POPULATION STRUCTURE, GROWTH AND CARCASS CHARACTERIZATION OF DOMESTICATED RABBITS (*Oryctolagus cuniculus* L.*)* IN NORTH RIFT AND WESTERN KENYA

BY

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DECLARATION

Declaration by the Candidate

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DEDICATION

I would like to dedicate this work to the Almighty God for the gift of life and strength to carry out this work; and to my husband Mr. Daniel Sergon and our children for their encouragement, material and moral support throughout the period of the study.

ABSTRACT

Rabbit farming has the ability to enhance nutrition and reduce poverty through the production of meat, fur, and manure. The goal of the current study was to examine the population structure, growth, and carcass characterisation of domestic rabbits (*Oryctolagus cuniculus*) in North-Rift and Western Kenya. The goals of the study were to assess domesticated rabbit farming practices and issues that came up, as well as the animals' morphometric and growth qualities, genetic diversity, and carcass traits of crosses made in North-Rift and Western Kenya. The rabbit breeds with the required standards had enough space. The exploratory study approach was used and sampling was done using both stratified and systematic sampling with a sample size of 112 respondents. A computerized weighing scale was used to evaluate morphometric parameters, and a measuring tape was used to take body measures at known anatomical sites. Cross-tabulation chi square analysis was used to investigate the distribution of rabbit breeds. To obtain the least square means for measurements of body weight and body dimensions, the generalized linear modeling method was utilized. Statistically significant differences between the populations were established using the Duncan test. Seven microsatellite markers were utilized, which were consistently distributed throughout the rabbit genome and linked to traits related to growth and meat yield. Genomic DNA was taken from rabbit blood samples. It was determined how many alleles (No and Ne) had been observed and how many had been expected (Ho and He). Individual breeds were divided using factor analysis, and the grouping of rabbit ecotypes was displayed using a dendrogram population diagram. Using cross tabulation chi squares (2), the breed distribution of rabbits was examined. The GLM was used to estimate the least square means for body weight and dimension measurements. Males made up the majority of responders (56.3%. Main rabbit feed was vegetables from farms 68 (60.7%) rarely supplemented with pellets 23 (76.7%). Rabbits farming encountered various problems such as diarrhoea, predators, thieves, sudden deaths, and high costs of building materials (χ^2 = 121.81, d.f.=4, p = 0.0001). Different challenges and raising methods were used. The two most common meat breeds were New Zealand White 48 (43.6%) and Flemish giant 22 (20.0%) (p=0.0001). The majority of rabbits were kept in cages that were 1.5 meters by 1.5 meters in size (68.3%) and were around a meter tall. Ho and He's respective mean values were 0.903 and 0.89 in the study. The analyzed local populations showed different sub-structuring, which suggests that they had adapted to their separate AEZs, according to microsatellites. Each cross had an average litter size of 7.10±1.44 kits. In NZW*SF (2319±164), live weights (g) before fasting were not substantially high The live weight (g) at slaughter exhibited the same pattern. There were no discernible differences in fasting loss between the crosses. NZW*SF (2203±206) has the highest non-significant weight (p>0.05) that was ever recorded. The NZW*R (1083±96.0) cross, which had a hot carcass weight, had a non-significantly greater weight compared to other crosses. Giblets did not weigh differently between crossings (p>0.05). Total edible parts, dressing yield, carcass percentage, carcass with giblets and dressed head percentage, inedible parts percentage, spleen, lungs, and trachea percentage, and the ratio of inedible to edible parts were all the same among the crosses. The results suggested that farmers may use the superior New Zealand White rabbit breed, which was discovered, to enhance their native varieties.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEZ	Agro-egological Zone
AMOVA	Analysis of Molecular Variance
AnGR	Animal Genetic Resources
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists International
ARBA	American Rabbit Breeder Association
BM,	Bungoma
bP	base pairs
BS	Busia
BSI	British Standards Institution
BW0	Initial Body Weight
BW1	Body weight at week one
CIA	Chloroform Isoamyl alchohol
CRD	Completely Randomized Design
CTAB	Cetyl Trimethyl Ammonium Bromide
DAPC	Discriminamt Analysis of Principal Components
DE	Digestible energy
D-loop	Displacement loop region of mitochondrial DNA
DNA	Deoxyribonucleic Acid
Dr	Dutch
EU	European Union
F1	First Filial
FAO	Food and Agriculture Organization
FCE	Feed Conversion Efficiency
FCR	Feed Conversion Ratio
FGr	Flemish Giant
GATK	Genetic Analysis Tool Kit
gDNA	genomic Deoxyribonucleic Acid
GIT	Gastro-intestinal Tract
GLM	General Linear Model
He	Expected Heterozygosity
HLTTO	Heart, lungs, thymus, trachea, and oesophagus

Ho	Observed Heterozygosity
HO:	Null hypothesis
HP	Haptoglobin
HPX	Haemopexin
KALRO	Kenya Livestock and Agricultural Research Organization
Kb	Kilobase
KK	Kakamega
LD	Longissimus Dorsi
MNA	Mean Number of Alleles
*Mt*DNA	Mitochondrial Deoxyribonucleic Acid
NACOSTI	National Commission for Science and Technology
NARL	National Agricultural Research Laboratories Kabete
NDVI	Normalized Difference Vegetation Index
Ne	Expected number of alleles
NGO	Non-Governmental Organization
ng/µl	Nanogram per microliter
No	Observed number of alleles
NR	North Rift
NZWR	New Zealand White Rabbit
PCA	Principal Component Analysis
PIC	Polymorphism Information Content
pmoles/µl	Picamoles per microlitre
Pr	Palomino rabbit
RC	Refference Carcass
RFLP	Random Fragment Length Polymorphism
RHDV	Rabbit haemorragic disease virus
RNA	Ribonucleic acid
Rpm	Revolutions per minute
Rr	Rex rabbit
SE	Standard Error
SFr	Silver Fox rabbit
SW	Slaughter Weight
SSR	Single-Sequence Repeats

VH	Vihiga
WRSA	World Rabbit Science Association
µl	microliters

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CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The rabbit (Oryctolagus cuniculus), also known as the European breed, is a well-known mammal worldwide, both in its wild and domesticated forms. All around the world, little farms are used to grow rabbits (Olagunju, Adeniyi, & Oladele, 2018). They are members of various genera in the families Lepidae and Palaeloginae, suborders of the order Lagomorpha, and superorder Glives (Olagunju, Adeniyi, & Oladele, 2018). The body type, size, and color of rabbit breeds are utilized to phenotypically separate them (Serem *et al*., 2013). It has been determined that rabbits with weights of 1.4–2 kg, 4–5.4 kg, and 6.4–7.3 kg, respectively, fall into three categories: small breeds, middle breeds, and giant breeds (Khan *et al*., 2018). The domesticated equivalent displays impressive breed variety with variances in size, color, and fecundity (Flisikowska *et al*., 2014). Only a few of the 47 different rabbit breeds are bred in Kenya, according to the AmericannRabbit Breeders Association (2010). (Serem *et al*., 2013). Like all parts of agriculture, the profitability of rabbit farming is heavily influenced by management and market prospects (Hungu *et al*., 2011; Mfuko, 2017). Despite the increased acceptance and advantages of rabbit husbandry, there are still several challenges, including sickness. The success of the project depends on housing, space, regular sanitation, and nutritious food (Hungu *et al*., 2011). Kenya is a developing nation with a sizeable rural population that depends on agricultural output as its main source of revenue. However, the lack of parent breeding stock, the high expense of commercial feed, and farmers' limited access to scientific information (Cherwon, Wanyoike & Gachuiri, 2020; Wambugu, 2015).

