of reasoned action (TRA) (Ajzen, 1991). Icek Ajzen established TPB as a way to predict a person's behaviour under incomplete volitional control which was unattainable using the TRA (Ajzen, 1991). Both TPB and TRA assume that a person's performance of a particular behaviour relies on individual's behavioural intention to perform the actual behaviour (Silva *et al*., 2017). According to Ajzen (1991), intentions represent how firm people are willing to try to perform a particular behaviour. Therefore, behavioural intention is taken as the immediate antecedent of any actual behaviour. In this study's context, intention represents farmers' willingness to use insect-based livestock feed in dairy cattle production.

Contrary to TRA which describes behavioural intention using only two constructs, attitude and subjective norm, TPB includes a third element, perceived behavioural control, which directly influences actual behaviour and indirectly affects behaviour through behavioural intention (Taherdoost, 2018). Hence, in TPB, behavioural intention is often determined by three constructs; attitude towards the behaviour, subjective norm and perceived behavioural control (Figure 2.1). Attitude towards a behaviour represents a person's positive or negative feelings towards a particular behaviour. Subjective norm refers to the perceived social pressure from significant others to perform or not perform a particular behaviour. On the other hand, perceived behavioural control refers to an individual's perceived ease or difficulty in performing a certain behaviour (Ajzen, 1991, 2015).

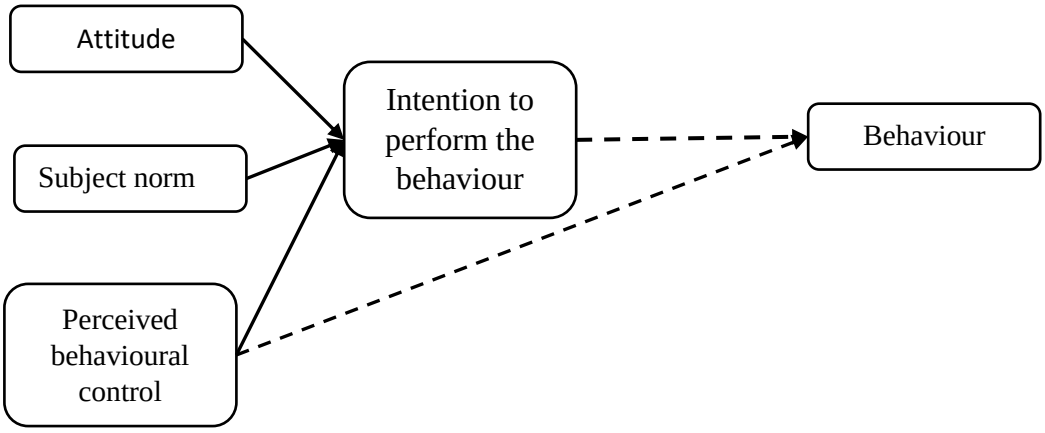

Figure 2.1: Theory of planned behaviour (Ajzen, 1991)

Depending on a study's context, the significance of the three constructs (attitude, subjective norm and perceived behavioural control) in influencing intention may differ between behaviour and situations. The more favourable the attitude and subjective norm, and the greater the perceived behavioural control, the stronger should be one's intention to perform a particular behaviour (Ajzen, 1991; Jokonya, 2017). The TPB framework also identifies the significance of other variables, including demographic and socioeconomic factors (e.g., age, gender, education and income) in influencing intentions. However, these variables are considered background factors in TPB as they are expected to influence intentions indirectly by their effects on attitude, subjective norm and perceived behavioural control (Ajzen, 2015).

Previous studies have applied the TPB framework in the assessment of: cattle farmers' intentions to adopt improved natural grassland (Borges *et al*., 2014); intention to diversify agricultural production among farmers (Senger *et al*., 2017); farmers' intention to use nutrient management planning (Daxini *et al*., 2018); farmers' intention to conserve on-farm biodiversity (Maleksaeidi and Keshavarz, 2019); consumers' willingness to purchase insect-based foods (Chang *et al*., 2019); intentions to use agroforestry technologies among smallholder farmers (Buyinza *et al*., 2020); and

farmers' intention to adopt insect farming for livestock feed (Diaz *et al*., 2021). This study uses the TPB framework to assess willingness to use insect-based livestock feed among smallholder dairy farmers in Murang'a county of Kenya.

2.2.4 The approaches for assessing preferences for livestock feed attributes among smallholder dairy farmers

To elicit individual preferences and predict their behaviour in market and non-market valuations, researchers have proposed several approaches (Hanley *et al*., 2001; Louviere and Woodworth, 1983). In the recent past, choice experiments have been widely used as one of the emerging approaches in the measurement of individual preferences in different fields (Louviere and Woodworth, 1983; Otieno *et al*., 2011; Wang *et al*., 2022). The approach is a survey-based, stated preference method for eliciting individual preferences based on hypothetical markets (Koemle and Yu, 2020). Discrete choice modelling draws on Lancaster's theory of consumer choice, whereby consumers derive their utility from the attributes a good possesses instead of the good itself (Lancaster, 1966). Thus, the method enables the valuation of marginal contribution of a product's attributes compared to its general preference ratings (Hanley *et al*., 2001), which is necessary to inform the introduction of new products or farm innovations.

The choice experiments have been used to study how people trade-off between different products attributes (Koemle and Yu, 2020). In a hypothetical scenario, the method applies several choice profiles, where people select one from a set of alternatives, and the alternative is represented by a set of product attributes, thus indicating the important product attributes that influence people's choices (Wang *et al*., 2022). The key objective in discrete choice modelling is to analyze people's choices in relation to products attributes which can be specified as a binary logit or probit model, multinomial logit, nested logit, ordered logit or mixed logit (Hensher and Greene, 2003; Revelt and Train, 1998). This approach was used in the study to assess smallholder dairy farmers' preferences for livestock feed attributes and their marginal willingness to pay for each feed attribute.

2.3 Empirical literature

This section provides the empirical studies relevant to livestock feed systems, farmers' willingness to use insect-based livestock feed and preferences for livestock feed attributes.

2.3.1 Characterization of the livestock feed systems among smallholder dairy farmers

Njarui *et al*. (2016b) assessed livestock feed resources utilization and management in smallholder mixed crop-livestock farms in Kenya. Data were collected in the coastal lowlands, mid-altitude eastern region, central highlands and north western highlands regions among 786 smallholder farmers. The study findings revealed that 98 and 70 percent of farmers in the coastal lowlands and north western highlands respectively, mainly used natural pastures to feed the livestock. Napier grass was the major livestock feed resource during the first half and last month of the year, utilized by more than 65 percent of farmers in the mid-altitude eastern region. An equal proportion of farmers (45-50%), mainly used both natural pastures and Napier grass to feed the livestock throughout the year in the central highlands. According to the study findings, maize stovers were the primary livestock feed utilized during the dry season and were more broadly used in the mid-altitude eastern region where the dry season was more prominent. Majority of the smallholder farmers (79-99%) experienced feed shortage in the study areas. The most widely adopted strategy to mitigate feed scarcity across most of the regions was feeding livestock with conserved feeds mainly hay (55-62% of farmers).

Jimma *et al*. (2016) assessed available feed resources, feed management and utilization systems in Ethiopia. The study collected data in the zonal Woreda and special Woreda of central zones of Southern Nations Nationalities and Regional State. Data were collected through focus group discussion, key informant interview and individual household survey. The results revealed that some of the major livestock feed resources utilized in the study area comprised natural pastures, crop residues, maize stalk,

sugarcane, Napier grass and bamboo tree leaves. The most commonly used feed shortage coping mechanisms by the small-scale farmers were utilization of tree leaves, crop residues, enset and sweet potato vines (42.9% of farmers). According to the study findings, majority of the households (77.8%) experienced feed scarcity in the months of January, February and March. Concerning the uptake of feed conservation strategies, most of the farmers (57.1%) conserved feeds in form of hay for the dry season while none of the farmers conserved feed resources in form of silage. Additionally, none of the farmers' utilized flour milling by products as livestock feed in the study area.

Umutoni *et al*. (2015) characterized available feed resources and assessed the feeding practices among farmers to improve milk production in Senegal. Data collection was conducted in Kaolack and Kolda regions among 73 farmers. The study collected data through focus group discussions, personal direct observations and a household survey questionnaire on size of livestock, available feed resources, feeding practices, supplementation purpose, supplementation practices and milk yield. The study results indicated that natural pasture and crop residues were the main livestock feed resources utilized. Supplementation was practiced by all farmers during the dry season, though it was done in a random manner without any consideration for measurement. The results of the study also revealed that the main constraints faced by farmers in accessing feed supplements were limited resources, unavailability of the feed supplements at the local markets and high cost of feed supplements.

Collectively, the three studies reviewed in this section provide insights on the commonly utilized feed resources in SSA context, and attributes that can be used to characterize the livestock feed systems among smallholder dairy farmers in Murang'a county of Kenya.

2.3.2 Assessment of farmers' willingness to use insect-based livestock feed

Diaz *et al*. (2021) assessed the determinants of intention to adopt insect farming for livestock feed among smallholder farmers in Colombia. The study applied a theoretical framework based on theory of planned behaviour and the technology acceptance model.

Data collection was undertaken in Santander region among 100 smallholder farmers. Binary logistic regression models were used to estimate the factors influencing farmers' intention to adopt insect farming for livestock feed. The model results revealed that smallholder farmers' intention to adopt insect farming for livestock feed was mainly influenced by subjective norms, perceived ease of use, education and perceived importance of feed attributes. The study concluded that majority of smallholder farmers in the study area accepted insects as an alternative source of feed, particularly when they felt supported, encouraged and not judged by their significant others, and also when they believed that the innovations implemented were adaptable. The present study employed a similar methodological approach (TPB) to assess smallholder dairy farmers' willingness to use insect-based livestock feed.

Okello *et al*. (2021) investigated poultry farmers' perceptions of commercial insect-based feed products and factors that would influence their adoption in Kiambu County in Kenya. The study obtained data from a random sample of 310 poultry farmers and employed a multiple regression model to estimate the determinants of farmers' perceptions. The results indicated that more than 90 percent of the chicken farmers were willing to utilize insect-based feeds. According to the model results, the poultry farmers' perceptions of insect-based feed were significantly influenced by their awareness of insect-based feed attributes, education, group membership, wealth status and off-farm income. The present study focuses on smallholder dairy farmers since acceptance of insect-based livestock feed may vary by the type of livestock value chain.

Sebatta *et al*. (2018) assessed the perceptions and willingness of poultry farmers to use insects as a source of protein ingredient in poultry feed in Uganda. The study obtained data from a random sample of 287 poultry farmers. A probit regression model was employed to assess the determinants of farmers' willingness to rear and use insects for poultry feed. The study findings indicated that more than 70 percent of poultry farmers were willing to use insects in poultry feeds. The model results revealed that awareness that poultry feed on insects, farmer's age, rearing exotic chicken for commercial use,

frequency of feed price fluctuation and belief that insects were suitable for formulating poultry feeds, significantly influenced farmers' willingness to use and rear insects for poultry feed. The study provides insights on some of the factors influencing farmers' acceptance decisions on insects as an alternative source of protein in livestock feed. However, the study did not explore the effect of psychological factors on acceptance decisions which the current study takes into account in assessing willingness to use insect-based livestock feed among smallholder dairy farmers in Kenya.

2.3.3 Assessment of preferences for livestock feed attributes among smallholder dairy farmers

Based on data obtained from a random sample of 289 beef cattle farming households from four states of the East Coast Economic Region in Malaysia, Najim *et al*. (2015) evaluated farmers' preferences in feeding cattle. The study's findings revealed that in terms of feeding practices, farmers mostly preferred grazing on pasture, followed by a combination of roughages, cut and carry grass, and silage. Palm kernel cake was the most preferred for concentrate use, followed by no concentrate use, a combination of concentrates and commercial pellets. Concerning good feeding practices, using concentrates feeds was the most preferred followed by supplying drinking water to cattle, considering nutritional requirements, utilizing roughage feed, feeding non-protein nitrogenous substances and utilization of microbial technology. The study provides insights on some traits that are critical in livestock farmers' choice of feed and feeding practices. However, the study did not consider farmers' preferences for specific feed and feeding practice characteristic which could influence farmers' choice of various feed practices. The present study takes into account the marginal contribution of each feed attribute in assessing smallholder dairy farmers' preferences for livestock feed attributes applying the choice experiment approach.

Using data from a sample of 32 farmers in dairy management groups, Njenga *et al*. (2013) examined farmers' preferences for tropical forage legumes in smallholder farming systems in Kenya. A participatory variety selection was undertaken to

understand farmers' perception of the preference for forage legume varieties. Farmers were presented with different scorecards and were asked to choose their preferred alternatives based on particular forage legume characteristics. The results revealed that Vetch forage was the most preferred legume, followed by *Desmodium uncinatum*, Burgundy bean, and *Lablab purpureus*. Regarding the characteristics possessed by a forage legume, the most preferred characteristics were the forage nutrient value and herbage production. The study concluded that receiving adequate information on the important attributes of each forage legume was vital as it would inform the choice of legume options to be made available to the farmers. The study provides understanding on some of the traits that could possibly be utilized to assess preferences for livestock feed attributes among smallholder dairy farmers in Murang'a county of Kenya. The current study applied a choice experiment approach to account for farmers' trade-offs when selecting various feed products. It also increased the sample size to 378 smallholder dairy farmers to improve the sample representation.

Kiptot *et al*. (2015) examined dairy farmers' preferences and adoption of livestock feed practices in Kenya. The study obtained data from a random sample of 181 farmers in dairy management groups. The study used structured questionnaires to collect data on farmer preferences and feed practices. The descriptive results revealed that Napier grass was the most preferred among the livestock feeds, followed by Boma Rhodes, dry maize stover, Lucerne, oats and mineral supplementation. The study also found that some of the main reasons for the preference for various feed sources were based on different feed characteristics, including potential for drought-resistant, fast growth, high nutrition content, extended storage and ability to increase milk yield. While the study did not analyze the marginal contribution of each livestock feed characteristic, it provides insights on some of the traits that are critical in farmers' selection of livestock feed products. The insights were very useful in designing the choice experiment applied in assessing preferences for livestock feed attributes among smallholder dairy farmers in Murang'a county of Kenya.

2.4 Overview of literature and the study research gaps

The review of theoretical literature is based on three distinct theories — the theory of the firm, theory of planned behaviour and utility maximization framework. The theory of the firm provides a theoretical foundation used for modelling smallholder dairy farmers decisions with regard to utilization of livestock feed. The theory of planned behaviour, however, is used to model farmers' willingness to use insect-based livestock feed. Additionally, the review of the utility maximization framework provides the study with a theoretical underpinning for modelling farmers' preferences for livestock feed attributes.

From the review of the empirical literature, there is an emerging body of literature on characterization of the livestock feed systems (Jimma *et al*., 2016; Njarui *et al*., 2016b; Umutoni *et al*., 2015). These studies have examined available feed resources, feed practices, major constraints faced by livestock farmers in feed access and coping strategies to mitigate the feed challenges. A significant finding from the review of literature reveals that limited studies have assessed livestock feed security especially in SSA context (Cordeiro *et al*., 2022). This study contributes to the existing gap in literature by assessing livestock feed security at the household level applying a modified version of the FIES approach.

Additionally, the empirical literature indicates that studies assessing farmers' willingness to use insect-based livestock feed are still limited. A few studies have been conducted in SSA (Okello *et al*., 2021; Sebatta *et al*., 2018). However, while these studies assess the determinants of farmers' intention to adopt insect-based feeds, they have not accounted for the effect of psychological factors which have been recently shown to be important in explaining individuals' behavioural decisions. The present study varies from these studies by considering the influence of psychological factors on farmers' willingness to use insect-based livestock feed based on the theory of planned behaviour.

Furthermore, the empirical literature shows that there are limited studies on farmers' preferences for livestock feed attributes. Previous studies conducted by Kiptot *et al*. (2015), Najim *et al*. (2015) and Njenga *et al*. (2013) provide limited understanding of preferences for specific feed attributes (source of protein, source of energy, brand of feed product, effect of product on yield and price) and trade-offs farmers make when choosing livestock feed products. The present study addresses this gap by taking into account the marginal contribution of each livestock feed product attribute, applying the choice experiment approach. Understanding the preferences for specific attributes is necessary to inform feed formulation decisions among feed manufacturers.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter provides the methodology that the study employed. It describes the research design, theoretical framework, specification of empirical models, measurements of variables, study area, sampling procedure, data collection and analysis.

3.2 Research design

The study used a descriptive non-experimental cross-sectional research design to attain its objectives. According to Kothari (2004), a descriptive non-experimental research design is ideal when the research objectives are descriptive in nature and there is need to describe the relationships between variables. The study used a combination of mixed methods approaches - both qualitative and quantitative approaches in data collection. The qualitative data were collected through key informant interviews and focus group discussions with the respondents. The quantitative data were collected by administering a household survey questionnaire and choice experiment cards to the respondents.

3.3 Theoretical and analytical framework

This section provides the theoretical and analytical framework for assessing livestock feed security – one of the indicators considered in the characterization of the livestock feed systems, willingness to use insect-based livestock feed and preferences for livestock feed attributes.

3.3.1 Theoretical and analytical framework for assessing livestock feed security

The first objective of this study sought to characterize livestock feed systems and mainly focused on; types of livestock production systems, type of feed resources, sourcing arrangements, seasonality of feed, expenditure on feed and livestock feed security. The characterization of the livestock feed systems was achieved using descriptive statistics in terms of means, measures of dispersion (standard deviations), frequencies and

percentages. A one-way analysis of variance and Pearson's chi-square test were conducted to test if there were any statistical differences in aspects that characterize the feed systems across different agro-ecological zones in the study area.

From a review of literature, the study adopted one dimension of food security (access to food) (FAO, IFAD, UNICEF, WFP and WHO, 2022) to develop a scale for estimating the livestock feed security. The livestock feed security was measured using eight questions in four domains (anxiety and uncertainty concerning livestock feed access; compromising on quality and variety of feed; reducing quantities of feed; and livestock going without feeding) borrowing from the Food Insecurity Experience Scale (FIES) approach (FAO, IFAD, UNICEF, WFP and WHO, 2019) and adapted in a livestock context, Table 3.1. The farmers' responses to the eight questions were binary 'yes' or 'no', based on a one-year recall period. Their responses were used to estimate livestock feed security experience score as given in equation (3.1).

$$LFSES_i = \sum_{j}^{v} Z_j \qquad for\ j = 1,2,\dots,8 \ \ and \ \ i = 1,2,\dots,n \tag{3.1}$$

Where $LFSES$ is the livestock feed security level for the i^{th} household and Z is the household response to the j^{th} livestock feed security question. The livestock feed security scores range between 0 and 8, where a score of 0 indicates a feed secure household; 1-3 indicates a mildly feed insecure household; 4-6 indicates a moderately feed insecure household; and 7-8 indicates a severely feed insecure household. The questions used to measure livestock feed security based on the four domains of feed security are presented in Table 3.1.

Table 3.1: Questions used to measure livestock feed security

Domain	Question
Anxiety and uncertainty of livestock feed	1. Did you worry that your livestock would not have enough feed to eat because of lack of resources?
Compromising on quality and variety of livestock feed	2. Did your livestock have to eat a limited variety of feed due to lack of resources?
	3. Did you have to give your livestock some type of feed that they really did not want to feed on or disliked because of a lack of resources to obtain other types of feed?
Reducing quantities of livestock feed	4. Did you have to give your livestock less feed than you felt they needed because there was not enough feed?
Livestock going without feeding	5. Did you ever lack any kind of feed to give your livestock because of limited land to cultivate own feed?
	6. Did you ever lack any kind of feed to give to your livestock because of extreme drought?
	7. Did you ever run out of feed for the livestock due to lack of resources?
	8. Did your livestock ever go without feeding for a whole day due to lack of access to feed?

Source: Adapted from Ville *et al*. (2019) and adjusted in line with the study's context

3.3.2 Theoretical and analytical framework for assessing willingness to use insect-based livestock feed

The study draws on the theory of planned behaviour (TPB) to explore factors influencing smallholder dairy farmers' willingness to use insect-based livestock feed. According to Ajzen (1991), human behaviour emerges from an individual's intention to perform a specific behaviour. The intention to perform a particular behaviour (in this study, smallholder dairy farmers' willingness to use insect-based livestock feed) is often determined by three constructs; attitude towards the behaviour, subjective norms and perceived behavioural control (Ajzen, 1991; Diaz *et al*., 2021).

In the past, TPB has been widely used to predict behaviour changes in individuals concerning the uptake of various agricultural practices, farm innovations or novel products. Following previous studies (e.g. Arunrat *et al*., 2017; Daxini *et al*., 2018; Diaz *et al*., 2021; Micha *et al*., 2015) the study adopted an extended version of the TPB model

to include demographic and socioeconomic characteristics in assessing the determinants of smallholder dairy farmers' willingness to use insect-based livestock feed (Figure 3.1).