The most prevalent rabbit breeds in Kenya are New Zealand White, Californian White, Flemish Giant, French Ear Lop, Chinchilla, Angora, Kenya White, and their hybrids (Serem *et al*., 2013). Oryctolagus cuniculus rabbits produce an abundance of tasty meat for domestic usage (Khan *et al*., 2017). All three of the aforementioned studies—Petreu-Mag *et al*. (2019), Lai *et al*. (2018), and Cullere and Dalle Zotte (2018)—have discussed the potential applications of rabbit meat in supplying the world's protein needs. Certain rabbits are a viable meat substitute in Africa due to their high prolificacy, short gestation period, early sexual maturation, high genetic selection potential, high feed conversion efficiency, efficient space utilization, and ability to breed quickly after kindling (Cullere and Dalle Zotte, 2018). Both wild and cultivated European rabbits are members of the single species Oryctolagus cuniculus, the sole living member of the genus Oryctolagus (Seixas *et al*., 2014a). Oryctolagus cuniculus domesticus is the only known ancestor of domestic rabbits (*Linnaeus*, 1758). O. cuniculus, considered the sole accepted origin of domestic rabbits, is the only known single direct source of all known domestic rabbits, and there is no empirical evidence to refute this claim. Significant behavioral, morphological, physiological, and reproductive changes have been brought about by domestication (Carneiro *et al*., 2014).

Prior to western Europe's domestication of rabbits, which began at the end of the 18th century, it was the early 16th century (Amato, 2017). Consequently, the domesticated rabbit and the wild rabbit are both descendants of the Oryctolagus cuniculus species (Owuor *et al*., 2019; Petrescu-Mag *et al*., 2019). The homogeneity of domesticated rabbit breeds and their shared genetic diversity subset with wild rabbits in France are revealed through historical records (Owuor *et al*., 2019). The majority of wild rabbit populations are currently found in Europe, although new populations are emerging due to human-mediated introduction in other parts of the world (Neimanis *et al*., 2018). At

various levels of analysis of mitochondrial DNA sequence variation, microsatellites, protein electrophoretic polymorphisms, and immunogenetic markers, several population genetic studies have shown that rabbit domestic breeds are genetically very homogeneous and represent a small subset of the species' genetic diversity (Drygala *et al.*, 2016). Domestication has been illustrated by the increasing variability in phenotypic, behavioural and physiological characteristics (Neimanis *et al*., 2018). High variability is dominant in indigenous rabbits due to absence of high genetic drift (change in the frequency of an existing gene variant in a population due to random chance) coupled with inconsistent and inadequate selection programmes in the past (Lai *et al*., 2018).

Several studies based on mitochondrial DNA polymorphism within the rabbit's native range reveal two highly divergent maternal lineages. The two domestic breeds have a well-defined geographical distribution. i.e., one lineage found in south-western Iberia, while the other found in north-eastern Spain (Seixas *et al.*, 2018). These subspecies are well distinct genetically (Fontanesi *et al*., 2021). Harrison and Lawson (2016) showed that there is a clear dichotomy in the rabbit genome, with some loci retaining their high degree of distinctiveness despite extensive gene flow after secondary contact. In line with the identification of two subspecies within the Iberian Peninsula, the overall phylogeographical pattern reveals long-term regional isolation of two rabbit populations, followed by recent interaction and admixture (Lado *et al*., 2019). Due to high amounts of gene flow, the majority of loci in both *O. c. algirus* and *O. c. cuniculus* exhibit low differentiation; however, several loci, including the autosomes, *mt*DNA, X chromosome sites near centromeres, and the Y chromosome, exhibit significant differentiation (Carneiro *et al*., 2014; Seixas *et al*., 2014a).

According to Alves *et al*. (2015), there is significant genetic variation between the breed of rabbits found in France and the Iberian Peninsula, with the *mt*DNA level displaying the allele size mean variances across all loci, similar allelic profiles, and the population with the same mean number of alleles being the most distinctive feature. The rabbit genome has two different lineages, according to prior studies on mitochondrial DNA (*mt*DNA), Y-linked loci, and X-linked loci, with mtDNA and two X-linked loci being primarily subspecies-specific (Alda & Doadrio, 2014). The results demonstrate that there are two very different Y chromosome lineages from which rabbit breeds descended, which most likely shares the genetic signature of significant population subdivision for the *mt*DNA molecule reported in Iberian populations (Pinheiro *et al*., 2016). Previous research using selectrophoretic analysis discovered significant geographic variability in the frequencies of three main electromorphs in the wild populations of the European rabbit (*Oryctolagus cuniculus*) (Hlavackova *et al*., 2019). A third electromorph is only found in the hybrid zone between the two rabbit subspecies in Iberia, where the frequency of two electromorphs differs greatest between two distinct subspecies of European rabbits (Ferreira *et al*., 2015). Genetic diversity and genome-wide variance are directly impacted by variations in a number of variables, including effective population numbers, population structure, inbreeding, migration, and recombination rates (Bourgeois *et al*., 2017). Compared to *O. c. cuniculus*, *O. c. algirus* species exhibits higher polymorphism that is rarer and has a more accurate distribution of allele frequencies (Carneiro *et al*., 2014). In 10 autosomal regions, Alves *et al*. (2015) found a substantial difference between *O. c. algirus* and *O. c. cuniculus*. The findings demonstrated that there was distinct evolutionary divergence across subspecies at two centromeric loci, but there was little to no geographic trend at the other eight loci in the allele clustering.

With fewer than 200 genomic areas, Carneiro *et al*. (2014) recognized various degrees of differentiation across and among the subspecies. The smallest sections, less than 200 Kb, have a tiny number of genes (Carneiro *et al*., 2014). According to Hou *et al*. (2020), drift in the populations' geographic isolation can lead to mutation structuring as well as various forms of natural selection.

According to Alves *et al*. (2015), there are approximately 200 rabbit breeds with a wide range of uses, including companion animals, wool, meat, and fur. These breeds show a huge variation in a number of features that have accumulated during the smallest periods of time since domestication. The domesticated rabbit serves a greater range of commercial and experimental uses because of its phenotypic variability (Fontanesi *et al*., 2021).

When taking into account all rabbit breeds, the loss of genetic diversity due to domestication is significant since using a breeding plan will result in a strain that is more diverse than the pure breed (Alves *et al*., 2015; Badr *et al*., 2016). A distinct and discernible evolutionary tree is visible in domestic rabbits (Alves *et al*., 2015). Therefore, the discovery of the genetic modifications sheds light on the fundamental processes through which genetic variation affects phenotypic variety (Schneider & Meyer, 2017)

Domestication has altered the phenotypic and genetic makeup of organisms, and as a result, humans now place an inherent, monetary, and cultural value on these new creations (Alves *et al*., 2015). Six microsatellites accounted for 18% of the 21% loss in genetic diversity caused by initial domestication in the wild (Carneiro *et al*., 2014). According to studies, the amount of breed differentiation in rabbits is generally higher than it is in many other domestic animals (Alves *et al*., 2015). Using microsatellites, it

has been determined that there are 6–13% of sheep breeds, 7–11% of cattle breeds, 8–12% of horses, and 7% of goat breeds. Nevertheless, the average value for domesticated rabbits was reported to be indistinguishable to those values for dogs as well as for pigs at 27% (Schneider & Meyer, 2017).

The genotypic studies at the genomic level have concentrated on describing its genetic diversity and geological distribution, with mixed results ranging from a strong phylogeographical pattern based on two highly divergent but overlapping mtDNA of the *Oryctolagus cuniculus cuniculus* and *O. c. algirus* to the lack of complete population structures as derived by the study of autosomal microsatellites (Fontanesi *et al*., 2021). (Seixas *et al*., 2018). According to Alves *et al.* (2015), it is simpler to identify and deduce the structures through breed crosses than from a recent origin of domestication (Carneiro *et al*., 2014). Portrayal of important genetic resources eventually will serve as a crucial prerequisite for the proof of identity, effective management and utilization of the rabbit, which will smoothen and consequently facilitate their conservation (Thumiki, 2018). The identification of the loci in the underlying local species is crucial for functional ecological, evolutionary, conservation and agronomical purpose (Bourgeois *et al*., 2017). Therefore, an assessment of genetic diversity within populations, haplotype frequencies and possible association with phenotype in each population would be needed to explore this possibility (Thumiki, 2018). However, empirical models supporting speciation among rabbit breeds are impartially scarce but can be derived from mapping trials (Alves *et al*., 2015; Carneiro *et al*., 2014).

Despite its social economic, commercial as well as the scientific value of the domestic rabbits, large-scale efforts by scientific community to understand the impact of the domestication process on rabbits genome are lacking (Carneiro *et al*., 2014). Rabbit meat is recognized to be high in protein and low in fat, making it a healthy choice (Cullere & Dalle Zotte, 2018).

1.2 Statement of the problem

Rabbit farmers in the study areas encounter constraints and problems. Rabbit cannibalism in the area of study has not been dealt with. During the gestation period rabbits need to be adequately fed and currently this is not done in the areas of study. Even after giving birth, feeding must be increased because the does must recover a lot of energy in order to provide the newborn kittens with the best care possible. In order to prevent the does from eating on their infants, it is important to feed the kittens enough, especially when they are weaning. Farmers should pay more attention to kittens and think about separating them all at once to protect them from their mothers. Poor husbandry methods and insufficient physiological growth are the main obstacles to rabbit farming. Farmers misuse rabbit pellets, which are enriched with nutrients to suit the daily nutritional demands of rabbits, including calcium, proteins, vitamins, and other energy requirements. Since no relevant material has been found, this is not a practice in the aforementioned fields of study. Contrarily, regular feeding of the pellets may cause gastrointestinal issues in the rabbits, increasing the cost of treatment for the farmers.

The rabbit farmers find it challenging to collect significant amounts of rabbit urine and droppings for hygienic purposes because they raise rabbits in locally constructed rabbit cages. Some farmers have thought about keeping rabbits as pets in their houses and

have raised lovely varieties of bunnies, which have decreased the market supply because the rabbits are mainly kept for appearance.

Consequently, the aforementioned communities in the two study zones have diminished the bunnies' principal worth and their advantages. This has made it challenging for farmers in these regions to transition to a large-scale system due to a lack of demand driven by inadequate knowledge and cultural norms.

The majority of genetic research on rabbit breeds has focused on the geographic expansion of the species in Europe, which has produced a robust phylogeographical form of two incredibly distinct *mt*DNA lineages. These rabbit genetic research have focused on a small number of breeds and genetic markers that have an uncharacterised population structure. This is especially true in Kenya, where there aren't many studies that have looked at how domestic rabbit populations are structured.

It has been advantageous to research the genetics of reproductive isolation using both naturally hybridizing species and experimental crosses. While naturally hybridizing animals are predicated on genomic variances in their permeability to alien alleles, laboratory crossings tend to manage both the environmental and genetic backgrounds. In affluent countries, investigations on genotypic compositions have mostly concentrated on particular breeds or genetic markers. The population structure and distribution of the domesticated rabbit breeds in East and Central Africa, particularly Kenya, are poorly understood.

Numerous scholars that used genetic and archaeological research to trace the history of the breeds, with an emphasis on the spread of the European species, have documented the phylogenetic studies on rabbit breeds. The domesticated rabbit has little genetic

variety as a result of introgression, according to one of the few studies conducted in Kenya that examined the genetic diversity of the rabbit breeds. The phylogeny, distribution, population structure, genetic diversity, and phenotypic traits of farmed rabbits are mostly unknown in the North Rift and Western Kenya. Since breeding stock is chosen from own stocks or from neighboring farms, there is also a shortage of high-quality stock.

Exchange of males (bucks) for breeding is done among some rabbit farmers, either for free or at an agreed fee. This is a problem in the area which requires some study so as to provide solutions to avoid inbreeding.

Currently in the study areas there is low rabbit meat production and it has been found that rabbit farming practice is an emerging system of investment in the past few decades. As a result, there has been an immediate need for white meat, preferably rabbit meat. For that reason, it means there is a problem as pertaining to the rabbit meat yields and carcass traits. The market supply of rabbit meat has not met the demand of the consumer due to very few farmers already in the rabbit farming business in the area.

The importance of rabbits to the households in Kenya brings in the need to delineate and distinguish the genetic diversity of the breeds in both North Rift and Western Kenya; and besides, examine the growth characteristics of the domesticated rabbits. Currently there are existing issues in the said area, which needs to be addressed and therefore this research aims to address these aspects to improve rabbit farming in Kenya and improvement in food security and livelihoods.

This study therefore aimed to determine the population structure, growth and carcass characterization of domesticated rabbits in North-Rift and Western Kenya.

1.3 Justification and significance of the study

Diversity studies are crucial for giving different stakeholders the information and tools they need to make informed decisions about animal genetics. They also help local farmers have the desirable breeds they need for high productivity and good meat yield, which contribute to food security and nutrition, income generation, and improved living conditions.

Rabbit farming is one of the more recent animal raising ventures with a lot of potential for meat, fur, wool, meat, and manure that can help improve nutrition, reduce poverty by providing revenue for rural households, and further Kenya's development agenda. The benefits of producing rabbit meat in underdeveloped nations as an alternative source of animal protein have recently come to the attention of a larger global audience.

The current rabbit population in the research regions has poor genetic potential for producing meat; therefore, it is necessary to identify, define, and optimize them for quick growth and high meat production for improved food security and livelihoods.