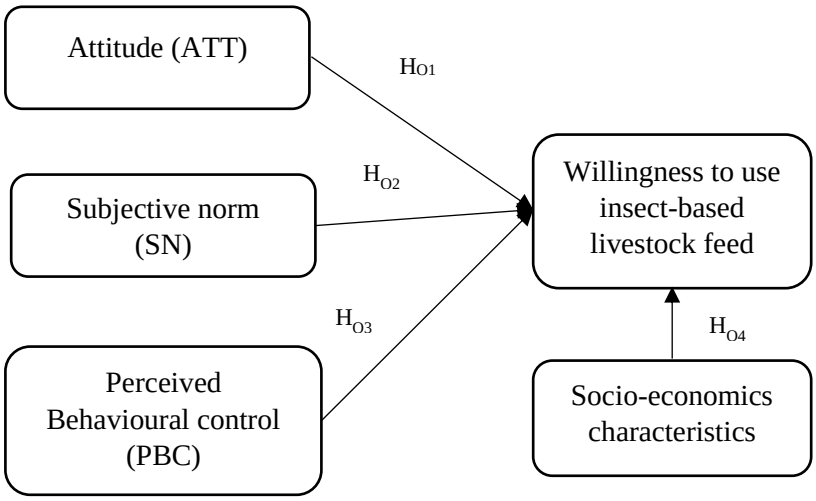

Figure 3.1: Conceptual framework on smallholder farmers' willingness to use insect-based livestock feed in dairy cattle diet (adapted from Daxini *et al*. (2018))

Based on the extended TPB framework, the study sought to test the following null hypotheses:

H_{O1}: Attitudes have no significant effect on smallholder dairy farmers' willingness to use insect-based livestock feed.

H_{O2}: Subjective norms have no significant effect on smallholder dairy farmers' willingness to use insect-based livestock feed.

H_{O3}: Perceived behavioural control has no significant effect on smallholder dairy farmers' willingness to use insect-based livestock feed.

H_{O4}: Socioeconomic characteristics have no significant effect on smallholder dairy farmers' willingness to use insect-based livestock feed

3.3.3 Theoretical and analytical framework for assessing preferences for livestock feed attributes

The study draws on the utility maximization approach to model smallholder dairy farmers' preferences for livestock feed attributes. Following Lancaster theory of consumer choice (Lancaster, 1966), the preferences for feed were treated as bundles of characteristics or traits. The theory assumes that utility is derived from the characteristics associated with the livestock feed products. Therefore, a smallholder dairy farmer faced with alternative feed products will choose the alternative whose attributes yield the highest level of utility.

In the case that a dairy farmer has to make a choice between alternative i and j depending on the resulting utility levels, the farmer will choose alternative i provided that $U_i > U_j$ is satisfied as shown in equation 3.2.

$$Pr(i \neq j \; \forall \; i \in N) = Pr\,(\beta_1 X_{i1} +, \ldots, +\beta_n X_{in} + \mu_i \geq \beta_1 X_{j1} +, \ldots, +\beta_n X_{jn} + \mu_j) \qquad (3.2)$$

Where N represents the entire set of choices of livestock feed attributes (source of protein, source of energy, brand of feed product, effect of product on yield and price) presented to the farmer; X_{in} is the n^{th} characteristic for alternative (i); β_n is a vector of parameters to be estimated and is associated with the n^{th} characteristic of the i^{th} alternative. The decomposition of the structure of farmers' preferences for feed product attributes (source of protein, source of energy, brand of feed product, effect of product on yield and price) was achieved using the choice experiment approach. In order to determine the probability of alternative i being selected in equation 3.2 using a choice model, the study employed a mixed logit model. The empirical specifications of the choice experiment and mixed logit model are discussed in section 3.4.2.

3.4 Empirical models specification

3.4.1 Estimation of willingness to use insect-based livestock feed

Due to the nature of the dependent variable for objective two i.e., the binary random variable y_i takes the value 1 if the farmer is willing to use insect-based livestock feed and zero otherwise, the study first estimated an ordinary probit regression model. The choice of the model was grounded on the assumption that the model's residuals were normally distributed. Based on the results, the study proceeded to test for heteroskedasticity and estimated a heteroskedastic probit (hetprobit) model. The study discusses the empirical models as follows:

In modelling the determinants of farmers' willingness to use insect-based livestock feed, the binary probit model assumes that the latent variable y^* is linearly related to the observed variables ($X's$). i.e.

$$y_i^* = X_i\beta + \varepsilon_i \quad (3.3)$$

Where X_i represents the vector of explanatory variables (attitudes, subjective norms, perceived behavioural control and socioeconomic characteristics) for the ith observation, β is a vector of regression coefficient and ε_i is the unobserved error term. The relationship between y^* and the observed binary variable y can be specified as:

$$y_i = \begin{cases} 0 \; if y_i^* \leq \mu \\ 1 \; if y_i^* > \mu \end{cases} \quad (3.4)$$

Where μ represents a parameter cut point. The disturbances associated with y_i^* are assumed to have a normal distribution and the model is specified as:

$$\Pr(y_i = 1) = \emptyset(X_i\beta) \quad (3.5)$$

Where $\emptyset$ denotes a standard normal cumulative distribution function with a constant variance 1. The standard probit model assumes that the disturbance term is homoscedastic and the probability can be given as:

$$\Pr(y_i = 1) = \emptyset\left(\frac{X_i\beta}{\rho}\right) \quad (3.6)$$

Such that, when ρ is a constant (equals to 1), it is removed from equation to estimate β. However, Moussa (2019) recommends that after estimation of the ordinary probit model, it is necessary to test the null hypothesis of homoscedasticity. This is because if the study reject's the null hypothesis, the obtained parameter estimates will be biased and inconsistent. Therefore, in this study, we relax the assumption of homoscedasticity by allowing the variance of the disturbance term to vary as a function of the predictor variables and not fixed at one (1).

The heteroskedastic probit model (hetprobit) as proposed by Alvarez and Brehm (1995) can be written as:

$$\Pr(y_i = 1) = \emptyset\left(\frac{X_i\beta}{\rho_i}\right) \quad (3.7)$$

Where $\rho_i = \exp(Z_i\, Y)$ and Z_i is a vector of covariates of the ith observation that are suspected to have heteroskedasticity and Y is a vector of parameters associated with ρ variables. If $Y = 0$, then the hetprobit model is identified as an ordinary probit model.

Just like the ordinary probit model, the hetprobit model can be estimated by a maximum likelihood. The log-likelihood for a hetprobit can be written as:

$$logL = \sum_i \left(y_i log\emptyset\left(\frac{X_i\beta}{\exp\,(Z_iY)}\right) - (1 - y_i)log\left[1 - \emptyset\left(\frac{X_i\beta}{\exp(Z_iY)}\right)\right]\right) \quad (3.8)$$

The coefficients obtained from the ordinary probit model are usually interpreted with the marginal effects. This with respect to X_j can be specified as:

$$\frac{\partial \Pr\,(y_i = 1)}{\partial X_j} = \emptyset(X_i\beta)\beta_j \quad (3.9)$$

The marginal effects for a hetprobit model can be given as:

$$\frac{\partial \Pr\,(y_i = 1)}{\partial X_j} = \emptyset\left(\frac{X_i\beta}{\exp\,(Z_iY)}\right)\left(\frac{\beta_j}{\exp\,(Z_iY)}\right) \quad (3.10)$$

3.4.2 Empirical specification of choice experiment for assessing preferences for livestock feed attributes

In the initial step of the choice experiment design, the study identified the most important feed attributes through a review of the literature, focus group discussions with farmers and key informant interviews with key stakeholders including feed processors, the local agricultural officer and livestock officer. The feed attributes considered were those related to the commercial feeds used to supplement the dairy cattle basal diet. These attributes were; source of energy, source of protein, brand of feed product, the effect of feed product on milk yield and price of feed product.

In the study, source of energy and protein were included because of their likely influence on the cost of the feed and productivity of milk. The price of feed product and the effect the product has on milk yield are important for farm profitability. The brand of the product was included as an indicator for quality of the feed product. This was considered important in light of the proliferation of many livestock feed products with a number of them being of low quality (Tegemeo Institute of Agricultural Policy and Development, 2021). The attributes and their levels applied in the choice experiment are presented in Table 3.2.

Table 3.2: Livestock feed attributes and their levels in the choice experiment

Attribute	Description	Levels	Reference level
Source of energy	The attribute represents the source of energy utilized in the formulation of livestock feed product. Three energy sourcing options; maize, wheat and cassava were considered in the study. The attribute was included to assess preference for cassava which can be used as an alternative energy source to replace common cereals (maize and wheat) whose use is becoming problematic because of competing uses with humans and other industrial uses (Shiferaw *et al*., 2011)	Maize Wheat Cassava	Maize
Source of protein	The attribute represents the source of protein utilized in the formulation of livestock feed product. Three protein sourcing options; soybean, fishmeal and insect were considered in the study. The attribute was included to assess preference for insect which can be used as an alternative protein source to replace traditional protein source (soybean and fishmeal) which is one of the most expensive and limiting ingredients to feed the livestock (Kim *et al*., 2019)	Soy meal Fishmeal Insect meal	Soy meal
Brand	This attribute represents the brand name of the feed product providing farmers with information on the manufacturer or company	Branded Unbranded	Unbranded
Yield	This attribute represents the percent increment in milk yield as a result of the different types of feed supplements utilized	No increment 25% 50% 75%	No increment
Price	The attribute represents the amount of money livestock farmers pay for a kilogram of energy and protein feed supplements	KES. 20 KES. 40 KES. 60 KES. 80	

Kenyan currency 1 USD=102.25 KES at the time of the survey

The identified attributes and their levels were combined with the experimental design that generated choice sets. A full factorial design of the identified attributes and their levels would have resulted in 256 ($2^3 \times 1^2 \times 2^4$) possible choice sets. Since it was not practical to work with such a large number of choice sets, it was assigned to Ngene 1.2 software to generate a feasible number of choice sets (ChoiceMetrics, 2018). A fractional factorial efficient design comprising 18 paired choice sets was obtained using the Halton (500) sequence. The 18 paired choice sets were randomly blocked into two blocks of 9 choice sets such that each farmer could easily evaluate nine choice sets. Each

choice task consisted of two alternatives (options one and two) and indifference between the two options or neither option (alternative three) to allow the dairy farmers to be flexible in their choices. An example of one of the choice cards presented to the dairy farmers is shown in Figure 3.2.

Prior to the survey, a pretest was carried out with 30 dairy farmers to estimate a more efficient design that would reduce errors in the final design of the choice experiment. The choice experiment was administered as part of a household level questionnaire survey using in-person interviews. When making choices, farmers were asked to carefully evaluate the options on each choice card and to choose the most preferred option for each choice card. Nine different choice cards were presented to each dairy farmer.

Attribute	**OPTION 1**	**OPTION 2**	**OPTION 3**
Source of energy	**Maize** 	**Cassava** 	**None of the two options**
Source of protein	**Soy meal** 	**Insect meal** 	
Brand	**Unbranded** 	**Branded** 	
Yield increment	**25%**	**50%**	
Price per kilogram	**KES 20**	**KES 40**	
I prefer			

Figure 3.2: An example of one of the choice cards

Drawing on the random utility theory (McFadden and Train, 2000), dairy farming households are assumed to be rational and maximize their utilities by making tradeoffs between livestock feed attributes (source of protein, source of energy, brand of feed product, effect of product on yield and price). Borrowing from (Wang *et al*., 2018), we assume a linear function for the utility of a dairy farmer expressed as:

$$U_{ij} = \beta X_{ijk} + \varepsilon_{ij} \quad (3.11)$$

where U_{ij} represents the i^{th} dairy farmer's utility from the livestock feed product j, X_{ijk} represents the k^{th} attribute of feed product j for dairy farmer i, β is a vector of coefficients which are homogenous across dairy farmers, and ε_{ij} is an error term assumed to be independently, identically distributed (i.i.d.) type I extreme value. Therefore, a dairy farmer's utility associated with alternative feed product j can be expressed as:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (3.12)$$

where V_{ij} represents the utility determined by the observed livestock feed product's attributes (source of protein, source of energy, brand of feed product, effect of product on yield and price), and ε_{ij} represents the unobserved term which reflects factors that are known to the dairy farmer but unknown to the researcher. The likelihood that alternative feed product j is preferred by dairy farmer i is given as:

$$P_{ij} = prob(V_{ij} + \varepsilon_{ij} > V_{is} + \varepsilon_{is}; \forall s, j \in T_i, \forall s \neq j) \quad (3.13)$$

where $T_i = \{t_1, \dots, t_T\}$ represents the choice situations faced by dairy farmer i. The probability of dairy farmer i selecting alternative feed product j can be expressed by the standard logit model as:

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_{j=1}^{J} e^{V_{ik}}} \quad (3.14)$$

According to (Hensher and Greene, 2003), the standard logit model exhibits the independence of irrelevant alternatives (IIA) assumption, assuming all livestock farmers' preferences are homogenous. To relax the IIA assumption in this study, we employed the mixed logit model (also called the random parameters logit model), allowing for sample preference heterogeneity. The mixed logit model also addresses other three limitations of the standard logit model. It allows for random taste variation,

unrestricted substitution patterns and correlation in unobserved factors over choice situations (Wittink, 2011).

In the mixed logit model, the deterministic component of the utility function takes the following form:

$$V'_{ij} = (\beta' + \sigma_i)X_{ijk} + \varepsilon_{ij} \quad (3.15)$$

Where β' represents a vector of attribute coefficients in the population level and σ_i is individual specific deviation from the mean β'. When mixed logit model is assumed, the unconditional choice probability is the integral of the logit formula over all possible values of random parameters:

$$P_{ij} = \int \frac{e^{V'_{ij}}}{\sum_{k=1}^{K} e^{V'_{ik}}} g(\beta|\theta)d\beta \quad (3.16)$$

Whereby; $g(\beta|\theta)$ indicates the joint density of random parameters. Therefore, the probability of a dairy farmer $i's$ choices over $T_i = \{t_1, \dots, t_T\}$ choice situations, $P_{i_{(t_1,\dots,t_T)}}$, can be given as:

$$P_{ij_{(t_1,\dots,t_T)}} = \int \prod_{t=1}^{T} \left[\frac{e^{V'_{ij}}}{\sum_{k=1}^{K} e^{V'_{ik}}}\right] g(\beta|\theta)d\beta \quad (3.17)$$

Following Acheampong *et al.* (2018) and Chawala *et al.* (2019), the marginal willingness to pay (MWTP) for each attribute is computed as:

$$MWTP = -1^{*}\left(\frac{\beta_i}{\beta_{price}}\right) \quad (3.18)$$

Whereby; β_i represents the estimated coefficient of attribute i (source of protein, source of energy, brand of feed product and effect of product on yield), and β_{price} is the estimated price coefficient. In the mixed logit model, the study treated the price coefficient as fixed while allowing all the other attributes to vary assuming normal

distribution. Revelt and Train (1998) noted that the advantages of fixing the price in the model assure the correct sign of the coefficient and allow for the easy derivation of the distribution of the willingness to pay.

3.5 Description and measurement of variables

The description and measurement of variables applied in the estimated models are presented in Table 3.3.

Table 3.3: Description and measurement of variables applied in the estimated models

Variables	Description and measurement
Dependent variable	
Choice	Choice of an alternative in a choice set (1 if the alternative is chosen, 0 otherwise)
Willingness	Willingness to use insect-based livestock feed (1 if willing, 0 otherwise)
Independent variables	
Feed attributes	
Source of energy	Energy source used as feed supplement (maize [a], wheat, cassava)
Source of protein	Protein source used as feed supplement (soy meal [a], fish meal, insect meal)
Brand	Represent name of a feed manufacture (1=branded, 0 unbranded [a])
Yield	Percent increment in milk yield (no increment [a], 25%, 50%, 75%)
Price	Price of feed supplement in Kenya shillings per kilogram (20, 40, 60, 80)
Household characteristics	
Age	Age of the household head in years
Farming experience	Farming experience of household head in livestock farming in years
Household size	Total number of members in a household
Farm size	Total amount of land owned by the farm household in acres
Land tenure status	Type of land ownership (1=own land with a title deed, 2= own land without a title deed, 3= rented land, 4= family land)
Dairy cattle	Total number of dairy cattle kept by the household at the time of the survey
Milk yield	Milk yield in liters per cow per day
Distance to the market	Distance from the farm to the nearest market in kilometers
Distance to tarmac road	Distance from the farm to nearest tarmac road in kilometers
Household income	Annual income from all income sources in the household in Kenya shillings (KES) in the last year preceding the survey
Gender	Sex of the household head (1= male, 0 otherwise)
Education level	The highest level of education attained by the household head (1 if post-primary, 0 otherwise)
Access to extension service	Household access to extension service within the last year preceding the survey (1= had access, 0 otherwise)
Access to credit	Household access to credit during the last year preceding the survey (1= had access, 0 otherwise)
Access to insurance service	Household access to insurance service (1= had access, 0 otherwise)
Group membership	Membership to a farmer group (1= belongs to a farmer group, 0 otherwise)
Household wealth category	Measure of a household's cumulative living standard∗ (Poorest, Middle, Wealthiest)
Awareness on insect feed	Awareness on insect-based livestock feed (1= aware, 0 otherwise)

[a] represents the reference level; ∗ The study employed (Hjelm *et al*., 2017) approach for computation of a household wealth index, which was arrived at through Principal Component Analysis (PCA). Households were classified into three categories. The wealthiest category- those with a wealth index above the mean value plus standard deviation, middle category- those with a wealth index within the range of mean and standard deviation and poorest households- those with a wealth index below the mean and standard deviation.

The constructs used to predict dairy farmers' willingness to use insect-based livestock feed (attitude, subjective norm and perceived behavioural control) was attained using a set of statements based on a five-point likert scale; (1) very unlikely, (2) unlikely, (3) neutral, (4) likely and (5) very likely. The statements that the study used are presented in Table 3.4.

Table 3.4: Description of TPB constructs and measurements of variables

TPB constructs	Description and measurement	Label	Statements
Intention	Farmers' willingness to use insect-based feed; ordinal item ranging from (1) very unlikely to (5) very likely	BI	Assuming insect-based feed was made available, what would be your likelihood of purchasing it for your dairy cattle
Attitude	Farmers' favourable or unfavourable appraisal of a particular behaviour of interest; ordinal items ranging from (1) strongly disagree to (5) strongly agree	ATT1	I would feed my dairy cattle on insect-based feed if it improves on their milk yield
		ATT2	I would feed my dairy cattle on insect-based feed if the price is lower than for other protein feed sources
		ATT3	I would feed my dairy cattle on insect-based feed if there is no other feed available
		ATT4	In my community, it is a taboo to use insect-based feed in the dairy cattle diet
Subjective norm	Farmers' perceptions of significant others or a set of organizations approving their use of insect-based feed; ordinal items ranging from (1) strongly disagree to (5) strongly agree	SN1	I would feed my dairy cattle on insect-based feed if my animal health officer assures me that they are safe for my dairy cattle
		SN2	I would feed my dairy cattle on insect-based feed if I got an approval from a trusted organization such as government research institutes, dairy cooperatives and university research centres
		SN3	I would feed my dairy cattle on insect-based feed if I hear or see on media (e.g., television, radio) that the feeds are good
		SN4	I would feed my dairy cattle on insect-based feed if my customers for milk have no problem with it
Perceived behavioural control	Farmers' volitional control over the use of insect-based feed; ordinal item ranging from (1) strongly disagree to (5) strongly agree	PBC	Buying insect-based feed for my dairy cattle, as soon as they become available for sale, will be entirely my choice

ATT Attitude; *SN* Subjective norm; *PBC* Perceived Behavioural Control; *BI* Behavioural Intention

Following previous literature Daxini *et al*. (2018) and Verbeke *et al*. (2015), farmers' willingness were categorized into two groups, farmers "willing" and those " not willing"

to use insect-based livestock feed depending on the responses to the willingness statement. The farmers who selected "very likely" and "likely" were categorized as those "willing" to use insect-based livestock feed in dairy production and labelled as 1. While those who selected "very unlikely" and "unlikely" were categorized as "not willing" to use insect-based livestock feed and labelled as 0. In the data six (6) respondents had selected the "neutral" response and were thus dropped from the analysis (since they were seen to have refrained from revealing their willingness).