Global research has shown that rural areas face health issues. White meat production from rabbits can be fostered as an alternative to the natural overdependence on consumption of red meat from small and big ruminants. The study's conclusion will be a quickly expanding rabbit with high meat output, market weight, farmer adoption, and employment opportunities for women, young people, and those with impairments.

The findings of this study may help stakeholders and farmers identify the best genotype to maintain in a particular environment. The morphological and genetic characterization and documenting of Kenya's native domesticated rabbits is crucial for their protection.

Because of their popularity, cheap investment needs, and low economic hazards, as well as their contributions to family nutrition, income creation, and gender empowerment, a unique case is made for the sustainable growth of smallholder, low-input rabbit production systems in Africa.

Animal proteins come from large ruminants like sheep, goats, and cattle. However, the business is unstable because it needs a lot of area and its maintenance costs are significant (Bottom & Brooks, 2018). Rabbits (*Oryctolagus caniculus*) are the most practical solution to address these problems. The results of this study provide conclusions and suggestions for improving rabbit farming in Kenya and enhancing livelihoods and food security.

1.4 Objectives

1.4.1 Main Objective

This study evaluated different attributes of domesticated rabbits that assist in ascertaining whether or not they are suitable for rearing in North Rift and Western Kenya.

1.4.2 Specific objectives

i. To evaluate domestic rabbit farming techniques and problems encountered in North Rift and Western Kenya
ii. To determine the distribution and morphometric characteristics of domesticated rabbit breeds in North Rift and Western regions of Kenya
iii. To evaluate the growth characteristics of domesticated rabbit breeds in North Rift and Western Kenya

iv. To determine the genetic diversity of domesticated rabbit breeds in North Rift and Western Kenya

v. To evaluate the carcass traits of the crosses of domesticated rabbit breeds in North Rift and Western Kenya

1.4.3 Hypotheses

The study was guided by the following hypotheses:

i. Ho_1: There is no significant difference in the farming techniques and problems encountered in farming of domesticated rabbit breeds in North Rift and Western Kenya.

ii. Ho_2: There is no significant difference in Morphometric characteristics in domesticated rabbit breeds in North Rift and Western Kenya.

iii. Ho_3: There is no significant difference in genetic diversity of domesticated rabbit breeds in North Rift and Western Kenya.

iv. Ho_4: There is no significant difference in growth characteristics of domesticated rabbit breeds in North Rift and Western Kenya.

v. Ho_5: There is no significant difference in carcass traits of the crosses of domesticated rabbit breeds in North Rift and Western Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

2.1.1 Origin of domestic rabbit

The rabbit (*Oryctolagus cuniculus*), also known as the European breed, is well-known both in its wild and domesticated versions around the world. The domesticated equivalent displays impressive breed variety with variances in size, color, and fecundity (Flisikowska *et al*., 2014). The only surviving species of the genus *Oryctolagus, Oryctolagus cuniculus,* includes both wild and farmed European rabbits (Seixas *et al*., 2018). *O. cuniculus* is regarded as the sole identified ancestor of domestic rabbits, and it is the only known source of all domestic rabbits. Due to domestication, there have been significant changes in its physiology, behavior, morphology, and reproductive patterns (Carneiro *et al*., 2014).

It is acknowledged that raising rabbits might be a significant industry (Alves *et al*., 2015; Ferreira *et al*., 2015). The business has been around for hundreds of years in developed nations like the United States of America (USA) and Europe, where the majority of the world's livestock is raised for meat (Ibrahim *et al*., 2020). When compared to other types of animal protein, rabbit meat is thought to be the most nutrient-dense (2018). According to Cullere & Dalle Zotte (2018), domestic rabbit meat has a high protein content and little fat, which makes it good for your health. According to Cullere & Dalle Zotte (2018) and Rafati *et al*. (2018), domestic rabbits have the ability to meet the world's protein demands through providing meat for world’s protein needs has been reported by Cullere & Dalle Zotte, (2018). In some cases, they offer manure, fur, skins, and wool (Somerville and Sugiyama, 2021). In developing world,

small pieces of land where farming is practiced continue to decline in size with increase in human population (Crist *et al*., 2017). These farms feed most of the human population.

The majority of resource-poor and low-income farmers in Africa raise domestic rabbits, a practice that is increasingly changing from a hobby in rural areas to a commercial venture in urban areas. From growing a few rabbits, mostly of native breeds, for family consumption in Egypt and Nigeria to major commercial operations (imported breeds) with hundreds of domestic rabbits designed for meat production (Tembachako and Mrema, 2016). Nigeria, Ghana, Zambia, and Togo are major players in Africa's rabbit industry (Oseni & Lukefahr, 2014; Cullere and Dalle Zotte, 2018). Kenya falls significantly short of the 16.34 kg of red meat protein that is suggested by the FAO, making domestic rabbit production a feasible meat option (Cullere and Dalle Zotte, 2018).

The most popular rabbit breeds in Kenya are the New Zealand White, Flemish huge, Californian White, Kenya White, and their crosses with the Angora and Chinchilla. These varieties are known to produce flavorful meat for home consumption (Ogolla *et al*., 2018). The profit margins in the rabbit farming business are determined by management and market opportunities, just like in all other businesses (Tembachako and Mrema, 2016). When compared to other livestock sub-sectors in Kenya, older farmers are less interested in producing and consuming rabbits than are young people, though this trend is improving (Cherwon *et al*., 2020). Given that they can be fed locally sourced veggies, raising rabbits is a cheap business (Tembachako and Mrema, 2016).

Figure 2.1: Some of domestic rabbits reared in Kenya (Source; Author, 2022)

2.1.2 Global rabbit farming and production

Everywhere in the world, rabbit husbandry is different. The United States was the first nation to introduce balanced pelleted feeds for large-scale production and wire mesh caging systems (Oseni and Lukefahr, 2014). France and Italy began using the large-scale manufacturing method of rabbit rearing in the late 1950s (Mfuko, 2017). There are 23 nations in the globe that are regarded as particularly strong in rabbit production, according to Gidenne *et al*. (2020). The top producers of rabbits are stated as being

Hungary, France, Russia, Ukraine, and Italy. China and Hungary are the two main exporting nations (24 to 40 thousand tons of frozen rabbit products per year). In addition to meat items, rabbit skin has a significant commercial value worldwide, with France being the top producer.

In the 1970s, there was an explosive adoption of New Zealand white rabbits and it offshoot the Californian rabbit, while the traditional European breeds underwent a regression (Kong, 2018). Large scale production units were introduced into Spain, Belgium and the Federal Republic of Germany and with various breed stain being developed from the original breeds (Miranda, 2018).

With units of 200 to 1000 hybrid does being raised in buildings with artificial or controlled ventilation, industrial rabbit production is a significant endeavor in central Europe (Alves *et al*., 2015; Ferreira *et al*., 2015; Gall-Reculé *et al*., 2017). Promotion of backyard rabbitries in rural and peri-urban parts of Mexico produced mostly for domestic consumption and mixed commercial units. The production of rabbits in the Caribbean region is focused on foraging and is often done in small native breeds that are descended from imported animals. In Cuba, better breeds of rabbits are produced in smaller batches of 25 to 100 does alongside more conventional methods using more intense production systems (Rafati *et al*., 2018; Musyoka *et al*., 2019). At the same time, globalization increased the visibility of rabbit production and rabbit meat consumption in geographical areas where people had not previously been aware of them. This, together with the increase in popularity of the rabbit as a pet animal has resulted in a myriad of public campaigns in the specific European Union (EU) member states over the last ten years directed at public administrations on the welfare of rabbits.

2.1.3 Rabbit production in Africa

The biggest producers of rabbits in Africa are Nigeria and Ghana, with smaller amounts coming from the Democratic Republic of the Congo, Cameroon, Cote d'Ivoire, and Benin (Ayagirwe *et al*., 2018). Commercial manufacturing techniques have been introduced in several nations, with the majority being family-owned (Carneiro *et al*., 2014; Mfuko, 2017). The rabbit production in Nigeria is largely traditional, non-commercially oriented, family consumption targeted, and smallholder type operation comprising 2-7 does and 3 bucks (Mfuko, 2017; Ume *et al*., 2016). About 3.4- 5.2% of the Nigeria population may be keeping rabbits with women and children being mostly involved. Rabbit keeping is both intensive and semi-intensive, though some scattered free-range backyard rearing was recorded (Mfuko, 2017). The rabbit production systems in Ghana are traditional with household consumption being the major influencing factor. The major breeds of rabbits kept were the California White, New Zealand White and crossbreds of varied genetic variations with the small-scale backyard and medium-scale commercial rabbit holdings being dominant (Osei *et al*., 2019).

The necessity to revitalize such national rabbit programs for long-term sustainability is evident given the rising levels of poverty in Africa (Mfuko, 2017; Ume *et al*., 2016; Osei *et al*., 2019). Due to their popularity, minimal investment needs, and low economic risk, as well as their benefits to family nutrition, income creation, and female empowerment, smallholder, low-input rabbit production systems are made a particular case for in Africa.

2.1.4 Rabbit production in Kenya

Rabbit keeping in Kenya was introduced by missionaries and was extended by the partnership between the Kenyan and German governments, saw the enterprise activity gain prominence irrespective of it regarded previously as a partime among teenage boys (Kale *et al*., 2016; Cherwon *et al*., 2020). The rabbit population in Kenya is estimated at 600,000 with the higher populations in Central, Western and Rift Valley regions of the country (Osei *et al*., 2019). However, in the last three years, the interest in rabbit keeping has tremendously grown due to reduction in land-size holdings (Cherwon *et al*., 2020; Mutai, 2020).

Due to limitations and insufficient documentation production processes, rabbit farming has not advanced in Kenya (Wambugu, 2015). This was linked to the fact that the business was intended for young boys and had nothing to do with parents or adults (Wambugu, 2015; Mfuko, 2017; Mutai, 2020). In their research on rabbits, Owuor *et al*. (2019) emphasized that domesticated rabbits in Kenya may have originated in Europe and that the prevalence of foreign breeds may have contributed to limited genetic diversity.

In Kenya, raising rabbits has largely continued to be a means of supplying minor amounts of money and subsistence meat. Californian white, Dutch, New Zealand white, Flemish Giant, Chinchilla, and French Lop are the most popular breeds raised; they are developed from genetic stock that is readily available in the area (Boucher *et al*., 2021). There aren't many people using wire mesh cages or pellet feeding, and there aren't many commercial production methods (Mfuko, 2017). Serem (2014) observed that in Kenya, rabbits are raised mostly on green vegetables that are readily available as their only source of diet, with a sizable portion also receiving a combination of forage and

purchased concentrates. The results of investigation suggest that some heavy breeds may influence farmer decisions as a result of breed characteristics.

Considering all enterprises in either farming or any other business, the key consideration to maximise profits is to improve on market and the management. Rabbit farming is not an exception. Mfuko (2017) indicated that market availability as well as management contributes a lot in rabbit farming. Even with the increasing interest and benefits from rabbit rearing, the industry is faced with several challenges such as diseases. Housing, space, regular sanitation and proper feeding determines the fate of rabbit farming (Tembachako & Mrema, 2016; Mfuko, 2017). In east Africa, Kenya is one of the developing countries endowed with ever increasing population situated in the rural land, engaged in subsistence agricultural production as a major means of livelihood. By funding and giving technical know-how on how to conduct such projects, the Kenyan government and non-governmental organizations (NGOs) are encouraging the rural population to get involved in small income-generating enterprises like rabbit farming for the rural farmers. Lack of parental breeding stock, the high expense of commercial diets, and restricted access to professional guidance on how to raise rabbits are all obstacles to rabbit farming (Wambugu, 2015; Cherwon *et al.*, 2020).

2.2 Production characteristics and constraints of domesticated rabbit breeds in North Rift and Western Kenya

2.2.1 Farm characteristics and rabbit production system

Small farms have been under increasing pressure as a result of the growing pressure on the human population, which has led to smaller and smaller farms (Baruwa, 2014). Currently, the human population receives animal protein from both small and large

ruminants. These livestock include poultry, cattle, goats, pigs, and sheep. But with fewer household farms and more expensive commercial livestock feed, ruminant livestock rearing has decreased (Baruwa, 2014; Kale *et al*., 2016; Osei *et al*., 2019). Domestic rabbits (Oryctolagus caniculus) have therefore emerged as a more advantageous solution to these problems because of their traits such as high genetic selection potential, early maturity, prolificacy, rapid development, high feed conversion efficiency, and efficient use of space (Hassan *et al*., 2012; Baruwa, 2014; Kale *et al*., 2016; Ume *et al*., 2016).

The majority of rabbit farmers are men, and raising rabbits has long been seen as a family project, essentially a company that provides the young boys with financial support. According to Chah *et al*. (2017), the low market for rabbit meat discourages farmers from large-scale production, while Hungu (2011) noted that due to its lower demand on space, rabbit farming is one of the modest but important commercial activities carried out in central Kenya. The majority of rabbit farmers are unemployed locals who raise chickens, cattle, and sheep in addition to other types of livestock and various crops (Kale *et al*., 2016; Tembachako & Mrema, 2016; Cherwon *et al*., 2020).

Due to their huge maturity weight, the New Zealand White and Flemish giant lead the list of breeds raised by farmers in Africa. According to Olagunju *et al*. (2018), the most well-known domestic rabbit breed raised in Kenya is the New Zealand White. Others include the crosses of the Californian White, Chinchilla, and Flemish giant. Hungu, (2011) continues by stating that the two popular domestic rabbit breeds ideal for meat production are New Zealand White and Flemish giant, which is the main goal of the African rabbit producers. According to Chah *et al*. (2017), Californian, New Zealand, and Flemish giant rabbits are the most popular domestic rabbits since farmers can easily

obtain their breeding stock from nearby rabbit farmers. The popularity of Californian, New Zealand, and Flemish giants is also boosted by their superior maternal skills and higher litter sizes (Fadare, 2015; Olagunju *et al*., 2018; Daszkiewicz & Gugoek, 2020). Due to their high flesh-to-bone ratio traits, New Zealand White, Californian rabbit, and Flemish giant are the most popular breeds raised for meat production in various regions of the world (Kale *et al*., 2016; Tembachako & Mrema, 2016; Cherwon *et al*., 2020). Numerous advantages have been linked to rabbits, including the provision of meat as the primary focus of consumption and sales, with considerable research demonstrating that rabbit meat is among the most nutrient-dense meat (Mbutu, 2013).