In order to estimate the reliability and validity of the items and scale used to measure the constructs, the study conducted a Cronbach's alpha test and principal component analysis (PCA). In the testing of reliability, the study excluded the statements on willingness and perceived behavioural control since they each had only one statement. The Cronbach's alpha of (attitudes and subjective norms) was greater than 0.7, implying good reliability. The general accepted rule is that Cronbach's α coefficient below 0.6 represent an unacceptable level of reliability (Ursachi *et al*., 2015). Equally, the composite variable for attitude and subjective norm had a Cronbach's α of 0.918 and 0.783 respectively, implying that the items and the scale used had a good internal consistency.

The value of factor loadings (0.807 to 0.937) from PCA for the two constructs (attitude and subjective norm) were each above the recommended level of 0.6, indicating construct validity (Chang *et al*., 2019; Pambo *et al*., 2018) (Table 3.5 presents the results of Cronbach's α and factor loadings of the constructs). Based on the results in Table 3.5, two statements ('*in my community, it is a taboo to use insect-based feed in dairy cattle diet*') and ('*I would feed my dairy cattle on insect-based feed if my customers for milk have no problem with it'*) were eliminated and therefore excluded from the analysis of determinants of willingness – since they had factor loadings below the accepted threshold.

Table 3.5: Results of factor loadings and reliability for attitudes and subjective norms

Items	*Factor loading*	*p-value*	*Cronbach's α*
Attitudes			0.918
I would feed my dairy cattle on insect-based feed if it improves on their milk yield	0.928	0.000	
I would feed my dairy cattle on insect-based feed if the price is lower than for other protein feed sources	0.919	0.000	
I would feed my dairy cattle on insect-based feed if there is no other feed available	0.937	0.000	
In my community, it is a taboo to use insect-based feed in the dairy cattle diet	0.221	0.000	
Subjective norms			0.783
I would feed my dairy cattle on insect-based feed if my animal health officer assures me that they are safe for my dairy cattle	0.832	0.000	
I would feed my dairy cattle on insect-based feed if I got an approval from a trusted organization	0.875	0.000	
I would feed my dairy cattle on insect-based feed if I hear or see on media (e.g., television, radio) that the feeds are good	0.807	0.000	
I would feed my dairy cattle on insect-based feed if my customers for milk have no problem with it	0.004	0.941	

Statistically significant at $p<0.01$

3.6 Description of the study area

The study was conducted in Murang'a County in the central highlands of Kenya. The county occupies a total area of 2,558.8km^2 and lies between latitudes 0^o 34' South and 1^o 7' South and Longitudes 36^o East and 37^o 27' East. Murang'a County was selected because it is one of the leading dairy production regions in Kenya (Orwa and Oyoo, 2020). However, the potential of dairy products in the county is limited by various challenges, including limited access to quality and adequate livestock feeds, high cost of commercial feeds and declining land sizes for fodder production (Tegemeo Institute of Agricultural Policy and Development, 2021). Figure 3.3 shows the study area location in Kenya.

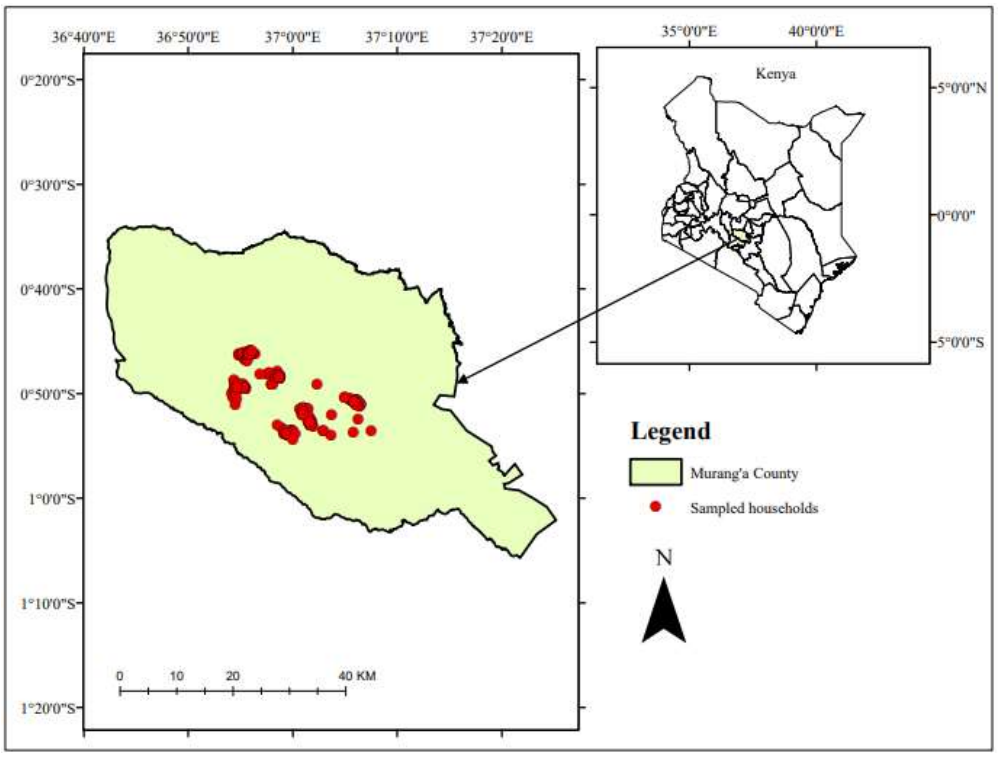

Figure 3.3 : A map showing the study area

3.7 Sampling procedure

3.7.1 Sampling frame

The target population was the smallholder dairy farmers in Murang'a County of Kenya. It provided the study with an understanding of the possible interventions that could be put in place to support dairy production in the county. The sampling frame of the study was a list of smallholder dairy farming households identified by local county officials and village elders.

3.7.2 Sample size determination

The sample size of the study (n) of dairy farming households was determined following Cochran's formula (Cochran, 1977) as given in equation (3.19):

$$n = \frac{(t)^2 * (p)(q)}{d^2} \qquad (3.19)$$

Whereby; n is the sample size; t is the confidence interval of 1.96; p is the proportion of the target population (0.5); the variable q which is computed as, 1- p is the weighting variable. $(p)(q)$ is the estimate of variance; and d is the accepted marginal error of 0.05. Following this formula, $n = \frac{(1.96)^2 * (0.5)(0.5)}{0.05^2}$ the sample size was determined as 384 farmers. Six questionnaires were incomplete and were excluded from the survey data, reducing the study's sample size to 378 dairy farming households.

3.7.3 Sampling technique

The study employed a multistage random sampling technique. In the first stage, two sub-counties were purposively selected to represent the regions with a relatively higher concentration of farmers practicing dairy production. Three wards were purposively selected from each sub-counties to represent different agro-ecological zones (namely the upper midland 1 (UM1), the coffee-tea zone; upper midland 2 (UM2), the main coffee zone; and upper midland 3 (UM3), the marginal coffee zone) in the county. In the third stage, three enumeration villages were purposively selected from each ward to represent different social-cultural and economic characteristics. In the fourth stage, the research team worked with the local county officials and village elders to generate a list of dairy farming households. From the lists generated, dairy farming households were randomly sampled and interviewed proportionate to the population of each village.

3.8 Data collection

Data were collected through household survey questionnaires, key informant interviews (KIIs) and focus group discussions (FGDs). Two FGDs (one from each sub-county) were conducted with smallholder dairy farmers recommended by the local livestock officers. The FGDs were important in understanding types of livestock production systems, challenges faced in livestock production, types of feed sources utilized, feed sourcing arrangements, important characteristics in selecting livestock feed products and the nature of livestock productivity. On the other hand, six KIIs were held with critical stakeholders, including feed processors and the local agricultural and livestock officers. The KIIs aimed to attain a better understanding of livestock feed formulations

- feed ingredients used, challenges surrounding their utilization among livestock farmers, pricing and farmers' preferences.

3.9 Data analysis

Data collected was coded, cleaned and entered in IBM Statistical Package for Social Sciences (SPSS) software version 26.0 to run the descriptive statistics (means, standard deviations, frequencies, percentages, minimum and maximum values). This was to ensure that the data obtained was relevant - had no errors and missing values.

Regarding the first objective, to characterize the livestock feed systems among smallholder dairy farmers in Murang'a county of Kenya, the study run descriptive statistics in terms of means, standard deviations, frequencies and percentages. Characterization was done mainly on livestock production systems, type of feed resources, sourcing arrangements, seasonality of feed, expenditure on feed and livestock feed security. The second objective which is to assess willingness to use insect-based livestock feed, was analyzed using a heteroskedastic probit (hetprobit) regression model run in STATA version 16 software. Finally, the third objective to assess preferences for livestock feed attributes applying a choice experiment approach, was analyzed using a mixed logit regression model. The study also performed diagnostic tests specifically Wald chi-square test, Lagrange Multiplier test and log likelihood on the data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the study findings and discussions based on the study objectives. The chapter has four sections. The first section (section 4.2) presents the descriptive results of the variables which were included in the study's empirical models. The second section (section 4.3) presents results and discussions on characterization of livestock feed systems in the study area. The empirical results and findings on the willingness to use insect-based livestock feed and preferences for livestock feed attributes among smallholder dairy farmers are discussed in (section 4.4) and (section 4.5) respectively.

4.2 Descriptive statistics of household characteristics

Descriptive statistics in terms of means, measures of dispersion (standard deviation), and frequencies were used to present the results of the sampled dairy farming households based on three agro-ecological zones (AEZs) in Murang'a County. The AEZs are namely the upper midland one (UM1); upper midland two (UM2); and upper midland three (UM3). Statistical tests such as one way analysis of variance (ANOVA) and Pearson's chi-square test were used to test for heterogeneities in household characteristics across the three AEZs. Table 4.1 presents the results for continuous variables and Table 4. ***2*** for categorical variables.

Table 4.1: Descriptive statistics for continuous variables

Variable	Pooled sample (N=378)		Agro-ecological zone[1]				
			UM1 (N=126)	UM2 (N=118)	UM3 (N=134)		
	Mean	Std dev.	Mean	Mean	Mean	F	p-value
Age (yrs)	52.1	14.7	50.7	53.1	52.5	0.85	0.43
Experience in dairy farming (yrs)	16.3	13.7	16.5	15.8	16.7	0.13	0.88
Household size (no.)	4.0	2.0	4.0	4.0	4.0	0.85	0.43
Farm size (acres)	1.5	1.3	1.7	1.1	1.6	3.83	0.02
Dairy cattle (no.)	3.0	2.0	3.0	2.0	3.0	2.90	0.06
Milk yield (litre/cow/day)	6.3	6.3	8.7	5.4	4.9	14.95	0.00
Distance to nearest market (km)	2.5	2.1	1.8	1.9	3.7	37.69	0.00
Distance to nearest tarmac road (km)	1.8	1.7	1.6	1.2	2.4	19.95	0.00
Household yearly income (KES)	280,903	277314.2	316,169	244,436	279,855	2.05	0.13

[1]See text for description of the agro-ecological zones; statistically significantly different at 1%, 5% and 10% levels based on one-way ANOVA. *Kenyan currency 1 USD=102.25 KES* at the time of the survey

The results in Table 4.1 show that the mean age of the dairy farmers was 52 years implying that dairy farming in the study area is dominated by mid-aged farmers. This observation compares well with an average age of 50 to 56 years reported in other Kenyan smallholder surveys (Kamau *et al*., 2018; Lutomia *et al*., 2019; Okello *et al*., 2021). The study considered the age of the farmer an important individual characteristic that defines the knowledge and experience gained by farmers in the uptake of farm practices and innovations over a period of time (Mwangi and Kariuki, 2015).

The average years of farmers' experience in dairy farming was 16 years, suggesting that the farmers are relatively experienced in dairy farming. The study considered years of experience in dairy farming an important farmer characteristic in influencing household decision making concerning uptake and utilization of farm practices and technologies (Dhraief *et al*., 2018). The results in Table 4.1 further show that the average household size was four (4) members which compares well with the county mean of three (3) members reported in the national population and housing census (Republic of Kenya, 2019). The study included household size as an indicator of family labour availability among the dairy farming households (Mwaura *et al*., 2021).

The average farm size was 1.5 acres which is relatively smaller compared to an average of 2.5 to 3.2 reported in other Kenyan smallholder surveys (Murage *et al*., 2019; Wekesa *et al*., 2018). The average farm size reported in the study compares well with the county's average of 1.4 acres reported in the County Integrated Development Plan 2018-2022 (Murang'a County Integrated Development plan, 2018). Comparatively, the results show that household in UM1 and UM3 had significantly ($p<0.05$) bigger farm sizes compared to those in UM2. The difference in the mean farm sizes across the AEZs could explain the differences in the scale of livestock production. Farm size is important in livestock production because of its influence on the choice of agricultural enterprise, scale of operations in terms of herd size and / or type of livestock kept, production system and livestock feed sourcing arrangements (Njarui *et al*., 2016a).

The average number of dairy cows per household was three (3) which is consistent with an average of three (3) dairy cows reported by Okello *et al*. (2021) and Tegemeo Institute of Agricultural Policy and Development (2021) in Murang'a county. Consistent with the pattern of farm size, households in UM1 and UM3 had significantly ($p<0.1$) higher scale of operation in terms of number of dairy cows when compared to those in UM2. The variation in the scale of operation across the three AEZs could be attributed to the differences in the average size of land holdings which can determine herd sizes owned by farmers.

Concerning milk productivity, Table 4.1 results show that the average milk yield was 6.3 litres per cow per day. The average milk yield is slightly lower than an average productivity of 9.6 litres/cow/day reported by Tegemeo Institute of Agricultural Policy and Development (2021) in Murang'a county. The difference in the reported average milk productivity in the study area may be due to the season data was collected. Comparatively, the results indicate that households in UM1 had significantly ($p<0.01$) higher milk yields compared to those in UM2 and UM3. The higher milk yields observed among households in UM1 could be explained by their ownership of bigger farm sizes which can support production of additional feeds for the dairy cows. From the FGDs and KIIs, farmers

reported that ownership of bigger farm sizes contributed to the supply of dairy cows with required amounts of feed roughages which can enhance livestock productivity.

The average distances from the farm to the nearest market was approximately 2.5 km while the distance was 1.8 km to the nearest tarmac road. Households in UM1 and UM2 were significantly ($p<0.01$) closer to the market centres and tarmac road compared to those in UM3. This imply that households in UM1 and UM2 have better access to markets than those in UM3 which could be attributed to the differences in the households' access to infrastructural facilities. The average distance to the market reported in this study compares well with an average of 2.1 km reported by Okello *et al*. (2021) in Murang'a county. The study included distances to the markets and tarmac roads as proxy of market related transaction costs which can influence farmers' access to livestock inputs and marketing of livestock products.

With regard to household income (from various sources), the results showed that the mean household annual income was KES 280,903 (translates to an average of KES 23,408.6 per month which is an equivalent of $ 228.9 per month). Using the mean household size of four (4) members per household, the average per capita income for the households was calculated as KES 5,852.1 ($ 57.2) per month. The result compares well with the Kenya National Bureau of Statistics (2022) report indicating an average gross national income of KES 241,466.8 (which translates to an average of KES 20,122.2 per month) and monthly per capita income of KES 5,159.5 ($ 47.0).

Table 4. 2: Descriptive statistics for categorical variables

Variable	Pooled sample (N=378)	Agro-ecological zone				
		UM1 (N=126)	UM2 (N=118)	UM3 (N=134)	χ^2	p-value
Gender (1 if male)	83.6	91.3	81.4	78.4	8.52	0.01
Highest education attained (1 if post-primary)	53.9	60.5	47.0	53.7	4.40	0.11
Household land tenure status						
Own land with a title deed	24.8	15.4	24.1	34.4	12.09	0.00
Own land without a title deed	10.4	4.9	12.9	13.2	5.99	0.05
Rented land	2.5	0.8	5.2	1.6	5.39	0.07
Family land	62.3	78.9	57.8	50.8	22.64	0.00
Membership in a farmer group (1 if yes)	47.6	61.9	37.3	43.3	16.37	0.00
Access to extension service (1 if yes)	29.6	31.0	23.7	33.6	3.08	0.21
Access to credit (1 if yes)	28.0	41.3	23.7	19.4	16.97	0.00
Access to health, livestock and crop insurance service (1 if yes)	36.5	50.8	30.5	28.4	16.77	0.00
Wealth index						
Poorest	54.9	35.2	75.2	55.7	39.13	0.00
Middle	28.0	34.4	18.0	30.8	8.93	0.01
Wealthiest	17.1	30.4	6.8	13.5	25.52	0.00

Statistically significantly different at 1%, 5% and 10% levels based on Pearson's chi-square test

The results in Table 4. 2 indicate that overall, the majority of households were male-headed (84%). This could be attributed to the fact that most smallholder farm households in sub-Saharan Africa are male dominated (Perez *et al*., 2015). The study's finding is supported by other Kenyan surveys; Mwangi *et al*. (2020) and Okello *et al*. (2021) who found that majority of smallholder farming households in Kenya were male headed. The gender of the household head varied significantly ($p<0.05$) across the three AEZs with households in the UM1 having a relatively larger proportions of male heads. The study included gender of the household head because of its influence on household decision making and resource allocation in agricultural activities.

The results also indicate that more than half of the dairy farmers had attained post-primary education (54%) implying fairly good literacy levels of the smallholder dairy farmers. The finding differs from the results reported by Okello *et al*. (2021) in Kenya, where majority of smallholder dairy farmers had attained primary level of education. According to Thuo and Njoroge (2018), education is an important individual characteristic which can

influence and determine the traits farmers depict as they source and utilize information relevant to farming. Farmers who are educated can access and utilize different information sources which can improve their level of farm productivity.

Concerning land tenure status, the households' most common form of land tenure was family land (62%). The proportion of households who owned family land was significantly ($p<0.01$) higher in UM1 compared to UM2 and UM3. This variation could be attributed to the differences in farm sizes across the AEZs which determine land succession within the family (Table 4.1). The study considered land tenure an important farm characteristic which can influence decision making in land use, control and resource allocation in relation to agricultural activities.

In terms of institutional support, 48 percent of farmers were members of farmer groups. UM1 had significantly ($p<0.01$) higher proportions of farmers with membership to farmer groups compared to UM2 and UM3 implying that farmers in the UM1 invest more on social networks. The difference in group membership across the AEZs could explain the differences in various resource ownership. Household membership to a farmer group was considered as a measure of social capital and collective action. This variable is important in livestock production because of its influence on farmers' bargaining power, transaction costs and access to market information and credit services (Sinyolo and Mudhara, 2018).

The results further showed that only 28 percent of the farmers had access to credit indicating a very low level of credit access by the smallholder dairy farmers. UM1 had significantly ($p<0.01$) higher proportions of farmers with access to credit facilities compared to UM2 and UM3. This variation could be associated with the differences in land ownership and farm sizes reported in (Table 4.1). Moahid and Maharjan (2020) states that total farm size increases credit needs following demand for farm inputs. Agricultural land is considered a prominent collateral in acquiring formal credit among rural households. The study considered credit access as a significant institutional support which influences farmers' access to livestock inputs (feeds, machinery, land, veterinary drugs and

vaccines), uptake of dairy technologies and investment in other farm capitals including upgrading dairy breed and increasing flock size.

Regarding farmers' access to insurance services on health, livestock and crop, the results showed that only 37 percent of the farmers had access to insurance services. UM1 had significantly ($p<0.01$) higher proportions of farmers with access to insurance services compared to UM2 and UM3. The low level of access and variation in insurance services across the study zones could be explained by the fact that there is generally limited uptake to agricultural insurance often associated with lack of awareness and perception that insurance companies are difficult in paying out claims (Nshakira-Rukundo *et al*., 2021). The study considered insurance services to be important institutional support service which can influence farmers' risk management strategies in agricultural production and marketing.

In general, only 30 percent of the farmers had access to extension implying a very low level of extension access among smallholder dairy farmers in the study area. From the FGDs and KIIs, farmers and agricultural officers attributed the low level of access to extension in the study area to the transfer of extension services in the rural areas of Kenya with limited resources such as extension staffs and transport facilitation for extension workers. These results are consistent with Mbeche *et al*. (2022) who reported a weak extension-research-farmer linkages among smallholder tea farmers in Kenya. Access to extension service is an important institutional support to livestock farmers as it enables farmers to obtain relevant information on the existence, benefits and effective use of various farm technologies (Mwangi and Kariuki, 2015).

Results for the wealth index showed that most households (55%) were reportedly poor while only 17 percent were wealthy. As expected, UM1 had significantly ($p<0.01$) higher proportions of households who were wealthy at 30 percent compared to 7 percent in UM2 and 14 percent in UM3. The variations in wealth categories could be explained by differences in household utilities (land size, herd size), milk productivity, access to public services and institutional support reported in the study findings. The wealth index was

considered as a measure of households' cumulative living standard which comprises households' productive and non-productive assets, and utilities (Hjelm *et al*., 2017). Wealth status can influence households' access to resources and their uptake of farm technologies.