2.2.2 Rabbit housing

One of the most crucial elements in the production of rabbits is housing (Mbutu, 2013). A rabbit house is described as having free access to a room or the entire house and never being confined to a cage. As it enables them to express their natural behavior and live up to their full potential as companion animals, this method of keeping rabbits is becoming more and more popular. Domestic rabbits can be reared outside or inside, with housing that offers protection from predators and shelter from harsh weather. Options include indoor cages, outdoor hutches, and free-range homes (Borter & Mwanza, 2010; Clauss & Hatt, 2017). The majority of rabbit farmers, according to Olagunju *et al*. (2018), keep their rabbits in cages rather than letting them roam freely, which provides protection against predators like birds of prey and mongooses, among other things (Courchamp *et al*., 2000). The cages used for small-scale rabbit farming are primarily one-level tier systems, which need cheap building expenses (Mbutu, 2013; Oseni & Lukefahr, 2014).

Comparatively speaking to raising other animals, farmers spend less money on housing constructions for rabbits. To comfortably house the rabbits until they reach adulthood, simple buildings constructed of wood, wire mesh, and some beddings are good. For this reason, the majority of farmers have discovered that commercial rabbit farming is simpler. Similar to this, a single spacious cage may calmly house up to 30 growing rabbits. The plan enables farmers to rear as many rabbits as possible with the least number of cages. A reasonable minimum cage size is 30"x30"x24" for a rabbit, which weighs about 5-6 pounds when it is an adult. A rabbit home is approximately 1.5 m × 1.5 m, which is consistent with (Hungu, 2011).

According to (Mailafia *et al*.), the measurements can occasionally be larger depending on the quantity of rabbits and the price of constructing supplies (2010). A good housing facility with adequate arrangement of ventilation is the most important factor in a rabbit house. A good house denotes proper cages or hutches and arrangement for feeding, watering and cleaning practices. Housing is important for keeping the broiler rabbits in one roof and to prevent them from running away. There are several ways of housing rabbits and this depends on financial involvement and the climate of the place. The commonly used materials include tin cans, bamboos, old boxes, wood, bricks, asbestos sheets. Karcher steam cleaned floors and walls may be the components of the house. Majority of the structures are raised about a metre from the ground as anti-predation tactics against dogs, cats and mongooses (King, 2019). Building materials include iron sheets for roofs, combination of wood and wire mesh for wall and wood floorings. These materials according to Mailafia *et al*. (2010) are easy to find and mostly of low-cost in the rabbit farming areas of Kenya. In addition, Szendrő *et al*. (2012) on the rabbit hutches construction points out that rabbitries can be modified to suit the taste of the farmer. Similarly, rabbit rearing does not require complex housing because their space

requirements are not as demanding as with other types of livestock enterprises. This makes them the best option for youths.

2.2.3 Source of rabbit breed

When compared to other commercially domesticated animals, raising rabbits has been recognized as one of the most affordable livestock in agricultural techniques. From birth till maturity, a single rabbit can eat up to 2 kg of rabbit pellets. Suitable vegetables and hay can be added to the pellets as a supplement. The majority of rabbit owners choose to feed their animals feed pellets because they are nutritious, made up of compressed alfalfa, grains, and vitamins, and can be fed to rabbits of all ages. Feed pellets are the best kind of food for rabbits. Due to its modest initial investment, rabbit farming can be profitable in the majority of poor nations. They can be grown on forage and leftovers from the kitchen, leading to a grain-free diet with ever rising costs. Fast growth, high fecundity, great feed efficiency, and early maturity are all traits of rabbits. With proper care, rabbits can produce more than 40 kits annually, as opposed to a calf for a cow and up to two youngsters for a goat.

In terms of the financial structure, commercial rabbit farming in Kenya is a business venture to be considered. In the large-scale system, the majority of rabbit farmers have chosen to make their occupation a full-time one. Breeding stock is obtained from other nearby farmers, with consideration given to the breed's size and beauty as well as farmer advise. According to Oseni & Lukefahr (2014), the inability of rabbit farmers to decide which breed to keep is more closely related to low local awareness of rabbit farming and the lack of local agricultural extension officers in the areas for advice to the farmers, which disadvantages farmers from access to a variety of important genetic material. One of the agricultural industries in Kenya with the quickest growth rates is rabbit

farming. As small-scale farmers, many farmers have specialized in their crops. Farmers have alternative options for distributing their finished goods even though the rabbit market isn't yet widely accepted. In subsistence rabbit farming, where one male is suitable to service up to 10 females, Hungu (2011) noticed that one male served roughly five females. According to Dalle Zotte & Paci's (2013) investigation, 95.1% of the farmers in question had an average of 7.2 total born rabbits each birth. Matics *et al*. (2014) reported a litter size at birth ranging from 5 to 8 total born with 5 to 7 live births on a local population using traditional breeding.

2.2.4 Rabbit house cleaning practices and environmental considerations

Any sort of housing for rabbits, including cages, should have ample room for daily activities. Animals kept in confinement for a long time should have lots of room to move around. The domestic rabbit should be able to feel at ease in its enclosure (Matics *et al*., 2014). The house should size 3 by 1.5 by 1.5 units. To get rid of waste, rabbit housing needs to be cleaned every day. To make the housing dry, it is advised to add new straw.

The removal of uneaten fresh food and cleaning of the water and feed troughs are part of the daily routine for cleaning the rabbit house. This is because rabbits are thought of as particularly hygienic creatures. This is not typical in rabbit farming for subsistence because many farmers never clean the rabbit hutches on a daily basis. In contrast to other studies (Karikari & Asare, 2009; Mailafia *et al*., 2010; Szendr *et al*., 2012), Hungu (2011) noted that farmers in the central region of Kenya cleaned the rabbit houses by removing waste, sweeping, and disinfecting, while other studies (Karikari & Asare, 2009; Mailafia *et al*., 2010; Szendr *et al*., 2012) indicate that farmers practice manure removal only followed by addition of more fresh straw. The best substrate for rabbits

is grass hay, but for confined indoor rabbits, you can also use a foam rubber cushion, a towel covered in newspaper, and a thick covering of Timothy hay. Avoid using wood shavings, especially those that contain oils. To rest the mesh and stop it from slipping, a firm, non-slip platform is also essential (Matics *et al*., 2014).