Overall, the results indicate that there were marked differences in household characteristics across the three AEZs with regard to male-headed households, farm size, herd size, milk yield, distances to the nearest market and tarmac road, land tenure status, group membership, access to credit and insurance services, and wealth status. It seems that the households in UM1 were generally more endowed with resources compared to their counterparts; the resources cut across land, and even natural capital. These variations provide an opportunity for understanding the socioeconomic characteristics of smallholder dairy farmers in the specific AEZs.

4.3. Characterization of livestock feed systems

The first objective of this study sought to characterize livestock feed systems in the study area. The characterization is important in building understanding on various indicators that are important in improving access to livestock feed among smallholder farmers. The objective considered five indicators namely; i) dairy production systems, (ii) type of feed resources and sourcing arrangements, (iii) seasonality in feed utilization, (iv) expenditure on feed, and (v) livestock feed security. The findings of the five indicators are presented in sections 4.3.1 to 4.3.5.

4.3.1 Types of dairy production systems

Production systems in a livestock enterprise can generally be categorized based on the input-output relationship. Three broad production systems can be discerned; low input-low output (low extensive), moderate input-moderate output (semi-intensive) and high input-high output (highly intensive) system (Tegemeo Institute of Agricultural Policy and Development, 2021). The type of production system adopted by a livestock farmer can have a very significant influence on the feeding regimes. Understanding the production systems is therefore an important prerequisite for characterizing a feed system. The study

focused on dairy cattle which is one of the main livestock types farmed in the study area. A summary of production systems practiced by smallholder dairy farmers in the three AEZs is presented in Table 4.3.

Table 4.3: Smallholder dairy production systems

Production system (%)	Pooled sample (N=378)	UM1 (N=126)	UM2 (N=118)	UM3 (N=134)	p-value
Zero-grazing	97.1	99.2	96.6	95.5	0.196
Semi-intensive	2.9	0.8	3.4	4.5	0.196

Statistically significantly different at 1%, 5% and 10% levels based on Pearson's chi-square test

Results presented in Table 4.3 show that the prevailing production system for dairy cattle across the three study zones was zero-grazing system which is practiced by 97 percent of the farmers. This finding is consistent with that of Tegemeo Institute of Agricultural Policy and Development (2021) who found that zero grazing system was the most dominant production system among smallholder dairy farmers in the central highlands of Kenya. In the zero-grazing units, the farmers were restricting the dairy cattle movements while supplying them with feed and water.

In most households, the zero grazing units were made from erected wooden poles with iron sheet roofs. Most of the floors were soil based with only a few having concrete. The rearing of dairy cattle in a zero-grazing system was mainly attributed to the limited land holdings (an average of 1.5 acres) reported across the three AEZs (Table 4.1). None of the farmers in the three AEZs practised extensive (open grazing) system which was generally attributed to the farmers limited land holdings indicated by the study findings in section 4.2.

The farmers pointed out that the main purpose of keeping dairy cattle was to provide them with income through the sale of milk and provision of milk for home consumption. Other production purposes were to provide them with manure for planting, income through the sale of fattened bulls and generation of biogas from the manure for use in cooking. The major constraints to livestock production reported by the dairy farmers were limited land holdings for forage cultivation, inadequate access to good quality

forage during the dry seasons, and high cost and unreliable quality of commercial concentrate feeds.

4.3.2 Types of feed and sourcing arrangements

Feed is a critical element in providing adequate nutrition to the livestock. Therefore, in this section, the study sought to understand the various feed resources utilized by smallholder dairy farmers in the study area. Table 4.4 presents various feed resources utilized by smallholder dairy farmers in the three AEZs.

Table 4.4 : Types of feed resources

Feed types (%)	Pooled sample (N=378)	UM1 (N=126)	UM2 (N=118)	UM3 (N=134)	p-value
Napier grass	99.2	100	99.2	98.5	0.398
Crop residues (maize stover, haulms of beans, sweet potato vines)	91.0	88.1	94.1	91.0	0.302
Banana stems and leaves	33.9	34.1	37.3	30.6	0.533
Fodder trees leaves	12.7	13.5	11.0	13.4	0.803
Natural pasture (grazing)	2.9	0.8	3.4	4.5	0.196
Silage	18.5	26.2	5.9	22.4	0.000
Hay	43.4	60.3	36.4	33.6	0.000
Concentrate feeds	98.9	99.2	99.2	98.5	0.829

Statistically significantly different at 1%, 5% and 10% levels based on Pearson's chi-square test

Results presented in Table 4.4 show that generally, Napier grass was the most commonly utilized fodder grass with nearly all the dairy farmers (99%) in the three AEZs. The farmers indicated that Napier grass was usually chopped and provided to the dairy cows under zero grazing system. This finding concurs with that of Kashangaki and Ericksen (2018) and Njarui *et al*. (2021) who also reported that Napier grass was the primary fodder grass cultivated by over 90 percent of smallholder dairy farmers in the central highlands and eastern midlands of Kenya. According to Makini *et al*. (2019) and Kiptot *et al*. (2015), Napier grass is the most preferred fodder among smallholder dairy farmers in Kenya because of its desirable characteristics when compared with other fodder grasses. These include its drought-tolerant ability, ability to grow fast and regrow after cutting, evergreen, palatable, has high biomass and can be used to prepare silage.

Similarly, crop residues were widely used as supplemental dairy cattle feed with 88 to 94 percent of smallholder dairy farmers utilizing it across the three AEZs. The crop residues mainly comprised green and dry maize stover, haulms of beans and sweet potato vines. The use of crop residues as a principal source of livestock feed is also reported by Alaru *et al*. (2023) and Njarui *et al*. (2016b) in smallholder livestock systems in Kenya. The contribution of other residues, specifically banana stems and leaves to livestock feed was generally low across the study zones; less than 40 percent of the farmers utilized residues from banana stems and leaves. The low utilization of banana residues could be explained by the dairy farmers' perceptions that banana residues have an undesirable effect on milk quality i.e., taints milk when fed a lot to the dairy cattle. From observations, a few farmers utilized feed from green maize fodder. However, this was not a common practise among the smallholder dairy farmers in the study area largely attributed to limited land for forage cultivation and need for food crops production (Kashangaki and Ericksen, 2018).

Other feed resources utilized by farmers were fodder tree leaves and natural pasture. Fodder tree leaves were utilized by less than 15 percent of the farmers across the AEZs. The farmers mentioned that the common fodder tree utilized in the study area was *Grevillea robusta*. The tree leaves were used as an alternative fodder source for the dairy cattle during the dry season when other fodder resources were scarce. From the KIIs, it was reported that generally the low uptake of fodder tree leaves among dairy farmers in the study area was due to inadequate knowledge on the recommended fodder trees and nutritional benefits to the livestock. The results also reveal that the grazing of cattle directly on natural pasture was limited, with less than five (5) percent of farmers utilizing the practise across the three study zones. This is attributed to the diminishing land resource base, intensive land sub-divisions and need for food crops production (Makini *et al*., 2019)

In dairy production, feed conservation either as hay or silage is essential as it prolongs availability and quality of feed for livestock during the dry season (Makini *et al*., 2019).

The proportion of farmers utilizing hay feeding ranged between 30 to 60 percent, suggesting a growing uptake in the feed practise in recent years. Utilization of hay has also been reported by Njarui *et al*. (2016b) as one of the key feeding practices in cushioning livestock from feed scarcity in the central highlands of Kenya. As expected, use of hay to feed the dairy cows was significantly ($p<0.01$) higher among farmers in UM1 compared to those in UM2 and UM3. This variation in hay utilization in the three AEZs can be explained by the differences in household wealth status, access to market and credit facilities which have implications on feed availability and accessibility.

As shown in Table 4.4, the utilization of silage was generally low ranging from 6 to 26 percent across the three AEZs. FGD information indicated that the silage was mainly prepared from Napier grass and green maize stover. Low utilization of silage among smallholder dairy farmers in Kenya has also been reported by Makini *et al*. (2019) and Tegemeo Institute of Agricultural Policy and Development (2021). Similar to the pattern observed in the utilization of hay, the use of silage was significantly ($p<0.01$) higher among farmers in UM1 compared to those in UM3 and UM2. The variation in silage use in the three AEZs could be explained by the differences in resource endowment and access to information across the AEZs as shown in section 4.2. From the FGDs, the farmers generally attributed the low utilization of silage in the study area to limited land for forage production, lack of technical know-how on silage preparation, high cost of ensiling materials and high labour demand.

Concerning concentrate feeds, Table 4.4 shows that nearly all the smallholder dairy farmers (99%) in UM1, UM2 and UM3 used concentrates to supplement the dairy cattle. The farmers indicated that the concentrate diets were mainly utilized as supplemental feeds to increase milk productivity. This result is consistent with Alaru *et al*. (2023) and Kimenchu *et al*. (2014) who reported that over 80 percent of smallholder dairy farmers in central Kenya utilized concentrates to supplement the dairy cattle diets, primarily to enhance milk production. The different groups of concentrate feeds utilized by the smallholder dairy farmers across the three AEZs are presented in Table 4.5. The

concentrates were categorized into livestock feeds rich in energy, protein, compounded feeds (ready-mixed concentrate feeds manufactured by feed industries) and mineral supplements.

Table 4.5: Concentrate feeds

Concentrate feeds (%)		Pooled sample (N=378)	UM1 (N=126)	UM2 (N=118)	UM3 (N=134)	*p-value*
Energy	Maize germ	68.8	87.3	64.4	55.2	0.000
	Maize bran	28.0	15.9	41.5	27.6	0.000
	Wheat bran	29.4	43.7	22.9	21.6	0.000
	Wheat pollard	52.4	42.1	39.0	73.9	0.000
Protein	Cotton seed cake	14.8	18.3	12.7	13.4	0.409
	Soybean meal	10.8	16.7	5.9	9.7	0.073
	Fish meal	13.2	15.1	10.2	14.2	0.488
	Coconut meal	4.5	7.1	1.7	4.5	0.122
	Canola cake	2.9	4.8	2.5	1.5	0.283
	Sunflower cake	14.8	18.3	15.3	11.2	0.275
	Groundnut cake	6.1	7.1	4.2	6.7	0.595
	Macadamia meal	1.9	3.2	0.8	1.5	0.377
	Bone meal	4.2	3.2	5.1	4.5	0.750
Compounded feed	Dairy meal	49.2	50.8	41.5	54.5	0.099
Mineral supplements	Lick, rock and common salts	74.1	69.8	84.7	68.7	0.006

Statistically significantly different at 1%, 5% and 10% levels based on Pearson's chi-square test

Results shown in Table 4.5 indicate that overall, energy concentrates, dairy meal and mineral supplements were the most utilized feeds to supplement the dairy cattle across UM1, UM2 and UM3. Among the energy concentrates, maize germ was the most utilized by farmers (68.8%), followed by wheat pollard (52.4%), wheat bran (29.4%) and maize bran (28%). The Pearson's chi-square test results revealed significant differences ($p<0.01$) in the proportion of farmers who utilized energy concentrates across the three AEZs. Utilization of maize germ and wheat bran was highest among farmers in UM1 while the use of maize bran and wheat pollard was highest among farmers in UM2 and UM3 respectively. The variations in the utilization of the different energy concentrates across the AEZs was mainly attributed to availability of the feed ingredients in the specific AEZs. From the FGDs, the farmers indicated that they mostly

utilized energy concentrates since they were easily accessible at the local markets and relatively cheaper compared to the protein concentrates.

Protein concentrates are critical in livestock productivity, general health and growth (Makini *et al*., 2019). The results in Table 4.5 show that overall, a small proportion (15%) of the farmers used protein concentrates. Among the protein concentrates, cotton seed cake and sunflower cake were the most common (15%). The low usage of protein concentrates among farmers could be attributed to their high prices, low quality and limited availability at the local markets. At the time of the survey, the market price of the protein concentrates ranged between KES 80 to 120 per kilogram, compared to KES 20 to 30 per kilogram for the energy-based feed. The low utilization of protein concentrates among smallholder dairy farmers would have an influence on their willingness to utilize alternative protein feed sources (Chia *et al*., 2020).

Dairy meal was the main compounded feed used by 49 percent of farmers to supplement the dairy cattle diets. The farmers reported that feed supplementation with dairy meal was essential in improving milk yields. Utilization of dairy meal to supplement the dairy cattle to increase milk productivity has also been reported by Kimenchu *et al*. (2014) as a common practice among smallholder dairy farmers in central Kenya. However, more than half of the farmers indicated that they did not use dairy meal due to its perceived high cost and unreliable quality (Tegemeo Institute of Agricultural Policy and Development, 2021).

Most smallholder dairy farmers (74%) across the study zones provided mineral supplements to the dairy cattle. The commonly used mineral supplements were lick, rock and common salts. The proportion of farmers who used mineral supplements was significantly ($p<0.01$) higher in UM2 compared to UM1 and UM3. The difference in the use of mineral supplements in the three AEZs could be attributed to the differences in livestock mineral requirements among households in the specific AEZs. The farmers indicated that feed supplementation with mineral supplements is an economical practice that maximizes on the livestock performance (Makini *et al*., 2019).

Livestock feed sourcing arrangement was one of the important indicators used to characterize the feed systems in the study area. This indicator can play an important role in influencing smallholder dairy farmers' decisions on willingness to utilize alternative feed sources. Figure 4.1 presents the sourcing arrangements for various feed resources.

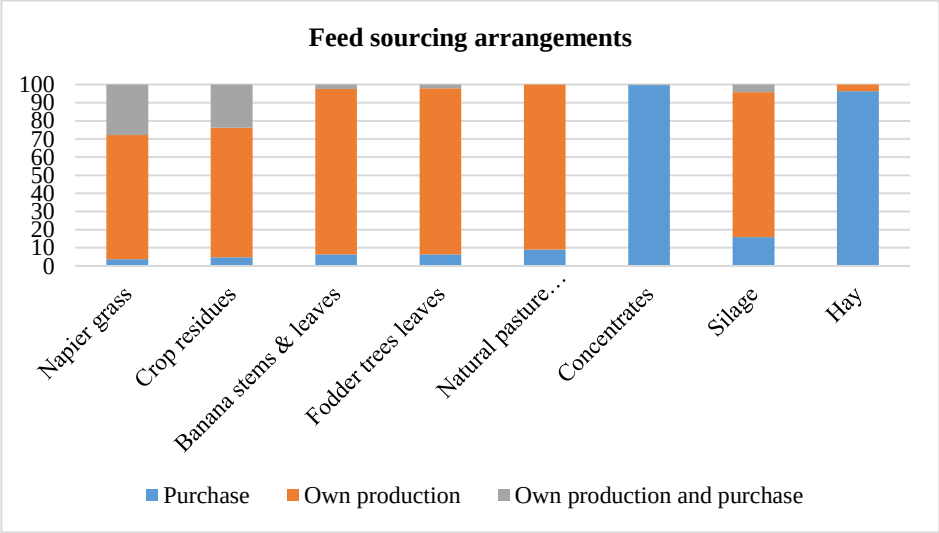

Figure 4.1: Feed sourcing arrangements

The results in Figure 4.1 show that the smallholder dairy farmers in the study area sourced most of the feed resources (Napier grass, crop residues, banana stems and leaves, fodder tree leaves, natural pasture and silage) from their own farms. However, sometimes the farmers could not obtain adequate Napier grass and crop residues from their farms and thus were forced to buy from other sources mostly from fellow farmers. Studies by Tegemeo Institute of Agricultural Policy and Development (2021) and Alaru *et al*. (2023) reported similar findings. This was generally attributed to the farmers limited land holdings for cultivation (an average of 1.5 acres) in the study area. Concentrates and hay were predominantly sourced commercially from dairy cooperatives, local agro-vet shops, stockists or feed companies supplying the local areas. However, none of the farmers utilized their own homemade dairy concentrates at the time of the survey, mainly attributed to their lack of technical knowledge on preparation of homemade concentrates and high cost of ingredients.

4.3.3 Seasonal feed availability and utilization

Table 4.6 presents Pearson's chi-square test results outlining the differences in the proportion of farmers utilizing various feed resources based on seasonal availability in the three study zones.

Table 4.6: Seasonality in feed utilization among smallholder dairy farmers

Feed type (%)		**Pooled sample (N=378)**	**UM1 (N=126)**	**UM2 (N=118)**	**UM3 (N=134)**	***p-value***
Napier grass	Wet season	16.2	7.1	16.8	15.7	0.082
	Dry season	13.4	14.1	14.2	20.6	0.353
	All year round	70.4	78.8	69.0	63.7	0.060
Silage	Wet season	2.0	4.2	0.0	2.6	0.591
	Dry season	82.0	66.6	80.0	71.4	0.240
	All year round	16.0	29.2	20.0	26.0	0.027
Crop residues (maize	Wet season	7.5	5.8	3.8	13.5	0.030
stover, haulms of beans,	Dry season	81.1	87.2	93.3	60.7	0.000
sweet potato vines)	All year round	11.4	7.0	2.9	25.8	0.000
Hay	Wet season	2.3	3.5	0.0	3.0	0.489
	Dry season	79.5	77.2	88.1	72.7	0.224
	All year round	18.2	19.3	11.9	24.3	0.378
Banana stems and leaves	Wet season	4.0	0.0	4.5	8.1	0.184
	Dry season	76.6	95.3	70.5	62.2	0.001
	All year round	19.4	4.7	25.0	29.7	0.008
Fodder trees (leaves)	Wet season	9.8	6.3	9.1	14.3	0.772
	Dry season	75.6	81.3	90.9	57.1	0.124
	All year round	14.6	12.4	0.0	28.6	0.134
Natural pasture (grazing)	Wet season	37.5	0.0	25.0	50.0	0.537
	Dry season	62.5	0.0	75.0	50.0	0.537
	All year round	0.0	0.0	0.0	0.0	
Concentrate feeds	Wet season	0.0	0.0	0.0	0.0	
	Dry season	2.2	1.1	1.9	4.0	0.431
	All year round	97.8	98.9	98.1	96.0	0.431

Statistically significantly different at 1%, 5% and 10% levels based on Pearson's chi-square test

The results in Table 4.6 generally show that out of the proportion of farmers who used the various feed resources presented in **section 4.3.2**, a large proportion of the farmers used Napier grass and concentrate feeds throughout the year. Crop residues, hay, banana stems and leaves and fodder trees were largely used in the dry season. Other feed resources utilized in the dry season were silage and natural pasture. However, some of the farmers also commonly used Napier grass and natural pasture in the wet season.

Out of the proportion of farmers who used Napier grass in **section 4.3.2**, 70 percent indicated that they utilized the feed all year round. This was mainly attributed to its desirable traits that comprise drought tolerant ability, ability to grow fast and regrow after cutting, evergreen, palatable and its use as silage (Kiptot *et al*., 2015; Makini *et al*., 2019). However, the farmers indicated that usage of Napier grass was predominant in the wet season when the feed resource was in abundance.

Out of the proportion of farmers who used crop residues in **section 4.3.2**, majority (81%) reported that they utilized crop residues from dry maize stover, beans haulms and sweet potato vines during the dry season. This result corroborates the findings of Alaru *et al*. (2023) and Njarui *et al*. (2016b) who reported that crop residues were the dominant feed during the dry season in smallholder livestock systems in Kenya. The proportion of farmers who used crop residues in the dry season was significantly ($p<0.01$) higher in UM2 compared to those in UM1 and UM3. According to Umutoni *et al*. (2015), crop residues are the most available feed resource utilized by farmers during the dry season when the quality and quantity of available forage has declined significantly.

Out of the proportion of farmers who used hay, silage, banana leaves and stems, and fodder tree leaves in **section 4.3.2**, a large proportion of the farmers indicated that they commonly utilized these feeds during the dry season to cushion the dairy cattle against feed scarcity. These results are supported by Jimma *et al*. (2016), Njarui *et al*. (2016b) and Tegemeo Institute of Agricultural Policy and Development (2021) who reported that utilization of hay, silage, banana stems and leaves and fodder tree leaves during the dry season was one of the commonly used copying strategy by smallholder farmers to cushion the cattle against feed scarcity.

Out of the proportion of farmers who used natural pasture in **section 4.3.2**, about 63 and 38 percent reported that they utilised the feed in the dry and wet season respectively. The farmers indicated that natural pasture was mainly utilized in the dry season due to severe feed shortage and in the wet season, because of excess pasture that had grown within the homesteads and by the road sides. Almost all the farmers (98%) utilized

concentrate feeds all year round irrespective of the season. According to Tegemeo Institute of Agricultural Policy and Development (2021) and Alaru *et al*. (2023), regular livestock supplementation with concentrates is key in enhancing livestock productivity and feeding value.