2.2.5 Rabbit feeding

Rabbits are lagomorphs with continuously growing open-rooted teeth. Lagomorphs with continuously expanding open-rooted teeth are rabbits. Throughout their lifetime, the teeth develop at a consistent rate of 10 to 12 cm every year (Matics *et al*., 2014). Two incisors, three premolars, and three molars make up the rabbit's dental structure (2/1 incisors, 0/0 Canines, 3/2 Premolars, and 3/3 Molars). Peg teeth are a second pair of tiny incisors that protect the palate from harm from the lower incisors' sharp edges. The incisors' (chisel-like) enamel ages more quickly. A region caudal to the incisors is known as the diasterma. Food maceration and grinding are done by the cheek teeth (Hungu, 2011).

There are many different sizes and shapes of rabbits. Rabbits have simple, glandular stomachs. Due to the position and growth of the cardiac sphincter, rabbits cannot vomit (Matics *et al*., 2014). The gastrointestinal pH of adult domestic rabbits ranges from 1.5 to 2.2. For cellulitis bacteria to colonize, neonates need a higher stomach pH. The microbial population in the rabbit's caecum is intricate and sensitive. In the rabbit caecum, where fiber is digested, gram-positive Bacillus spp. are among the most prevalent species (Szendr *et al*., 2012). The digestive system of the rabbit excretes feces in two different ways: caecotrophs, which are later reabsorbed, and hard feces, which are never reabsorbed. Cecotrophs have a thin mucus layer that shields them from the stomach's lining's low pH, which can destroy nutrients including vitamins, amino acids,

and volatile fatty acids. Since they are lagomorphs, rabbits produce both cecotrophs and hard stools as feces. Cecotrophs are eaten straight from the anus and differ from hard feces in that they are moist and mushy. The digestive transit time in rabbits is roughly 20 hours. Low-fiber diets are more likely to cause digestive issues in rabbits (Samkol & Lukefahr, 2008).

There should always be a plentiful supply of chlorinated water. Similar to rats, rabbits are particularly sensitive to water scarcity and require constant access to clean drinking water. Water for rabbits should be provided in a sturdy, unbreakable sipper bottle or a hefty crock (Szendr *et al*., 2012). Drinking from crocks puts rabbits at risk for "blue fur," a moist dermatitis of the dewlap associated with pseudomonas infections.

Rabbits in the wild can forage and eat for up to 70% of the day. They have a digestive mechanism that is comparable to horses', which were likewise made to graze continuously throughout the day. Lack of grazing can cause rabbits to become bored, sad, and even violent (Matics *et al*., 2014). Given that it is a member of the Lagomorpha order and is a monogastric herbivore, the rabbit exhibits a distinctive feeding behavior when compared to other household animals. The Logomorph family includes; Leporidae, (rabbits and hares), Ochotonidae (pikas) and Prolagidae (Sardinian, pikas and other extinct pikas). The dietary requirements of pet rabbit have in the past been misunderstood. Rabbits are ‘hind-gut fermenters. They need a high-fibre, abrasive diet which not only provides the right bacterial balance to keep their digestive system working properly but also keeps the teeth in good condition and regulates their weight (Samkol & Lukefahr, 2008). Rabbits enjoy eating dry grass and green vegetation that can be found easily in the environment. They also enjoy vegetables such as cabbages and can eat; maize, banana and cassava peels. Rabbit’s feed varies from a daily diet of

mostly high-quality grass hay, pellets, fresh vegetables, fresh and clean drinking water (Szendrő *et al*., 2012). Grass hay enables rabbit gut to function properly. Hay is important for rabbits for many reasons such as helping to wear down their teeth that are constantly growing, also fiber keeps movements through the digestive tract (Matics *et al*., 2014).

It is common knowledge that rabbits eat more at night. In New Zealand, the weight of the litter from breeding to weaning is roughly 100 pounds for rabbits raised for meat consumption. As a result, the conversion ratio is approximately 3:1. (3 kg of feed to produce 1 kg of weight gain). This crucial aspect of rabbit production might be negatively impacted by an imbalanced diet or excessive feed waste. Wanjala (2015) also hinted that New Zealand rabbit crosses perform better when fed pure concentrate compared to other crossings like Californian white crosses (Samkol & Lukefahr, 2008). The observed growth rate followed a pattern of low, high, and low weight again from weaners to growers to subadults. Low calorie intake can be attributed to weaning shock in weaners as they adapt to feed from milk to solid food (Matics *et al*., 2014).

Pellets concentrate supplementation varies from 20 g to 150 g per adult rabbit in commercial rabbit production systems (average rate of 70 g per rabbit per day). Feeding options for rabbits include commercial pellets, veggies harvested or uprooted from fields, and leftovers from kitchens (Samkol & Lukefahr, 2008). As forage and leftover food from the kitchen can be enough for rabbits kept for subsistence use, this suggests that domestic rabbit feeding is rather inexpensive. It is recommended to store rabbit pellets in a cool, dry location because they can ferment and mold when exposed to moisture. Brands of rabbit pellets can differ in their nutritional content. Due to their

high price, commercial rabbit diets are generally shunned by rabbit farms. (Hungu, 2011).

Daily intake behaviour of the rabbit is constituted of two meals: feeds and caecotrophes. Although rabbit is not a rodent one of its main feeding behaviour features is to gnaw. The information about the feeding behaviour has been mainly obtained on the domestic rabbit, either bred for meat or fur production, or as a laboratory animal. It basically involved rabbits receiving ad libitum a balanced complete pelleted feed, supplemented or not with dry forages or straw, but most generally without a real food free choice.

Additionally, the fact that most rabbits are fed vegetables is due to teenagers operating rabbit farms who are in school and lack the funds to purchase commercial feed. Tembachako & Mrema (2016) emphasized the significance of the rabbit farming industry due to its low initial capital requirements compared to other businesses that demand significant capital input. Samkol & Lukefahr (2008) admit that rabbit farmers with an average of fewer than seven rabbits (mostly kept for subsistence) do not purchase commercial rabbit pellets and as a result, their rabbit stock is fed only with forages that are readily available in the area. Farmers raise rabbits for meat for commercial purposes with a stock of more than 28 rabbits and supplement their diets with concentrates (Tembachako & Mrema) (2016).

2.2.6 Production problems and diseases

Some of the problems which currently limit the profitability of rabbit production are high disease losses, and the high labor intensity of rabbit raising (Matics *et al*., 2014). If these problems can be overcome, rabbit production may become more important in

the future. Because of their ability to efficiently utilize high forage diets, rabbits have the potential to become a major meat producing livestock species (Kumar *et al*., 2012).

There are some common diseases and problems seen in rabbits that can be prevented by ensuring an understanding of what a healthy rabbit requires and the subtle signs that can tell a rabbit is unwell. Rabbits are wonderful domesticated pets, but it should be remembered that they are very closely related to wild rabbits, and as such hide signs of illness until they are very unwell, as this would make them "easy prey" in nature (Tembachako & Mrema (2016).

A rabbit's teeth continually grow throughout its life and if a rabbit is not constantly grinding their teeth down by eating fibre, we start to see their molar teeth forming sharp spikes that damage their cheeks and tongue. This causes pain that makes them reluctant or unable to eat. The incisors at the front of the mouth can, in severe cases grow around in a curl meaning rabbits cannot close their mouth or eat at all. Once a rabbit stop eating their gut stops working and they can die (Kumar *et al*., 2012).