4.3.4 Expenditure on livestock feeds

Table 4.7 presents the farmers' average monthly expenditures in Kenya shillings (KES) on various feed resources across the AEZs.

Table 4.7: Average monthly expenditure on livestock feeds

	Pooled sample (N=378)		UM1 (N=126)	UM2 (N=118)	UM3 (N=134)	
Feed type	**Mean**	**Std dev.**	**Mean**	**Mean**	**Mean**	***p-value***
Energy concentrates	4,850.2	3,521.2	6,717.0	3,788.9	4,029.5	0.000
Protein concentrates	384.4	347.0	441.7	184.6	506.5	0.603
Dairy meal	2,679.1	2,490.0	4,297.5	1,218.9	2,443.1	0.038
Mineral supplements	829.7	652.8	1,070.8	863.5	573.4	0.011
Hay	3,463.4	2,332.3	4,513.8	2,311.4	3,490.2	0.183
Napier grass	3,761.1	2,905.6	2,398.8	1,543.6	6,994.8	0.360
Crop residues	1,139.4	1,093.2	866.7	832.1	1,666.4	0.164

Statistically significantly different at 1%, 5% and 10% levels based on one-way ANOVA; *Kenyan currency 1 USD=102.25 KES* at the time of the survey

The results in Table 4.7 show that on average, the farmers had high expenditures on energy concentrates (KES 4,850.2), Napier grass (KES 3,761.1) and hay (KES 3,463.4) across the study zones. These results are not surprising because from earlier observations on feed resource utilization, the feed resources were most commonly utilized by the smallholder dairy farmers in the study area. As expected, the farmers had less expenditures on protein concentrates (KES 384.4) and mineral supplements (KES 829.7). The less expenditure on protein concentrates was largely attributed to their low utilization among farmers across the three AEZs. The less expenditure on mineral supplements could explain the fact that farmers gave the mineral supplements to the dairy cattle as micronutrients, and thus require them in small quantities when feeding the livestock (Gachuiri and Lukuyu, 2021).

Comparisons across the three AEZs showed that farmers in UM1 had significantly ($p<0.01$) higher expenditures on energy concentrates, dairy meal and mineral supplements compared to those in UM2 and UM3. The variation in the feed expenditures could be explained by the differences in resource endowment in the three AEZs as shown in section 4.2 which can have implications on feed access. That is, farmers who are more endowed with resources are likely to spend more on feed acquisition compared to their counterparts with less resources. The findings imply the need for interventions to build the capacity of resource-poor dairy farmers in accessing financial support that can enhance their access to livestock feeds.

4.3.5 Livestock feed security status

Livestock feed security was one of the key elements used to characterize the livestock feed system among the sampled households. The study applied the conceptualization in the measurement of food security to develop a scale for assessing livestock feed security. Such an approach has been used to assess the level of seed security by Mwangi *et al*. (2020) and Mucioki *et al*. (2018). The livestock feed security levels were measured using eight questions in four domains; 1) anxiety and uncertainty concerning feed access; 2) compromising on feed quality and variety; 3) reducing feed quantities; and 4) livestock going without feeding. The households' responses to the eight (8) questions were used to compute the livestock feed security experience score within a period of one year preceding the survey. The feed security experience score ranges between 0 and 8, where a score of 0 indicate a feed secure household; 1-3 indicate a mildly feed insecure household; 4-6 indicate a moderately feed insecure household; and 7-8 indicate a severely feed insecure household. The results are presented in Table 4. 8.

Table 4. 8: Status of household livestock feed security

During the last 12 months, was there a time when... because of lack of money or other resources: **(%)**	**Pooled sample (N=378)**	**UM1 (N=126)**	**UM2 (N=118)**	**UM3 (N=134)**	**p-value**
Anxiety and uncertainty of livestock feed					
You were worried that your livestock would not have enough feed to eat?	59.3	49.2	66.1	62.7	0.016
Compromising on quality and variety of livestock feed					
Your livestock ate a limited variety of feed?	61.9	50.8	71.2	64.2	0.004
You gave your livestock some type of feed that they really did not want to feed on or disliked?	66.4	53.2	72.9	73.1	0.000
Reducing quantities of livestock feed					
You had to reduce the livestock feed rations?	59.5	53.2	62.7	62.7	0.357
Livestock going without feeding					
You ever lack any kind of feed to give your livestock due to limited land?	27.5	18.3	29.7	34.3	0.032
You ever lack any kind of feed to give to your livestock due to extreme drought?	29.6	16.7	36.4	35.8	0.000
Your household run out of feed for the livestock?	2.1	0.8	2.5	3.0	0.437
Your livestock go without feeding for a whole day due to lack of feed?	1.9	0.0	1.7	3.7	0.082
Household feed security level					
Feed secure	22.5	31.7	15.7	22.5	0.006
Mildly feed insecure	27.2	25.4	25.4	30.6	0.558
Moderately feed insecure	48.7	42.1	52.5	51.5	0.190
Severely feed insecure	1.6	0.8	1.7	2.2	0.646

Statistically significantly different at 1%, 5% and 10% levels based on Pearson's chi-square test

The results show that in the preceding twelve months of the survey, most households (59%) were worried that they would not have enough feed for their livestock. Comparisons across the three AEZs indicated that households in UM2 (66%) and UM3 (63%) were more worried about obtaining enough feed for their livestock compared to households in UM1 (49%). This could perhaps be explained by the differences in agro-ecological conditions in the three AEZs, whereby UM1 is characterized by more

favourable conditions for livestock feed production than UM2 and UM3. Therefore, households in UM1 felt more secure regarding feed availability and accessibility.

The results further show that more than half of the households compromised on quality and variety of livestock feed. 62 percent of the households reported providing limited variety of feed to the livestock while 66 percent reported providing poor quality feed to the livestock. FGD information suggested that a number of farmers considered some of the feed sources from tree leaves, weeds and banana stems to be of poor quality. The Pearson's chi-square test revealed that households in UM2 and UM3 mostly compromised on the quality and variety of livestock feed compared to households in UM1. This could be explained by the fact that households in UM1 had better access to markets and credit facilities which have implications on feed access and livestock feeding.

Similarly, about 60 percent of the households reported reducing the quantity of feed given to the livestock to limit feed intake and manage feed supply. Feeding less to the livestock has been reported by Njarui *et al*. (2016b) as one of the commonly adopted copying mechanisms to cushion the livestock against feed scarcity among small-scale livestock farmers in Kenya.

The experience of livestock going without feeding was measured using a set of four questions. The results show that there are times in the twelve months preceding the survey when 28 percent of the households reported lacking any kind of feed to give the livestock due to limited land for forage cultivation, extreme drought (30%) and limited capital (2%). Limited land holdings, limited capital to invest, extreme drought and limited access to quality and adequate feeds have been reported to have major implications on livestock feeding in smallholder livestock systems in Kenya (Alaru *et al*., 2023; Kashangaki and Ericksen, 2018; Kashongwe *et al*., 2017; Lukuyu *et al*., 2011; Njarui *et al*., 2016b; Tegemeo Institute of Agricultural Policy and Development, 2021).

The results also indicate that the experience of livestock going without feeding was significantly higher among households in UM2 and UM3 compared to households in

UM1. This could be explained by the fact that households in UM1 utilized more conserved feeds, had bigger farm sizes, better access to credit and high investment in social capital and therefore had better access to resources that could be utilized to access adequate and quality feed.

Concerning household feed security levels, the results show that only 23 percent of the households were feed secure. Consistent with earlier observations on household feed insecurity experiences, households in UM1 were more feed secure than households in UM2 and UM3. The differences in feed security levels in the three AEZs could be explained by the fact that households in UM1 were more endowed with resources and capital that enabled them access to feed throughout the year. Additionally, the results indicate that 78 percent of the households experienced feed insecurity across the AEZs. Of these, 27 percent of the households were mildly feed insecure, 49 percent moderately feed insecure and only 2 percent were severely feed insecure. The results in this section revealed that smallholder dairy farmers across the three AEZs generally experienced livestock feed insecurity.

Overall, the findings on characterization of the livestock feed systems revealed that zero grazing was the dominant livestock production system across the study zones. The most commonly utilised feed resources were Napier grass, crop residues and feed concentrates. Only a small proportion of the farmers utilized conserved feed in form of silage attributed to limited land for forage cultivation, lack of technical know-how and high cost of ensiling materials. Among the concentrates, utilization of protein concentrates was very low largely attributed to their high prices and limited availability at the local markets. More than 70 percent of the sampled households experienced livestock feed insecurity. The findings suggest need for intervention to improve access to quality and affordable feed. These could include capacity building on feed conservation (hay and silage making) and utilization of emerging livestock feed sourcing alternatives.

4.4 Smallholder dairy farmers' willingness to use insect-based livestock feed

The second objective of this study seeks to assess smallholder dairy farmers' willingness to use insect-based livestock feed to supplement dairy cattle diets in Murang'a County of Kenya. The section is presented in three parts: Section 4.4.1 presents an overview of dairy farmers' awareness, practices and willingness to use insect-based livestock feed. In the following section the descriptive results of TPB constructs on use of insect-based livestock feed are presented and discussed. Finally, section 4.4.3 presents and discusses the empirical results and findings on the determinants of farmers' willingness to use insect-based livestock feed.

4.4.1 Farmers' awareness, practices and willingness to use insect-based livestock feed

Table 4.9 presents the results on awareness, practices and willingness to use insects as an alternative source of feed for dairy cattle.

Table 4.9: Farmers' awareness, practices and willingness to use insect-based livestock feed

Variable	(N=378)
Awareness	
Aware insects can be used as livestock feed? (% yes)	11.4
Practices	
If yes, have you ever used insects as feed? (%)	0.0
If never used insects as feed, would you consider giving them to your dairy cattle if they were made available? (% yes)	76.2
Willingness	
Assuming insect-based feed were made available, what would be your likelihood of purchasing them for your dairy cattle? (%, 1 if willing)	75.1

The results show that only 11 percent of farmers were aware of insects as feed prior to the survey. Television, radio, newspapers and farmer to farmer exchange of information were some of the channels through which farmers acquired information on the use of insects as livestock feed. None of the farmers who were aware had used insects to feed their dairy cattle prior to the study. While the farmers indicated a low level of awareness towards insects as livestock feed, majority (76%) of the farmers would be willing to use insect-based feed once it becomes available in the market. The high level of willingness

to use insects as feed could be linked to high costs of conventional protein sources which is a key challenge in livestock production in most developing countries (Domingues *et al*., 2020; Onsongo *et al*., 2018).

4.4.2 TPB constructs on use of insect-based livestock feed

In order to understand what would support or constrain farmers' willingness to use insect-based livestock feed, the study assessed attitudes, subjective norms and perceived behavioural control towards willingness to use insects as an alternative source of protein for dairy cattle. All the three constructs (attitude, subjective norm and perceived behavioural control) were attained using a set of statements measured on a five-point likert scale. Table 4.10 presents the results of TPB constructs on use of insect-based livestock feed.

Table 4.10: TPB constructs on use of insect-based livestock feed

Variables	Description	Mean	SD
ATT1	I would feed my dairy cattle on insect-based feed if it improves on their milk yield	4.35	1.21
ATT2	I would feed my dairy cattle on insect-based feed if the price is lower than for other protein feed ingredients	4.15	1.35
ATT3	I would feed my dairy cattle on insect-based feed if there is no other feed available	4.22	1.23
ATT4	In my community, it is a taboo to use insect-based feed in the dairy cattle diet	1.66	1.20
ATT		**4.24**	**1.17**
SN1	I would feed my dairy cattle on insect-based feed if my animal health officer assures me that they are safe for my dairy cattle	4.06	1.38
SN2	I would feed my dairy cattle on insect-based feed if I got an approval from a trusted organization such as government research institutes, dairy cooperatives and university research centres	4.02	1.35
SN3	I would feed my dairy cattle on insect-based feed if I hear or see on media (e.g., television, radio) that the feeds are good	3.57	1.60
SN4	I would feed my dairy cattle on insect-based feed if my customers for milk have no problem with it	3.55	1.72
SN		**3.88**	**1.21**
PBC	Buying insect-based feed for my dairy cattle, as soon as they become available for sale, will be entirely my choice	3.67	1.66

ATT, Attitude; SN, Subjective Norm; PBC, Perceived Behavioural Control; BI, Behavioural Intention; SD, Standard Deviation; TPB, Theory of Planned Behaviour

Table 4.10 results show generally positive attitudes on the perceived benefits associated with usage of insect-based livestock feed as an alternative source of protein for the dairy

cattle. The attitude statement with the most favourable appraisal was the perceived effect of insect-based livestock feed on milk yield (4.35), followed by availability of feed (4.22) and price (4.15). Similarly, farmers generally disagreed that use of insects as feed would be considered a community taboo (1.66), suggesting that they had a positive attitude towards insect-based livestock feed. The results for the subjective norm indicate that social referents such as animal health officers, trusted sources of information (television and radio), organizations (e.g., government research institutes, dairy cooperatives and university researchers) and milk customers would approve of farmers to use insect-based livestock feed. Also, farmers perceived behavioural control was positive (3.67), implying that the dairy farmers consider themselves to be in control of decisions to purchase and use insect-based livestock feed.

4.4.3 Determinants of farmers' willingness to use insect-based livestock feed

Table 4.11 presents the marginal effects of the ordinary probit and hetprobit estimates used to assess determinants of dairy farmers' willingness to use insect-based livestock feed. Their maximum likelihood estimates are presented in Appendix I. The dependent variable, dairy farmers' willingness to use insect-based livestock feed takes value 1 if farmers are willing to use insect-based livestock feed and 0 if they are not. The explanatory variables that were expected to influence the levels of willingness include farmers' awareness, TPB constructs (attitudes, subjective norms and perceived behavioural control), and household demographic, socio-economic and institutional factors.

To check the assumption of homoscedasticity, the null hypothesis, $Y = 0$, was tested using the Lagrange Multiplier test (LM test). From the results of maximum likelihood estimates (Appendix I) the null hypothesis of no heteroskedasticity is rejected at ten percent level of significance ($p<0.1$), implying that the hetprobit model was preferred in this study analysis. The probability value of Wald chi-square test is significant at one percent level indicating that the hetprobit model was a good fit for the study analysis.

Table 4.11: Marginal effects of determinants of dairy farmers' willingness to use insect-based livestock feed

	Probit model			Hetprobit model		
Variable	M.E. (dy/dx)	S.E.	*p-value*	M.E. (dy/dx)	S.E.	*p-value*
Awareness of insect-based feed	-0.037	0.083	0.659	-0.044	0.068	0.518
TPB Constructs						
Attitude	0.133***	0.031	0.000	0.156***	0.035	0.000
Subjective norms	0.116***	0.030	0.000	0.105***	0.025	0.000
Perceived behavioural control	0.148**	0.060	0.014	0.127**	0.052	0.015
Household characteristics						
Gender of household head	-0.035	0.065	0.593	-0.119***	0.044	0.008
Age of household head	0.002	0.002	0.429	0.003*	0.002	0.082
Farming experience	-0.002	0.002	0.310	-0.004**	0.002	0.050
Education of household head	0.067	0.052	0.201	0.038	0.043	0.376
Household size	-0.008	0.015	0.564	-0.014	0.013	0.291
Farm size	-0.023**	0.012	0.050	-0.007	0.007	0.274
Number of dairy cattle	0.017	0.017	0.316	0.032*	0.018	0.067
Distance from the farm to the nearest market	-0.009	0.012	0.448	-0.013	0.011	0.221
Household income	-0.003	0.033	0.924	-0.021	0.028	0.462
Wealth index (Wealthiest)	0.096	0.063	0.127	0.118***	0.044	0.008
Wealth index (Middle)	0.035	0.055	0.524	-0.024	0.064	0.704
Institutional arrangements						
Access to credit	0.031	0.058	0.585	0.121	0.085	0.154
Access to extension service	0.106**	0.051	0.038	0.108***	0.041	0.008
Access to insurance service	0.019	0.055	0.731	0.063	0.040	0.114

Note: M.E is marginal effect; S.E. is standard error; ***, ** and * indicate statistically significant level at 1%, 5% and 10% respectively; Poorest wealth category is the reference level.

The results in Table 4.11 indicate notable differences between the marginal coefficients of the ordinary probit and hetprobit estimates. First, there is a notable change in magnitude of a number of the explanatory variables when heteroscedasticity robust probit model is used compared to the ordinary probit model. Secondly, certain explanatory variables which are not significant in the case of ordinary probit model are significant when the hetprobit model approach is applied. For example, the marginal coefficients of gender and age of the farmer, farming experience, herd size and wealth index are significant when the hetprobit model is estimated. Following the LM and Wald chi-square tests presented in Appendix I, the study proceeds to discuss the hetprobit model results.

The hetprobit model results show that the willingness to use insect-based livestock feed was significantly related to both household characteristics and psychosocial factors (attitude, subjective norm and perceived behavioural control), therefore the second research hypothesis of the study was rejected. The farmers' attitudes positively and significantly ($p<0.01$) influenced willingness to use insect-based livestock feed. The marginal coefficient indicates that favourable attitudes increase the likelihood of having willingness to use insect-based livestock feed by 16 percent.

The high influence of attitude compared to other constructs suggests that favourable evaluation of the perceived effect of insect-based livestock feed on milk yield, feed availability and pricing was the main determinant of dairy farmers' willingness to use insect-based livestock feed. This could also be explained by the perception reported in FGDs that alternative feed sources can address the current livestock constraints – key of which are quality and affordability of conventional sources of protein (Mutisya *et al*., 2021; Onsongo *et al*., 2018). This study findings are supported by previous TPB studies which found attitude to be a positive and significant determinant of intention to use new farm innovations and practices (Daxini *et al*., 2018; Martínez-García *et al*., 2016).

Also, the results show that the marginal coefficient of subjective norm was positive and significant ($p<0.01$) implying that a stronger social influence increases the likelihood of having willingness to use insect-based livestock feed by 11 percent. The TPB results presented in Table 4.10 show that the strongest influence would come from animal health officers and trusted government or farmer organization officials. This is because farmers view these social referents are instrumental to the success of their farms and often respond positively to their advice (Ritter *et al*., 2017). The results of this study are in line with those of Diaz *et al*. (2021) and Senger *et al*. (2017) who reported subjective norm as a significant factor in adoption of new farm innovations and practices. In contrast to this study finding, Buyinza *et al*., (2020) reported that subjective norm did not have a significant influence on smallholder farmers' willingness to adopt agroforestry practices within Mt. Elgon region in Uganda.

Similarly, the marginal coefficient of perceived behavioural control (PBC) was positively and significantly ($p<0.05$) associated with willingness to use insect-based livestock feed suggesting that when farmers believe they are generally in control of the decisions to purchase feed, their likelihood to have the willingness to use insect-based livestock feed increases. This is because PBC reflects any constraining or supporting factors that may influence a behaviour (Borges *et al*., 2014). In this case, the presence of supporting factors (such as quality and reduced prices) is likely to facilitate the use of insect-based livestock feed. This finding is consistent with that of Aziz *et al*. (2015) on the impact of PBC on farmers' intentions.

With regard to household characteristics, age of the farmer positively and significantly ($p<0.1$) influenced willingness to use insect-based livestock feed. The marginal coefficient indicates that a one-year increase in age of the farmer, would increase the willingness to use insect-based livestock feed by 0.3 percent. This study finding could be attributed to the fact that older farmers may have experience and resources that would provide them with more opportunities for trying new farm innovations, thus the positive influence of age on willingness (Malesse, 2018). However, different farm technology adoption studies have revealed conflicting results on the influence of age in the uptake of farm technologies. In support of the study findings, Sebatta *et al*. (2018) found that age positively influenced the uptake of insect farming for feed among poultry farmers in Uganda. Contrary to the study findings, Udimal *et al*. (2017) found that older farmers were reluctant to adopt rice technology in Ghana.

However, the effect of farming experience on willingness to use insect-based livestock feed was negative and significant ($p\leq0.05$). The magnitude of the marginal coefficient indicates that an increase in farming experience by one year reduces the likelihood of having the willingness to use insect-based livestock feed by 0.4 percent. This finding could be attributed to the fact that farmers with long experience in farming tend to be more adhering to conventional technologies and are less willing to adopt new technologies. This study finding is consistent with Dhraief *et al*. (2018) who reported

that dairy farming experience was significantly and negatively associated with dairy farmers adoption of innovative technologies in Tunisia. Contrary to the study findings, Korir *et al*. (2023) and Quddus (2022) found that farming experience was positively associated with the uptake of livestock technologies in Ethiopia and Bangladesh, respectively.

The results also show that the marginal coefficient of gender of the farmer negatively and significantly ($p<0.01$) influenced the willingness to use insect-based livestock feed. This implies that the probability of having the willingness to use insect-based livestock feed by male farmers is 12 percent lower than that of female farmers. This result is expected since female farmers are often involved in livestock management practices including feeding which make them more aware of the challenges of accessing conventional feed sources (Waithanji *et al*., 2020). Therefore, this may explain female farmers' interest in the uptake of alternative feed sources compared to the male farmers.

The results further show that access to extension service exhibited a positive and significant ($p<0.01$) marginal coefficient implying that farmers who have access to extension services are more likely to be willing to use insect-based livestock feed. This is not surprising because the FGDs also confirmed the importance of extension services in the study area, in helping farmers acquire knowledge on the benefits and effective use of alternative feed sources. The study findings are supported by Omollo *et al*. (2018) who found that access to extension services positively and significantly influenced livestock farmers' decision to participate in fodder production in Kenya.

The wealth index, a measure of households' cumulative living standard was positively and significantly ($p<0.01$) correlated with willingness to use insect-based livestock feed. The marginal coefficient indicates that belonging in a higher wealth category increases the probability of having the willingness to use insect-based livestock feed by 9.8 percent. This result is supported by the view that wealthier households have access to more resources that can help them manage the risks associated with adoption of farm innovations. On the other hand, poor households tend to be more risk-averse and are

therefore reluctant to adopt farm innovations with potential production gains. Previous studies have shown that due to their resource constraints, poor households opt to continuously use low productive conventional farm practices with low profitability (Ogada *et al*., 2010). This study finding is consistent with that of Okello *et al*. (2021) who found that wealth index had a positive and significant influence on poultry farmers' perceptions of insect-based feed.

The results also reveal that herd size had a positive and significant ($p<0.1$) marginal coefficient implying that farmers with a large herd size have a higher probability of having the willingness to use insect-based livestock feed. The magnitude of the marginal coefficient indicates that as the herd size increases by one unit, the probability of having willingness to use insect-based livestock feed also increases by 3 percent. This result is not surprising since farmers with a large herd size are likely to be more constrained in accessing livestock feed compared to those with a small herd size. This could explain their interest in the uptake of non-conventional feed sources. Similar to the study findings, Dhraief *et al*. (2018) and Martínez-García *et al*. (2016) found that herd size had a positive influence on adoption of farm innovations among smallholder dairy farmers.

The findings in this section suggest various interventions that are needed to first, train and sensitize farmers on the benefits of using insects as an alternative source of livestock feed; second, take into consideration supporting factors including quality and reduced prices of alternative feed sources to promote uptake of insect-based livestock feed; third, support and strengthen extension service providers to reach out to farmers in their respective areas to facilitate information flow on non-conventional feed sources; and fourth, establish a partnership with farmers who are more endowed with resources to enhance knowledge sharing on use of insects as an alternative source of livestock feed.

4.5 Preferences for livestock feed attributes

This section presents and discusses the results and findings for the third objective of this study. It assesses smallholder dairy farmers' preferences for livestock feed attributes

and their determinants. It also considers dairy farmers' willingness to pay for livestock feed attributes. Assessing farmers' preferences for livestock feed attributes is important in understanding the trade-offs they make when selecting various feed products.

4.5.1 Farmers' preferences for livestock feed attributes

A choice experiment approach was applied to assess preferences for livestock feed attributes. The study considered the five most important attributes; source of energy, source of protein, brand of feed product, the effect of feed product on milk yield and price. In the study, source of energy and protein were included because of their likely influence on the cost of feed and milk productivity. The price of feed product and the influence the product has on milk yield are important for farm productivity. The brand of the product was considered as an important indicator for quality of the feed product. A mixed logit model was used to analyze farmers' preferences for the feed attributes. This is because the mixed logit model allows for sample preference heterogeneity which is not accounted for using the standard logit model (Wittink, 2011). The results of the mixed logit estimates are presented in Table 4.12.

Table 4.12: Farmers' preferences for livestock feed attributes

Attributes	Mean	*p-value*	SD	*p-value*
Price	-0.021***	0.000		
	(0.005)			
Source of energy: Reference level (Maize)				
Cassava	-0.670*	0.064	0.090	0.765
	(0.361)		(0.301)	
Source of protein: Reference level (Soy meal)				
Fish meal	0.154	0.782	1.692***	0.004
	(0.555)		(0.592)	
Insect meal	-1.530***	0.002	1.173***	0.000
	(0.493)		(0.277)	
Yield: Reference level (No increment)				
25% increment	1.454***	0.000	0.002	0.993
	(0.149)		(0.233)	
50% increment	4.574***	0.000	1.663***	0.005
	(0.886)		(0.587)	
75% increment	3.399***	0.000	1.431***	0.000
	(0.426)		(0.338)	
Brand of feed product: Reference level (Unbranded)				
Branded	1.591***	0.000	0.991***	0.000
	(0.290)		(0.212)	
Chi-square	298.43***			
Log-likelihood	-1174.93			
Replications	500			

Note: SD is standard deviation; Standard errors in parentheses; ***, ** and * indicate statistically significant level at 1%, 5% and 10% respectively; the level 'wheat' in the attribute 'source of energy' was omitted in the analysis owing to multicollinearity.

The results in Table 4.12 indicate that the mean coefficients for price, brand of feed product, effect of feed product on milk yield, source of energy from cassava and source of protein from insect meal were all statistically significant at standard levels. The mean coefficients of these variables (influence the product has on milk yield, brand of feed product, price, source of energy from cassava and source of protein from insect meal) had the expected sign.

The influence of feed product on yield was considered the most important attribute when selecting the preferred feed product. As expected, the mean coefficient of the attribute had a positive sign implying that smallholder dairy farmers in the study area attach great importance to feed products with the potential of increasing milk yields. The magnitude for 50 percent rise in milk yields was higher compared to 25 and 75 percent. This could be explained by the fact that the dairy farmers expected a 50 percent increase in milk

yield to be a more reasonable percentage from their experience in dairy farming. This finding is consistent to that of Kiptot *et al*. (2015) who found that smallholder dairy farmers in dairy management groups in Kenya had preferences for feeds with the ability to increase milk yield. According to Chawala *et al*. (2019), farmers' preferences for high milk yields could be attributed to an increase in household income. Preferences toward high milk yield is an important livestock production trait that have been reported by Chawala *et al*. (2019), Lukuyu *et al*. (2019) and Zewdu *et al*. (2018) to have positive implications on smallholder farm productivity across SSA.

The mean coefficient for branding was 1.59. This indicates a higher magnitude for branding suggesting that dairy farmers' preferences for branded feed products are stronger than for the unbranded ones. Branding of a feed product is considered important in light of the proliferation of many livestock feed products with a number of them being adulterated (BLGG Group, 2013). Therefore, having a manufacturer brand on a feed product is likely to increase a farmer's choice of a particular feed product. Brand image has been reported by Ashraf *et al*. (2017) and Isik and Yasar (2015) to have a positive and significant influence on individual preferences. Therefore, to ensure uptake of non-conventional feed products, feed manufacturers need to consider brand awareness creation in the commercialization phase in order to penetrate existing feed markets.

As expected, the mean coefficient of price was negative (-0.02) and statistically significant (p=0.00), indicating that the farmers preferred lower-priced feed products. This finding is consistent with consumer theory which indicates an inverse relationship between price and quantity demanded of a good (Jehle and Reny, 2011). According to Acheampong *et al*. (2018), farmers view farm inputs with lower prices as beneficial since they increase their incomes and thus improving their livelihoods. Similar findings are reported by Chawala *et al*. (2019) who found that smallholder dairy farmers in Tanzania preferred lower prices for dairy cattle traits. High feed prices have been reported as a major limiting factor to livestock productivity across smallholder production systems in SSA which requires effective policy interventions (Balehegn *et*

al., 2020; Ssepuuya *et al*., 2017; Tegemeo Institute of Agricultural Policy and Development, 2021).

The use of cassava as source of energy for feed had a negative and significant mean coefficient (p=0.06), indicating that the farmers have a negative preference for feed products formulated from cassava compared to maize. The study finding is not surprising since globally, maize is the preferred source of energy utilized in livestock feed formulation (Erenstein *et al*., 2022). This finding is consistent with that of Bello *et al*. (2015) who found that maize was the most preferred source of energy used in livestock feed formulation compared to cassava. The negative preference for cassava could be generally attributed to limited awareness and technological knowledge among farmers regarding the use of cassava as a feed ingredient. Additionally, some cassava types have been reported to be poisonous, so farmers may perceive them to be risky to utilize as livestock feed (Bello *et al*., 2015; dos Santos *et al*., 2015; Lukuyu *et al*., 2014). To improve preferences for non-conventional sources of energy in livestock feed formulation, interventions are required to create awareness and build capacity of feed manufacturers and farmers to increase production and utilization of alternative energy feed sources.

The use of insect as a source of protein had a negative coefficient (p=0.00), implying that the farmers would prefer feed products formulated using soy meal compared to insects. This result is not surprising since worldwide, soy meal is one of the most commonly utilized source of protein in livestock feed formulation compared to insects (Ssepuuya *et al*., 2017; van Huis, 2022). The negative preference for source of protein from insect meal could be attributed to the fact that utilization of insects as a source of livestock feed is relatively a new concept among smallholder dairy farmers in the study area. This is consistent with earlier findings of the study indicating a very low level of awareness of farmers towards insect-based livestock feed and lack of utilization of insect-based feed among the farmers. This study finding imply that to improve farmers' preferences for insects as an alternative source of protein in livestock feed formulation,

there is need for strategic provision of information to farmers through formal and informal education, public campaigns and marketing. This can result in a change in the preference structure toward a more positive preference for feed products formulated with insects as the key protein ingredient. Overall, the study findings indicate that there were significant preferences for the various livestock feed attributes among smallholder dairy farmers, thus the third research hypothesis of the study was rejected.

4.5.2 Farmers' marginal willingness to pay for livestock feed attributes

The study assessed the farmers' marginal willingness to pay (MWTP) for each livestock feed attribute. The MWTP is the ratio between the coefficients of attributes (source of energy, source of protein, milk yield and brand of feed product) and purchase price coefficient. It indicates the maximum amount of money that farmers are willing to pay in order to obtain a unit change in a specific attribute. The MWTP estimates are presented in Table 4.13.

Table 4.13: MWTP for each livestock feed attribute

Attribute	Mean	Std. err	*p-value*
Source of energy: Reference level (Maize)			
Cassava	-31.24*	18.42	0.090
Source of protein: Reference level (Soy meal)			
Fish meal	-11.48	30.79	0.709
Insect meal	-84.75***	26.80	0.002
Yield: Reference level (No increment)			
25% increment	62.32***	12.41	0.000
50% increment	218.15***	56.40	0.000
75% increment	158.92***	23.29	0.000
Brand of feed product: Reference level (Unbranded)			
Branded	79.270***	(17.374)	0.000

Note: Std. err is standard error; ***, ** and * indicate statistically significant level at 1%, 5% and 10% respectively; the level 'wheat' in the attribute 'source of energy' was omitted in the analysis owing to multicollinearity; MWTP values are in KES; *Kenyan currency 1 USD=102.25 KES* at the time of the survey

The results in Table 4.13 show that the attributes, feed with potential to increase yield and brand of feed product had positive MWTP. This implies that smallholder dairy farmers were willing to pay a higher amount to secure a livestock feed product that has the potential to increase milk yield and contains a manufacturer brand. These results are not surprising since the attributes had strong preferences. However, cassava and insect

attributes had negative MWTP. This indicates that the smallholder dairy farmers were willing to pay less KES 32 per kilogram for livestock feed products formulated with cassava than the amount they pay for those formulated with maize. Similarly, the dairy farmers would need a reduction of up to KES 85 in order to accept products formulated using insects as source of protein compared to soy bean.

These results show that even when price is an important attribute, farmers make trade-offs between the different ingredients utilized in livestock feed formulation. This implies that for farmers to accept these alternative feed sources (insects and cassava), they have to be of lower price compared to other alternatives. Similar observations are made by Pomalégni *et al*. (2018) and Chia *et al*. (2020) who found that smallholder livestock farmers in Kenya and Benin were more willing to pay a lower price for alternative feed ingredients compared to the local price for conventional feed ingredients.

Generally, the findings of farmers' MWTP for each feed attribute are not surprising since high cost and low quality of conventional sources of feeds have been reported to be the most critical constraints to improving livestock productivity in smallholder production systems across SSA (Chia *et al*., 2020; Sebatta *et al*., 2018; Tegemeo Institute of Agricultural Policy and Development, 2021). As a result, smallholder farmers are more interested in the uptake of high yielding, good quality, affordable and sustainable alternative feed sources in livestock production (Asindu *et al*., 2020; Paul *et al*., 2020; Tegemeo Institute of Agricultural Policy and Development, 2021).

4.5.3 Determinants of farmers' preferences for livestock feed attributes

To assess factors influencing farmers' preferences for livestock feed attributes, the attributes were interacted with household characteristics and analyzed using a mixed logit model. The results are presented in Table 4.14.

Table 4.14: Determinants of farmers' preferences for livestock feed attributes

Variable	Coefficient	Stand. error	*p-value*
Price	-0.015**	0.007	0.045
Source of energy: Reference level (Maize)			
Cassava	-1.033	0.827	0.212
Source of protein: Reference level (Soy meal)			
Fish meal	-1.244	1.078	0.248
Insect meal	-2.383**	1.091	0.029
Yield: Reference level (No increment)			
25% increment	1.505***	0.338	0.000
50% increment	6.442***	1.712	0.000
75% increment	3.801***	0.778	0.000
Brand of feed product: Reference level (Unbranded)			
Branded	1.385**	0.564	0.014
Cassava*household size	0.156	0.167	0.351
Cassava*farm size	0.033	0.068	0.622
Cassava*extension service	-0.053	0.311	0.865
Fish meal*household size	0.121	0.196	0.537
Fish meal*extension service	-0.160	0.699	0.819
Insect meal*household size	0.390**	0.182	0.032
Insect meal*farm size	0.015	0.083	0.857
Insect meal*extension service	0.150	0.592	0.800
Insect meal*farming experience	-0.013	0.036	0.717
Insect meal*credit access	-0.201	0.631	0.751
Yield increment by 25%*income	5.73e-07	4.10e-07	0.162
Yield increment by 50%*income	-1.15e-06	2.30e-06	0.618
Yield increment by 75%*income	2.65e-06**	1.26e-06	0.036
Brand*income	1.82e-06*	1.01e-06	0.070
Price*income	-7.61e-09	1.37e-08	0.580
Price*group membership	-0.011*	0.006	0.083
Standard deviations of random parameters			
Cassava	0.016	0.247	0.950
Fish meal	1.616***	0.571	0.005
Insect meal	0.921**	0.377	0.014
Yield increment by 25%	0.110	0.277	0.690
Yield increment by 50%	2.092***	0.569	0.000
Yield increment by 75%	1.681***	0.412	0.000
Branded feed product	1.092***	0.308	0.000
Chi-square	281.88***		
Log-likelihood	-1079.80		
Replications	500		

Note: Stand. error is standard error; ***, ** and * indicate statistically significant level at 1%, 5% and 10% respectively; the level 'wheat' in the attribute 'source of energy' was omitted in the analysis owing to multicollinearity

Table 4.14 results show that the interaction of household size and attribute, source of protein derived from insect meal was positive and statistically significant ($p<0.05$),

suggesting that larger households are more likely to adopt insect meal as an alternative source of protein in livestock feed compared to smaller households. Household size is linked to labour availability for farm operations and plays an important role in uptake of agricultural practices (Dhraief *et al*., 2018). Insect farming is reported to be highly labour intensive (Niyonsaba *et al*., 2021), hence, larger households can provide family labour, and as a result, they can adopt insect farming for livestock feed. Muriithi *et al*. (2021) and Mwaura *et al*. (2021) also found out that household size positively and significantly influenced the uptake of farm technologies.

The interaction of group membership and price attribute was negative and statistically significant ($p<0.1$), implying that dairy farmers who are members of groups are more concerned about price of feed products (are more likely to choose lower-priced feed products) compared to those who are non-members of farmer groups. Farmer groups have been reported to create an enabling environment for farmers through collective bargaining power toward input suppliers to access inputs at more affordable prices that would be challenging to obtain alone (Mutonyi, 2019). Similar observations are made by Ingutia and Sumelius (2022) and Sinyolo and Mudhara (2018) on the role that farmer groups play for smallholder farmers in accessing farm inputs.

Household income and attribute, potential of feed product to increase milk yield was positive and significant ($p<0.05$) implying that the higher the dairy farmers income level, the higher their emphasis on feed products with the potential of increasing milk yields by more than 50 percent of the total amount. This result is not surprising as higher yields are associated with higher farm income and higher household income (Meng *et al*., 2020). Household income also had a positive and significant ($p<0.1$) influence on the brand of feed product attribute. This suggests that the higher the dairy farmers income level, the higher their emphasis on a branded feed product. Generally, farmers with high income are more likely to invest in productivity enhancing farm inputs explaining the reason why smallholder dairy farmers with higher income are more likely to choose branded feed products. Similar findings were reported in a study by Chawala

et al. (2019) who found that smallholder dairy cattle farmers in Tanzania had a positive utility for dairy cows with high milk yields.

Overall, the findings in this section indicate that feed manufacturers should take into consideration the specific feed traits preferred by farmers with regard to improving feed quality, enhancing yields, and lowering feed prices in their formulation decisions. There is also need to sensitize smallholder farmers and support inventive small-scale feed manufacturers in scaling up and commercializing alternative feed sources. Additionally, interventions are required to enhance government policies and feed technologies to improve access to good quality and affordable feeds for farmers across smallholder dairy production systems in Kenya.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents a summary of the findings, conclusions and recommendations of the study and areas for further research.

5.2 Summary

Livestock is crucial to rural incomes, nutrition, food security and livelihoods in smallholder production systems in Kenya (Republic of Kenya, 2020). However, the potential of livestock as a driver for economic growth in Kenya is constrained by various factors, of which limited access and high cost of good quality livestock feed is the most critical constraint to improving livestock productivity in the country (Tegemeo Institute of Agricultural Policy and Development, 2021). In order to improve smallholder livestock farmers' access to good quality and affordable feeds in Kenya, policymakers, practitioners, and researchers are promoting the utilization of non-conventional feed sources rich in protein, particularly from insects (Chia *et al*., 2020; Okello *et al*., 2021; van Huis, 2022).

However, production and utilization of non-conventional livestock feed sources from insects is still very low among feed manufacturers and livestock producers in the country. This requires an understanding of the existing livestock feed systems; knowledge of farmers' feed preferences and the trade-offs farmers make when selecting various feed products. Therefore, the objectives of this study were: 1) To characterize the livestock feed systems among smallholder dairy farmers in Murang'a County, 2) To assess willingness to use insect-based livestock feed among smallholder dairy farmers in Murang'a County, and 3) To assess preferences for livestock feed attributes among smallholder dairy farmers in Murang'a County.

Data were collected among a sample of 378 smallholder dairy farmers in Murang'a County. Characterization of the livestock feed systems was analyzed using descriptive statistics across various characteristics, comprising livestock production systems, feed resources, sourcing arrangements, seasonality in feed utilization, expenditure on feed and livestock feed security. Farmers' willingness to use insect-based livestock feed was estimated using a hetprobit model and a choice experiment approach was applied to assess preferences for livestock feed attributes.

The results on characterization of the livestock feed systems indicate that zero grazing was the predominant dairy production system practiced by 97 percent of the farmers. The key challenges identified in the dairy production systems across the study zones were limited land holdings for forage cultivation, inadequate access to good quality forage during the dry season, and high cost and poor quality of concentrate feeds. The predominant feed resources utilized by farmers were Napier grass (99%), crop residues (91%) and concentrate feeds (99%) to supplement the dairy cattle diet. However, the utilization of protein concentrates and silage was limited among farmers attributed to limited land for forage cultivation, lack of technical know-how and high cost of ensiling materials.

Crop residues, hay, banana stems and leaves, and fodder trees were the most common feed resources utilized by farmers during the dry season whereas Napier grass and natural pasture were commonly utilized in the wet season. Further, farmers had the highest feed expenditures on energy concentrates, Napier grass and hay compared to other feed resources. Using the adapted feed security scale based on dairy farmers experience of worry, using less quality feed or reducing quantity of feed; the results show that majority of the households (78%) experienced livestock feed insecurity. Of these, 27 percent of households were mildly feed insecure, 49 percent moderately feed insecure and only 2 percent were severely feed insecure.

With respect to farmers' willingness to use insect-based livestock feed, the study findings revealed that only a small proportion of farmers (11%) were aware of insect-based livestock feed prior to the study. However, a considerable proportion of the farmers (76%) were willing to use insect-based livestock feed once it was available in the market. The results also showed that dairy farmers had generally a favourable attitude which reflected on their willingness to use insect-based livestock feed. The findings further revealed that the probability of farmers' willingness to use insect-based livestock feed increased with farmers' attitude, subjective norm, perceived behavioral control, age, herd size, access to extension service and wealth status, while it decreased with farming experience and being a male-headed household.

Finally, the findings on farmers' preferences for livestock feed attributes revealed that farmers' had positive and significant preferences for lower-priced feed products, feed with the potential to increase yield and branded feed products. However, farmers had negative preferences for feed products formulated with cassava compared to maize, as well as feed products formulated with insect meal compared to soy meal. Therefore, farmers were willing to pay a higher amount for feed with potential to increase yield and contain manufacturer brand, and less amount for alternative feed products formulated with insect meal and cassava. Further, the results revealed that farmers' preferences for livestock feed attributes were significantly influenced by household size, income and membership in a farmer group.

5.3 The conclusions

The study conclusions are organized based on the study objectives – i) characterization of the livestock feed systems, ii) willingness to use insect-based livestock feed, and iii) preferences for livestock feed attributes.

In terms of characterization, the study concludes that the smallholder livestock feed systems in Kenya are constrained by limited land holdings for forage cultivation, low feed conservation mechanisms, high cost and limited availability of protein

concentrates. These imply that interventions are needed to introduce innovative methods to support more forage production and train farmers on small-scale forage conservation.

With regard to willingness to use insect-based livestock feed, the study concludes that although farmers had a low level of awareness towards insect-based livestock feed, a large proportion of farmers were willing to use the feed once it was available in the market. This implies that there is a strong market potential of introducing alternative feeds such as insect-based livestock feed. Generally, the farmers' attitudes were positive and their volitional control towards the use of insect-based livestock feed was high. In addition, there was a high likelihood that dairy farmers significant others (family, relatives, livestock officers, livestock health officers) could influence them to use insect-based livestock feed. These findings suggest there is a great potential for the uptake of insect-based livestock feed among smallholder dairy farmers, if they were to be available. Additionally, farmers' age, herd size, access to extension service and wealth status were positively associated with willingness while farming experience and being a male-headed household negatively influenced farmers' willingness to use insect-based livestock feed.

Concerning preferences for livestock feed attributes, the study concludes that smallholder dairy farmers preferred feed with potential to increase yield, branded feed products and lower-priced feed products. This implies that feed manufacturers should take into consideration the specific feed attributes preferred by farmers with regard to improving feed quality, enhancing yields, and lowering feed prices in their formulation decisions. The study also concludes that household size, income and membership in farmer groups play an important role in farmers' decisions to choose the feed attributes.

5.4 The recommendations

The following recommendations are given based on the significant findings of the study. First, the study findings suggest the need for intervention to improve access to quality and affordable feed for smallholder dairy farmers. These include capacity building on feed conservation (hay and silage making) and utilization of emerging livestock feed

sourcing alternatives. Second, the study proposes the need for intervention to train smallholder dairy farmers on the benefits of utilizing insect-based livestock feeds. This would increase farmers' level of awareness and knowledge towards sustainable alternative feed sources, thus creating a market potential for insects as an alternative source of livestock feed in Murang'a County.

Third, interventions are required to train farmers on feed formulation to save on the cost of purchasing feed products and improve on the quality of feed provided to the dairy cattle. This would enhance the potential of dairy productivity and make dairy farming more profitable for resource-poor farmers. In addition, various agricultural stakeholders can collaborate to support emerging livestock feed manufacturers in scaling up and commercializing the production and processing of insect-based livestock feeds.

Fourth, identifying proper channels for information dissemination to smallholder dairy farmers is critical to the uptake of insect-based livestock feed. The study recommends the involvement of adequate social support systems in information dissemination to facilitate dairy farmers' access to information on insect-based feeds. Various livestock stakeholders including feed processors, livestock officers, local agricultural officers and farmer organizations can provide on-farm trials and demonstrations and farmers field schools to support awareness creation on use of insect-based livestock feed. Furthermore, interventions are required to improve or strengthen extension support services to educate smallholder dairy farmers on the benefits of using insects as an alternative source of livestock feed. This would promote the willingness of smallholder dairy farmers to utilize alternative feed sources and reduce competition between human-livestock-industries for conventional feed ingredients.

Sixth, interventions are required to build the capacity and competence of farmer groups to facilitate mass training and easy access to information on the utilization of insect-based livestock feeds. Finally, there is a need to establish a partnership with farmers

more endowed with resources to enhance knowledge sharing among fellow farmers on the availability and utilization of insect-based livestock feeds.

5.5 Areas for further research

To commercialize insect-based livestock feeds, the study proposes that future research studies consider the following: First, the study used an experiential scale adapted from the food insecurity experience scale to measure livestock feed security at the household level; further research can consider other approaches in assessing livestock feed security at the household level. Second, the study applied the theory of planned behaviour to model willingness to use insect-based livestock feed among smallholder dairy farmers; further work can consider other theoretical approaches in understanding the acceptance of insect-based livestock feeds among smallholder farmers. Finally, the study assessed preferences and trade-offs using a choice experiment approach in a hypothetical scenario; future studies can consider experimental auctions with actual products formulated using insects to move the analysis into a much really market context.

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APPENDICES

Appendix I: Coefficient estimates of determinants of farmers' willingness to use insect-based livestock feed

	Probit model			Hetprobit model		
Variable	Coef.	S.E.	*p-value*	Coef.	S.E.	*p-value*
Awareness of insect-based feed	-0.128	0.280	0.647	-0.140	0.207	0.499
TPB Constructs						
Attitude	0.483***	0.107	0.000	0.532***	0.116	0.000
Subjective norms	0.420***	0.107	0.000	0.359***	0.090	0.000
Perceived behavioural control	0.497***	0.190	0.009	0.391***	0.148	0.008
Household characteristics						
Gender of household head	-0.132	0.258	0.609	-0.512**	0.247	0.038
Age of household head	0.006	0.008	0.430	0.012*	0.007	0.099
Farming experience	-0.009	0.008	0.310	-0.014*	0.008	0.067
Education of household head	0.242	0.190	0.202	0.130	0.147	0.374
Household size	-0.030	0.053	0.565	-0.046	0.043	0.285
Farm size	-0.085**	0.043	0.050	-0.024	0.022	0.276
Number of dairy cattle	0.063	0.063	0.320	0.110*	0.060	0.065
Distance from the farm to the nearest market	-0.032	0.042	0.448	-0.046	0.038	0.230
Household income	-0.012	0.121	0.924	-0.070	0.095	0.462
Wealth index (Wealthiest)	0.396	0.295	0.180	0.507**	0.239	0.034
Wealth index (Middle)	0.130	0.208	0.533	0.581**	0.282	0.039
Institutional arrangements						
Access to credit	0.117	0.219	0.594	-0.652***	0.175	0.000
Access to extension service	0.416*	0.218	0.057	0.414**	0.180	0.022
Access to insurance service	0.070	0.205	0.733	0.223	0.146	0.127
Log-likelihood	-129.14			-120.07		
Pseudo-R2	0.34					
LR	132.03***					
Homoskedasticity (LM Test)	26.05*					
Wald test (χ^2 with 18 df)				67.61***		
Het-test (χ^2 with 2 df)				18.14***		

Note: Coef is coefficient; S.E. is standard error; ***, ** and * indicate statistically significant level at 1%, 5% and 10% respectively; Poorest wealth category is the reference level

Appendix II: Dairy farmers' questionnaire

INTRODUCTION AND INFORMED CONSENT

We are a team of researchers from Jomo Kenyatta University of Agriculture and Technology, undertaking a study that seeks to understand the preferences and acceptance of insect-based feed in Murang'a County. As part of the study, we are conducting a survey of livestock producing households and you have been identified as one of the respondents. Your participation is entirely voluntary and we do hope that you will agree to participate. This survey will take about 30-45 minutes, and the data collected will be used for academic purpose only. All the information you give will be strictly confidential, your name or identity will not be connected to any of your responses at any point. If you accept to participate in the interview, you can decide to withdraw at any moment.

Consent given Yes= [ ] No=0 [ ] (If yes, proceed to the next section; If no, find out the reason and terminate the interview.)

Questionnaire Number: _____

SECTION A: INTERVIEW INFORMATION

A01) Day/Month/year of interview _____/_____/**2019** A02) Interview Start: (hh: min) _____ A03) Interview Stop: (hh: min) _____	**Enumerator name and number** A05) Name: _____ A06) Number: _____
Interview area A07) **Sub-county:** _____ 1= Kandara 2= Kigumo A08) **Location:** _____ 1=Kangudu-Ini 2= Ithiru 3= Ruchu 4= Muthithi 5= Kigumo 6= Kinyona 7= other (specify) A09) **Ward:** _____ 1= Kangudu-Ini 2= Ithiru 3= Ruchu 4= Muthithi 5= Kigumo 6= Kinyona 7= Other (specify) A10) **Village:** _____	**GIS Coordinates of the interview location** A11) Latitude: _____ A12) Longitude: _____ **Respondent's name and number** A13) Name: _____ A14) Number: _____ **Data entry clerk** A15) Name: _____ A16) Number: _____ A17) Data entry done on (day/month/year) _____/ _____/2019

SECTION B: HOUSEHOLD SCHEDULE

B01) Gender of respondent	B02) Age of respondent	B03) Education level of respondent	B04) Marital status of respondent	B05) Household size (No. of household members)
1= male 0=female	Indicate age	1= Informal 2= Primary 3= Secondary 4= College 5= University	1= Married 2= Divorced 3=Separated 4= Widowed5= Widower 6= Never married	Indicate the total number of household members

SECTION C: HOUSEHOLD PROFILE

Please tell me who are the members of your household?

NOTE: A household is defined as a person regularly sharing meals and living in the same housing unit for the past 6 months. Start with the household head

C01) Person ID.	C02) First name	C03) Gender: 1= Male 0=Female	C04)Relation to household head (Refer to codes) 1= Household head 2= Spouse 3= Child 4= Grandchild 5= Step child 6= Parent 7= Brother/Sister 8= Nephew/Niece 9= Son/daughter in-law 10= Brother or sister in-law 11= Parent in law 12= Worker 13= Other relative 14= No relation	C05) Age [Write 0 if less than 1]	C06)Level of education 1= No formal schooling 2= Primary 3= Secondary 4= College 5= University

SECTION D: INFORMATION ON LAND HOLDING AND LAND USE SYSTEM

D01) What is the total area of land owned by the household?	In acres	

From the total land area how much land is allocated to the following activities? Kindly fill in the table below. (Skip the activity that is not relevant to the respondent or farmer)

D02) **Activity**	D03) 1= Yes 0= No	D04) Land allocation in Acres	D05) Tenure status
1. Homestead land			
2. Food crop production land			

3. Forage/fodder crop production land			
4. Grazing/ pasture land			
5. Unused land (fallow land)			
6. Forest and woodland			

D07 Codes for land tenure: 1= Own land (with title) 2= Owned land (without title) 3= Rented land (someone's else land) 4= Communal land 5= Family land 6= Other (please specify)

SECTION E: INFORMATION ON LIVESTOCK PRODUCTION

E01) For how many years have you been a livestock farmer? **Years**

E02) Do your household currently keep dairy cattle?	1 = Yes 0 = No	E03) If Yes to F02, what is the Total number kept?	E04) What are the three main purposes of production dairy cattle? (**Rank 1,2,3 where 1 is the most important and 3 is the least important)** **CODE A**			E05) What livestock management or production system do you practice on the farm?			E06) What are the three main challenges faced in each of the enterprise in order of economic importance (**1= most important and 3= least important**)
1. Dairy cows			**Rank 1**	**Rank 2**	**Rank 3**	CODE B	Wall	Roof	Floor	1. 2. 3.
Lactating							1= wood	1= grass	1= earth	
Non-lactating (dry cow)							2= stones 3= mud 4= iron sheet	2= iron sheet 3= tiles 4=wood	2= cement 3= wood 4= tiles	
Heifers										
Bull										
Young calves										
Codes		**CODE A FOR PRODUCTION PURPOSE** 1= own consumption 2= sale of output (milk) 3= For sale (actual livestock) 4= manure 5= biogas 6= hides and skin 7= transportation 8= other (specify)				**CODE B FOR CATTLE** 1= zero grazing/ stall feeding (intensive) 2= stall feeding and paddocking/grazing (semi-intensive) 3= grazing (extensive) 4= other(specify)				

SECTION F : INFORMATION ON FEED SOURCES

Now we would like to ask you questions concerning animal feed and feeding in your household in the last 12 months

F01) **Sources of Livestock feed**	F02) Used 1= Yes 0=No	F03) How is the feed sourced? **CODE A**	F04) Frequency of use of each feed source in the livestock diet **CODE B**	F05) Estimate the quantities and prices of different feed sources used to feed the livestock **per month (Covert if it is per day or week)**				F06) Main place of purchase **CODE C**	F07) Distance from the homestead to the feed source or place of purchase (km)	F08) Means of transport for the type of feed sourced **CODE D**	F09) Contribution of each feed source to the diet of the livestock throughout the year as a percentage (%))	F10) The feed source is mainly utilized during which months of the year?
				a. Unit of quantity of feed used in a **month** (e.g. kg, bales)		**b.** Quantity used in a **month**	**c.** Unit price (KES)	**d.** Total costs (KES) in a **month**				
1 Green forage (Napier grass)												
2 Silage (green maize only)												
3 Silage (dry maize stalks + nappier grass)												
4 Hay/ dry grass												
5 Dry maize stalks												
6 Crop residues (pulse and cereals)												
7 Roots and tubers and vines												
8 Banana stems and leaves												
9 Leaves and pods of trees and weeds												
10 Cut and carry grass												
11 Grazing												
12 Supplement ingredients	**IF UTILIZED, KINDLY FILL IN THE DETAILS IN THE NEXT SECTION (SECTION H)**											

(bran, oil cake, salt)					
13 Commercial mixed feeds					

Supplements : agro-industrial by-products obtained from processing of grain (bran), oil seed (oil meals), pulses (soybean meal),animal by-products (fishmeal), molasses, premixes, commercial mixed feeds (dairy meal)	**CODE A FOR SOURCING** 1=purchase 2=own production 3=own formulation 4=both own production and purchase 5= both own formulation and purchase 6= collected 7= other (specify) **CODE B FOR FREQUENCIES** 1= Daily 2=Once a week 3= 2-3 times a week 4= more than 3 times a week 5= Once a month 6= 2-3 times a month 7= more than 3 times a month	**CODE C FOR PLACE OF PURCHASE** 1= own farm 2=fellow farmer 3=cooperative 4=shop/Agrovet 5=feed company/processors 6= feed suppliers 7= food processors 8= grain millers 9= oil processing plants 10=Breweries 11= middlemen 12=others (specify)	**CODE D FOR MODE OF TRANSPORT** 1= Walking 2= wheelbarrow 3= bicycle 4= motorbike 5= personal vehicle 6= public transport 7= carts 8= pickup 9= Lorry 10= other (specify)

SECTION G: INFORMATION ON FEED INGREDIENTS FROM AGRO-INDUSTRIAL BY-PRODUCTS, PREMIXES AND COMMERCIAL MIXED FEEDS (TO BE ANSWERED BY THOSE UTILIZING FEED INGREDIENTS AND MIXED FEED SUPPLEMENTS IN SECTION G ABOVE)

G01) Ask the respondent and list all the feed ingredients and commercial mixed feeds they use to feed dairy cattle)	G02) Frequency of use in the corresponding livestock diet	G03)Unit of quantity of feed used in a **month (in kilograms)**	G04) Quantity of feed used in feeding dairy cattle per month (Indicate the total number of units used) if it is in days/ week convert	G05) Unit price (KES)	G06) Total costs (KES) in one **month**	G07) Main source of feed
Energy sources						
Protein sources						
Commercial mixed feeds						
Premixes and other food additives						

CODE A FOR ENERGY SOURCES: **1=** Maize germ 2= Maize bran 3= Maize grain (white) 4= Broken whole grain maize ('Njenga') 5= Whole maize meal (white) 6= Yellow corn 7= Wheat grains 8= Wheat bran 9= Wheat pollard 10= Wheat flour 11= Rice bran 12= Rice chicken 13= Sorghum grains 14= Millet grains 15= Sweet potato tubers meal 16= Other (specify) **CODE B FOR PROTEIN SOURCES:** **1=** Cotton seed cake 2= Soybean meal 3= Fish meal 4= Insects (crickets) 5= Coconut (copra) meal 6= Canola cake 7= Sunflower cake 8= Peanut (groundnut) cake 9= Simsim seed cake 10= Macadamia meal 11= Sardines ('Omena') 12= Fresh water shrimps (Ochong'a) 13= Pyrethrum meal 14= Bone meal 15= Blood meal 16= Other (specify**)** **CODE C FOR COMMERCIAL MIXED FEEDS**	**CODE D FOR PREMIXES: MINERAL PREMIXES:** **1=** Brown lime 2= Salt (common salt) 3= Rock salt 4= Lick salt (Superlick, Bayslick, Macklick super, twiga lick) 5= Dicalcium phosphate 6= Rock phosphate 7= Magnesium oxide 8=Mineral premix 9= other (specify) **CODE E ON FREQUENCY:** 1= Daily 2=Once a week 3= 2-3 times a week 4= more than 3 times a week 5= Once a month 6= 2-3 times a month 7= more than 3 times a month 8= Other **CODE F ON SOURCING PLACE:**

1= Dairy meal 2= Calf pellet 3= Dairy premix 4= Magic	1= own farm 2=fellow farmer/neighbour 3=cooperative 4=shop/Agrovet 5=feed company/processors 6= food processors 7= grain millers 8= oil processing plants 9= middlemen 10= other (specify)

SECTION H: AWARENESS OF INSECTS-BASED FEED		
Questions	**Reference Codes**	**Response**
I01) Are you aware of any livestock feed made from insects?	1= Yes 0= No	
I02) If Yes to I01 above, what was your source of information?	1= Government 2= Private extension 3= Cooperative/farmer association 4= NGO's 5= Fellow farmers 6= TV 5= Radio 6= Newspaper 7= Internet 8= Researchers /University scientists 9= Political leaders 10=Religious leaders 11= Other (specify)	
H03) If Yes to I01 above, have you ever fed your livestock on feed made from insects?	1= Yes 0= No	
H04) Apart from yourself, have you heard or know any farmer who is utilizing insect-based feed?	1= Yes 0= No	
H05) If No to I03 (**Never used livestock feed from insects**), would you consider giving your livestock insect feed if it was made available?	1= Yes 0= No	

I02) In this section, we will present you with 18 different choice questions (one choice question per page) separated into two blocks (1and2) each containing 9 choice sets. In each, you can choose between two different livestock feed options that you may purchase in a real market. Please compare all the characteristics of the livestock feed options, including their price, and choose the one you would buy. If you do not like any of the first two options of livestock feed, please select "OPTION 3" which represents the opt-out option. **Please notice that you will feel that the questions are similar, but you will realize the options of the livestock feed are different from one question to another. So please answer all the 9 questions from the respective block that you will be presented.** Please make sure that you answer all 9 questions sincerely depending on the block, having in mind your own preferences and purchasing behaviour.

(I02 A) BLOCK ONE CHOICE SETS		**(I02 B) BLOCK TWO CHOICE SETS**	
BLOCK ONE	CHOICE (OPTION 1 / OPTION 2 / OPTION 3)	**BLOCK TWO**	CHOICE (OPTION 1 / OPTION 2 / OPTION 3)
Choice Set 2		Choice Set 1	
Choice Set 3		Choice Set 4	
Choice Set 9		Choice Set 5	
Choice Set 10		Choice Set 6	
Choice Set 12		Choice Set 7	
Choice Set 13		Choice Set 8	
Choice Set 15		Choice Set 11	
Choice Set 16		Choice Set 14	
Choice Set 17		Choice Set 18	

SECTION J: ATTITUDES, SOCIAL INFLUENCE, PERCEIVED ABILITIES AND BEHAVIOURAL INTENTION TOWARDS UTILIZATION OF INSECT BASED FEED

Most of the livestock feeds are made from protein sources such as soya bean, fishmeal and cotton seed cake. If we were to replace one of the common protein sources for example soya bean or fishmeal with insects, please rate the extent to which you agree or disagree with each of the statement below.

1= Strongly Disagree 2= Disagree 3= Neutral 4= Agree 5= Strongly Agree

ATTITUDES TOWARDS UTILIZATION OF INSECT-BASED FEED		
J01) **Yield**	I would feed my dairy cattle on insects feed if it improves on my milk yield	
J02) **Price**	I would feed my dairy cattle on insects feed if the price is lower than other protein feed products	
J03) **Availability**	I would feed my dairy cattle on insects feed if there was no other feed available	
J04) **Cultural taboo**	In my community, it is a taboo to use feed from insects to feed the dairy cattle	

SOCIAL INFLUENCE TOWARDS UTILIZATION OF INSECT BASED FEED Please rate the extent to which you agree or disagree with each statement below 1= Strongly Disagree 2= Disagree 3= Neutral 4= Agree 5= Strongly Agree			
J05) I would feed my dairy cattle on insects feed if my animal health officer assures me that insects are safe for livestock feed			
J06) I would feed my dairy cattle on insects feed if my customers for milk have no problem with it			
J07) I would feed my dairy cattle on insects feed if I got an approval from a trusted organization (**let the respondent specify the organization**)			
J08) I would feed my dairy cattle on insects feed if I hear or see on media (e.g. TV, radio, Facebook) that feed from insects is good			
PERCEIVED ABILITIES TOWARDS UTILIZATION OF INSECT BASED FEED			
K09) Buying insect based feed for my dairy cattle, as soon as they become available for sale, will be entirely my choice	1= Strongly Disagree 2= Disagree 3= Neutral 4= Agree 5= Strongly Agree		
BEHAVIOURAL INTENTION TOWARDS UTILIZATION OF INSECT BASED FEED Please rate the extent to which you agree or disagree with the statement below			
J10) Assuming insects feed were made available, what would be your likelihood of purchasing them for your dairy cattle?	1= very unlikely 2= not likely	3= neutral 4= likely 5= very likely	

SECTION K: HOUSEHOLD LIVESTOCK FEED SECURITY (ACCESS AND QUALITY)			
No.	**Question** During the last 12 months…	1= Yes 0= No (skip to next question)	If Yes, how often did this happen? 1= Rarely 2= Sometimes 3= Often
K01)	Did you worry that your livestock would not have enough feed because of a lack of resources?		
K02)	Were your livestock not able to eat the types of feed you preferred because of a lack of resources?		
K03)	Did your livestock have to eat a limited variety of feed due to a lack of resources?		
K04)	Did you have to give your livestock some type of feed that they really did not want to feed on or disliked because of a lack of resources to obtain other types of feed?		
K05)	Did you have to give your livestock less feed than you felt they needed because there was not enough feed?		
K06)	Did you have to give your livestock fewer feeds or reduce the feed rations per day because there was not enough feed?		
K07)	Did you ever lack any kind of feed to give to your livestock because of lack of resources to get feed or cultivate own feed?		
K08)	Did any of your livestock sleep hungry because there was not enough feed?		
K09)	Did any of your livestock go a whole day and night without feeding on anything because there was not enough feed?		
K10)	Did you have to sell any of your livestock because there was not enough feed?		
K11)	Did you have to transfer any of your livestock to a friend, neighbour or relative because there was not enough feed?		
K12)	Did you feed your livestock on a certain type of feed because you had inadequate information on the feed quality?		
K13)	Did you ever feed your livestock on a certain type of feed because you had inadequate information on the animal requirements?		
K14)	Did you ever lack any kind of feed to give to your livestock because of extreme drought and/ or flood/heavy rains		
K15)	Did you ever lack any kind of feed to give to your livestock because of lack of aid or remittances?		

SECTION L: INFORMATION ON FARM INCOME FROM LIVESTOCK						
L01) In the last 12 months, has your household had any income from the sale of livestock?			1= Yes 0= No			
If **YES**, please tell us the number of livestock sold and the price received. **If NO to L01, skip to L09.**						
L02) Type of livestock	L03) In the last 12 months, did your household sell any of these livestock 1= Yes 0= No	L04) Quantity sold in the last 12 months (Indicate the total number of livestock sold)	L05) Unit price of the livestock (on average) KES	L06) Total price (KES)	L07) Mode of payment	L08) Where did you sell the livestock?
1. Dairy cattle (lactating)						
2. Dairy cattle (dry cow)						
3. Heifer						
4. Bull						
5. Calf						
MODE OF PAYMENT: 1= Cash 2= Credit 3= Cheque 4= Other (specify) **MAIN BUYER/ CUSTOMER:** 1= farmers 2= breeders/ livestock fatteners 3= open market centre 4= slaughterhouse/butcheries 5= Kenya Meat Commission (KMC) 6= private exporter 7= middlemen 8= Other						
L09) In the 12 months has your household sold any livestock products or sold livestock feed?			1= Yes 0= No			
If Yes, please tell us the amount of the following livestock products and feed sold and the price received during the last 12 months?						
L10) Sale of livestock products and feed	L11) In the last 12 months, did your household sell any of these products 1= Yes 0= No	L12) Amount of product retained for household use in a month (on average)	L13) Quantity sold in a month (on average)	L14) Unit	L15) Price per unit (KES) (on average)	L16) Total income from sales per month (KES)	L17) Where do you mainly sell your products?
1. Meat (beef) (kg)							
2. Milk (litres)							
3. Manure (kg)							
4. feed (kg)							
5. Other specify							
CODE A FOR MAIN BUYER/CUSTOMER: 1= Neighbour/Friend 2= Family member 3= Trader 4= Cooperative 5= county government 6= Local market 7=middlemen 8=Other (specify)							

SECTION P: INFORMATION ON HOUSEHOLD LIVING CONDITIONS			
M01)	What type of dwelling does the household live in?	1= Permanent building 2= Semi-permanent 3= Temporary 4= Traditional 5= Other (specify)	
M02)	If the dwelling in M01 above is permanent, what type is it?	1= house/bungalow 2= flat 3= maisonette/townhouse 4= Swahili type house 4= other (specify)	
M03)	What is its tenure status?	1= Owned 2= rented 3= No rent (squatting) 4= Supplied free by employer 5= Other (specify)	
M04)	How many habitable rooms does the household occupy? (excluding bathrooms, toilets, storerooms and garage)	Indicate the total number of rooms	
M05)	How many rooms does your household use for sleeping?	Indicate the total number of rooms	
M06)	Do you have a separate room which is used as a kitchen?	1= Yes 0= No	

M07)	What is the predominant wall material of the main house?	1= mud/wood 2= stones 3= brick/block 4= mud/cement 5= wood only 6= corrugated iron sheets 7= grass/straw 8= tin 9=plastered 10= other (specify)	
M08)	What is the predominant roof material of the main house?	1= grass 2= iron sheet 3= tiles 4= other (specify)	
M09)	What is the predominant floor material of the main house?	1= earth 2= cement 3= wood 4= tiles 5= other (specify)	
M10)	What is the main type of appliance used for cooking?	1= Ordinary jiko 2= Improved jiko 3= Traditional/ improved stone fire 4= Kerosene stove 5= Gas 6= electric cooker 7 = Other (specify)	
M11)	What is the main source of energy for cooking?	1= Collected firewood 2=Purchased firewood 3= Grass 4= Electricity 5= Gas/LPG 6= Biogas 7= Kerosene/paraffin 8= Charcoal 9= Biomass residue e.g. cow, coffee husks, sawdust dung 10= Other (specify)	
M12)	What is the main source of lighting in your household?	1= Electricity- grid 2= Own generator 3= Solar power 4= Paraffin lantern 5= Candles 6= Battery 7= biogas 8= rechargeable lamps 9= collected firewood 10= purchased firewood 11= grass/straw 12= dry cell (torch) 13= Other (specify)	
M13)	What is the main source of water for the household?	1= piped into dwelling 2= piped into plot/yard 3= public tap 4= tube/well/borehole with pump 5= protected dug well 6= protected spring 7= rainwater collection 8= unprotected dug well/springs 9= river/ponds/streams 10= tankers/truck 11= bottled water 12= other specify	
M14)	What is the main source of water used for food preparation in your household?	1= piped into dwelling 2= piped into plot/yard 3= public tap 4= tube/well/borehole with pump 5= protected dug well 6= protected spring 7= rainwater collection 8= unprotected dug well/springs 9= river/ponds/streams 10= tankers/truck 11= bottled water 12= other specify	
M15)	Do you use any methods to make the water safe to drink?	1= Yes 0= No	
M16)	If Yes to M15 above, what method do you use?	1= Boil 2= Bleach/chlorine 3= Sieve through a cloth 4= Water filter (ceramic, sand etc.) 6= Solar disinfection 7= Let it stand and settle 8= Buy bottled water 9= Other (specify)	
M17)	What kind of toilet facility does your household usually use?	1= Flush toilet 2= Ventilated improved pit latrine 3= Uncovered pit latrine 4= Covered pit latrine 5= Bucket toilet 5= No facility/bush/ field 6= Other (specify)	

SECTION N: INFORMATION ON HOUSEHOLD ASSETS (THEY SHOULD BE IN WORKING CONDITION)					
N01) Which of these assets does your household own?	N02) 1= Yes 0= No	N01) Which of these assets does your household own?	N02) 1= Yes 0= No	N01) Which of these assets does your household own?	N02) 1= Yes 0= No
1. Radio (with no other components)		10. Towel		19. Strip cup	
2.Black and white television		11.Generator		20.Water pump	
3. Colour TV set		12. Refrigerator		21. Water tank	
4. Mobile phone		13. Freezer		22. Milk containers	
5. Smart phone		14. Microwave		23. Spray nozzles/cattle sprayers	

6. Bicycle		15. Electric stove and oven		24. Axes, rakes, hoe, slasher	
7. Motor car		16. Frying pan		25. Chaff cutter	
8. Motorcycle		17. Electric iron		26. Solar panels	
9. Wheel barrow		18. Computer (desktop/laptop)			

SECTION O: INSTITUTIONAL AND SUPPORT SERVICES		
	REFERENCE CODES	RESPONSE
O01) Are you or any member in your household a member of a registered farmers' group or association?	1= Yes 0=No	
O02) If Yes to O01 above, what type of group?	1= Self-help group 2= SACCO 3= Community Based Organization (CBO) 4= A dairy cooperative society 5= Other (please specify)	
O03) Did you or any member in your household try to obtain or access credit over the last 12 months?	1= Yes 0= No	
O04) Did you obtain or get the loan/credit?	1= Yes 0= No	
O05) If Yes to O04 above, who was the provider?	1= Commercial bank 2= Micro-finance institution 3= Cooperatives 4= Shylock/local money lender 5= Mobile credit (Mshwari, branch, tala) 6= Sacco 7= Family/friends 8= Chama group 9= contractual out grower arrangement 10= Other (please specify)	
O06) What was the loan used for?	1=purchase animals 2=purchase animal feeds 3=veterinary services 4=AI services 5=others (specify)	
O07) Name of nearest town/market	Indicate name	
O08) What is the distance from the homestead to the nearest market?	In kilometers	
O09) What is the distance from the homestead to the nearest tarmac road?	In kilometers	
O10) Did you or any member in your household receive any extension services in the last 12 months?	1= Yes 0= No	
O11) If Yes to O10 above, what type of extension service was it?	1= Crop production 2= Livestock production 3= feed production and management 4= Conservation practices 5= others (specify)	
O12) Who was the main provider of the extension services?	1= Government 2= Private extension 3= Cooperative/farmer association 4= NGO's 5= Others (specify)	
O13) Who in the household accessed the service?	1= Household head 2= Spouse 3= Child 4= Farm manager 5= Other (specify)	
O14) Do you have an insurance cover?	1= Yes 0= No	
O15) If Yes to O14 above, please specify the type of insurance	1= Life insurance 2= Property insurance 3= Health insurance 4= Livestock insurance 5= Crop insurance 6= Funeral insurance 7= Disability insurance 8= Accident insurance 9= Others (specify)	

SECTION P: INFORMATION ON HOUSEHOLD INCOME			
Income source	**(P01)** Did anyone in your household earn income from this source last year? 1= Yes 0= No skip	**P02** If Yes, what is the total income per month? KES	**P03** If Yes, what is the total income per year? KES
1. Informal employment/casual labour			
2. Formal employment			
3. Agricultural/ agribusiness			
4. Business			
5. Remittances			

6. Petty trade (sale of wares or other products in the market apart from the listed items)			
7. Pension			
8. Rented out properties			

Appendix III: The choice experiment cards

Choice card 1

Attribute	Option 1	Option 2	Option 3
Source of energy	Cassava	Wheat	None of the two options
Source of protein	Fish meal	Fish meal	
Brand	Branded	Unbranded	
Yield increment	No increment	No increment	
Price per kilogram	KES. 40	KES. 60	
I prefer			

Choice card 2

Attribute	Option 1	Option 2	Option 3
Source of energy	Maize	Cassava	None of the two options
Source of protein	Insect meal	Soy meal	
Brand	Branded	Unbranded	
Yield increment	50%	50%	
Price per kilogram	KES. 40	KES. 20	
I prefer			

Choice card 3

Attribute	Option 1	Option 2	Option 3
Source of energy	Wheat	Wheat	None of the two options
Source of protein	Fish meal	Fish meal	
Brand	Unbranded	Branded	
Yield increment	75%	No increment	
Price per kilogram	KES. 80	KES. 40	
I prefer			

Choice card 4

Attribute	Option 1	Option 2	Option 3
Source of energy	Maize	Cassava	None of the two options
Source of protein	Soy meal	Insect meal	
Brand	Unbranded	Branded	
Yield increment	75%	50%	
Price per kilogram	KES. 80	KES. 20	
I prefer			

Choice card 5

Attribute	Option 1	Option 2	Option 3
Source of energy	Wheat	Wheat	None of the two options
Source of protein	Fish meal	Fish meal	
Brand	Branded	Unbranded	
Yield increment	No increment	No increment	
Price per kilogram	KES. 60	KES. 40	
I prefer			

Choice card 6

Attribute	Option 1	Option 2	Option 3
Source of energy	Maize	Cassava	None of the two options
Source of protein	Soy meal	Insect meal	
Brand	Branded	Unbranded	
Yield increment	No increment	50%	
Price per kilogram	KES. 20	KES. 40	
I prefer			

Choice card 7

Attribute	Option 1	Option 2	Option 3
Source of energy	Maize	Cassava	None of the two options
Source of protein	Insect meal	Soy meal	
Brand	Unbranded	Branded	
Yield increment	50%	75%	
Price per kilogram	KES. 20	KES. 60	
I prefer			

Choice card 8

Attribute	Option 1	Option 2	Option 3
Source of energy	Cassava	Maize	None of the two options
Source of protein	Soy meal	Insect meal	
Brand	Branded	Unbranded	
Yield increment	25%	25%	
Price per kilogram	KES. 40	KES. 40	
I prefer			

Choice card 9

Attribute	Option 1	Option 2	Option 3
Source of energy	Maize	Cassava	None of the two options
Source of protein	Soy meal	Insect meal	
Brand	Unbranded	Branded	
Yield increment	25%	50%	
Price per kilogram	KES. 20	KES. 40	
I prefer			

Choice card 10

Attribute	Option 1	Option 2	Option 3
Source of energy	Cassava	Maize	None of the two options
Source of protein	Soy meal	Insect meal	
Brand	Unbranded	Branded	
Yield increment	25%	75%	
Price per kilogram	KES. 20	KES. 80	
I prefer			

Choice card 11

Attribute	Option 1	Option 2	Option 3
Source of energy	Wheat	Wheat	None of the two options
Source of protein	Fish meal	Fish meal	
Brand	Branded	Unbranded	
Yield increment	25%	No increment	
Price per kilogram	KES. 80	KES. 60	
I prefer			

Choice card 12

Attribute	Option 1	Option 2	Option 3
Source of energy	Maize	Cassava	None of the two options
Source of protein	Insect meal	Soy meal	
Brand	Branded	Unbranded	
Yield increment	75%	75%	
Price per kilogram	KES. 60	KES. 60	
I prefer			

Choice card 13

Attribute	Option 1	Option 2	Option 3
Source of energy	Wheat	Wheat	None of the two options
Source of protein	Fish meal	Fish meal	
Brand	Branded	Branded	
Yield increment	No increment	25%	
Price per kilogram	KES. 60	KES. 80	
I prefer			

Choice card 14

Attribute	Option 1	Option 2	Option 3
Source of energy	Cassava	Maize	None of the two options
Source of protein	Insect meal	Soy meal	
Brand	Unbranded	Branded	
Yield increment	50%	75%	
Price per kilogram	KES. 20	KES. 80	
I prefer			

Choice card 15

Attribute	Option 1	Option 2	Option 3
Source of energy	Wheat	Wheat	None of the two options
Source of protein	Fish meal	Fish meal	
Brand	Unbranded	Unbranded	
Yield increment	No increment	25%	
Price per kilogram	KES. 60	KES. 80	
I prefer			

Choice card 16

Attribute	Option 1	Option 2	Option 3
Source of energy	Cassava	Maize	None of the two options
Source of protein	Soy meal	Insect meal	
Brand	Unbranded	Branded	
Yield increment	25%	25%	
Price per kilogram	KES. 40	KES. 20	
I prefer			

Choice card 17

Attribute	Option 1	Option 2	Option 3
Source of energy	Cassava	Maize	None of the two options
Source of protein	Insect meal	Soy meal	
Brand	Branded	Unbranded	
Yield increment	50%	No increment	
Price per kilogram	KES. 40	KES. 20	
I prefer			

Choice card 18

Attribute	Option 1	Option 2	Option 3
Source of energy	Wheat	Maize	None of the two options
Source of protein	Insect meal	Soy meal	
Brand	Unbranded	Branded	
Yield increment	75%	25%	
Price per kilogram	KES. 80	KES. 20	
I prefer			

Appendix IV: FGD tool for dairy farmers

Name	
Telephone no.	
Sub-county	
Ward	

1) Which are the three main livestock enterprises in your household?
2) What is the main reason for livestock production in your household?
3) Do you face any constraints in livestock production? 1= Yes 0= No
4) If Yes to 3, what are the five main constraints that you face? Rank in order of severity
5) Among these constraints how can you rate feed constraint? 1= Mild 2= Moderate 3= Severe
6) How do you cope with the feed constraint in livestock production in 5 above?
7) What types of feed sources do you give your dairy cattle? Rank in order of preference
8) What do you generally consider when you give your livestock feeds from these sources? (list the five main reasons in order of preference)
9) Now if you feed your livestock on concentrate feed, where do you mainly source the feeds?
10) What do you consider when purchasing the feeds in 9 above? Mention at least five main reasons in order of preference
11) Which ingredients would you be happy to see in the feed products you purchase? (list in order of preference for energy, proteins or any other type of ingredient)
12) Do you formulate your own livestock feed? 1= Yes 0= No
13) If Yes to 12, which ingredients do you use? Rank in order of preference for energy, protein and any other type of ingredient
14) What are some of the main reasons that make you prefer formulating your own livestock feed?
15) Do you observe any changes with your livestock when you feed them on concentrate feeds? 1= Yes 0= No
16) If Yes to 15, what are some of these changes?
17) Have you ever used livestock feeds formulated with cassava as the main source of energy? 1= Yes 0=No
18) If Yes to 17, were you satisfied with the outcome of the feed in your livestock diet? 1= Yes 0= No
19) If No to 17 above, are you willing to use the feed formulated with cassava as the main source of energy? 1= Yes 0= No
20) Have you ever used livestock feeds formulated with insects as the main source of protein? 1= Yes 0= No
21) If Yes to 20, were you satisfied with the outcome of the feeds in your livestock diet? 1= Yes 0=No
22) If No to 20 above, are you willing to use the feeds formulated with insects as the main source of protein? 1= Yes 0=No

Appendix V: Key informant interview tool

Date	
Location: (indicate sub-county and ward)	
Name of key informant	
Occupation	

1) What are the common livestock feed products utilized by the smallholder dairy farmers in the area?
2) Are you aware of any energy and/or protein sources used to formulate the livestock feed products? 1= yes 0= no
3) If yes to (2) above, please list the energy and protein sources you are aware of (please list the energy and protein sources separately)
4) In order of preference can you list the most preferred to the least preferred livestock feed sources listed in (3) above by smallholder dairy farmers in the area (please list the energy and protein sources separately)
5) What are some of the reasons indicated for the farmers' preferences of the first three energy and protein sources listed in 4 above?
6) Who are the main suppliers of the livestock feed ingredients or products? list in order of importance
7) What are some of the characteristics that the farmers consider when purchasing the livestock feed ingredients or products?
8) Are you aware of cassava as one of the energy sources used to formulate livestock feed? 1= yes 0= no
9) If yes to 8 above, do you know any local feed manufacturer using it to formulate livestock feeds? 1= yes 0= no
10) If yes to 9 above, please name any local feed manufacturer using cassava as a source of energy in the formulation of livestock feed.
11) Are you aware of insects as one of the protein sources used to formulate livestock feed? 1= yes 0= no
12) If yes to 11 above, do you know any local feed manufacturer using insects to formulate livestock feed? 1= yes 0= no
13) If yes to 12 above, please name any local feed manufacturer using insects as a source of protein in the formulation of livestock feeds.