Close monitoring, adequate ventilation in their housing, cleanliness, and shelter from bad weather are the most crucial elements in maintaining a healthy rabbit herd. A region may see disease outbreaks, which could have a disastrous effect on any plans for rabbit farming (Tembachako & Mrema) (2016). Rabbits are susceptible to a number of illnesses, including bacterial, viral, and fungal ones (Kumar *et al*., 2012). Ineffective levels of production can be caused by diseases. Common domestic rabbit diseases include *Pasturella multocida*, encephalitozoonosis, viral hemorrhagic sickness, and myxomatosis, which is caused by the myxoma virus and is prevalent in the wild rabbit population (Ogolla *et al*., 2017). Farmers' ability to produce rabbits is limited by a variety of factors, including skin illnesses, diarrhea, and predators like dogs and

raccoons (Tembachako & Mrema, 2016). Because domestic rabbits are vulnerable to predators like dogs, farmers create high cages that are roughly one meter off the ground. Lack of adequate and high-quality genetic stocks of rabbits, as was also noticed by Oseni & Lukefahr (2014) in Nigeria, is another issue faced by rabbit producers. The enterprise is hampered by the rapid deaths and mortality of the rabbits, as well as the expensive expenses of commercial food (pellets) and construction supplies like nails and iron sheets, as described in (Hungu, 2011). Additionally, the majority of rabbit farmers do not have a market because there is a lack of knowledge about the value of eating rabbit meat, which can affect consumer preferences.

2.3 Distribution and morphometric characteristics of domesticated rabbit breeds

2.3.1 Rabbit breeds distribution

There are more than 350 varieties of domesticated rabbits that are spread all around the world (Claudy, 2021). The domestic rabbit, also known as a bunny, pet rabbit, or bunny rabbit, is a subspecies of the European rabbit that is a member of the lagomorph family (Jenckel *et al*., 2021). Breeds are created through distinct selective breeding and, on rare occasions, through natural selection for remarkably distinctive traits. The spectrum of the rabbit's unique qualities is reflected in the variety of rabbit breeds found worldwide. According to Olagunju *et al*. (2018), the most popular rabbit breeds in Kenya include the Kenya White, Angora, Californian White, French Ear Lop, Chinchilla, and Flemish Giant, as well as their hybrids. Domesticated rabbit breeds are divided into three major divisions based on size and weight, according to Wanjala (2015). These breeds fall into one of three categories: heavy breeds, which weigh more than 5 kg, medium breeds, which weigh between 3 and 5 kg, or light breeds, which weigh between 2 and 3 kg. New Zealand White domesticated rabbit breed is mainly

reared or kept for commercial meat production with weights of upto 5 kg in adult buck, and 5.5 kg in doe. They are well-known for having meaty haunches and deep shoulders Olagunju *et al*., 2018). Some of the desired characteristics that the New Zealand White rabbit breed boasts are high carcass quality, good mothering ability, rapid growth rate, and good prolificacy. According to Serem (2014), the New Zealand White rabbit is the commonest breed kept for commercial meat production all over the world, more so in China, United States and Africa. Wanjala (2015) and Hawthorne (2021) indicated that New Zealand white is recognized for its high profit margins in both subsistence as well as in commercial rabbit meat production.

Industries that engage in the production of commercial rabbit meat value the high returns provided by the Flemish giant breed (Hawthorne, 2021). Wanjala (2015) also pointed out that this rabbit's pure breed does not produce the greatest meat for commercial purposes. The farmed Checkered Giant rabbit, which weighs over 5 kg, has a pied-shaped spine that is black and white in color. The body also has spots, and the ears are colored, and the nostrils have noticeable butterfly marks. Chinchilla bucks can produce 4- 5 kg of meat in 5 months, or an average of 7 kg. In addition to being raised for pets, this breed is also raised for the manufacture of fur (Fontanesi *et al*., 2014). It is well known that Californian white has black patterns on its white body (Ludwiczak *et al*., 2016). They are the second-largest farmed rabbit breed after New Zealand White and feature black tails, paws, noses, and ears. They are highly recognized for producing meat, and their backs are strongly-muscled. Adults typically weigh between 3.6 and 4.8 kilograms (Wanjala, 2015). French Lop, on the other hand, is a hybrid between English Lop rabbits measuring 4.5kg and more and Flemish Giants rabbits. It has a dense, velvety coat that is available in solid and speckled color variations. Agouti, sooty-fawn, and broken marked are further complementary hues (Ludwiczak *et al*., 2016).

2.3.2 Morphometric characteristics of rabbit breeds

Rabbits are sexually mature at the age of 4 to 4.5 months for medium breeds, giant breeds at an average age of at 6 to 9 months, while small breeds do so at an average age of 3.5 to 4 months. Rabbits are known to be receptive between 14-16 days where sex triggers the release of eggs (Rödel, 2022). Gestation for a doe takes about 31 days.

Living things' phenotypic characteristics can be described by their DNA's sequence and interactions with their environment (Krashniak & Lamm, 2017). The variation in phenotype is caused by variations in homologous DNA sequences, which are brought about through the process of speciation and the emergence of ecotypes and subspecies in the wild. In the case of domesticated animals, this results in the development of animal breeds (Utzeri, 2017). Domestic animal phenotypic diversity offers a singular opportunity to research genotype-phenotype interactions (Carneiro *et al*., 2014). Phenotype is therefore the outcome of the impact of genotype and environment on a character. The genotype is the outcome of the effects of genes at several loci. The environment is made up of a number of components: climate, habitat, the animals' microclimate, temperature, humidity, air speed, the rabbitry equipment, breeding techniques and feeding practices, and the human factor-the breeder.

Linear body dimensions in farmed rabbit breeds could be a way to describe their traits and be useful when choosing the best breed for either commercial or subsistence meat and fur production (Elamin *et al*., 2012). According to Carneiro *et al*., several linear body features have historically been measured and documented in numerous nations (2014). Body form has been thoroughly estimated qualitatively and quantitatively as important features in animals raised for meat production. Quantitative estimates have been made using measures of length and weight, whereas qualitative estimates have

been made using visual cues (color). According to Carneiro *et al*. (2014), linear body measurements have been used to describe breeds, assess breed performance, and estimate animal live weight. The majority of domesticated rabbit breeds have variable body weights depending on their habitat. The amount of food available to the breed depends on the production capacities of the various locales. The Normalized Difference Vegetation Measure (NDVI), a vegetation characteristic index, is a key element in explaining and forecasting species richness across the various study landscapes, according to Mayamba *et al*. (2020). Areas that receive high to moderate rainfall have a high NDVI. Crop type in a location is related to an organism's access to food, according to Chidodo *et al*. (2020). Heart girth, forelimb length, belly circumference, and tail length all vary in size according on the sex, claim Harcourt Brown & Harcourt Brown (2012).

Only a few rabbit breeds are raised in Kenya, including the New French lop, Angora, Rex, New Zealand White, Checkered Giant, Chinchilla, Californian white, Dutch, and Giant Flemish, according to the American Rabbit Breeders Association (ARBA, 2020). (Nasr *et al*., 2017a). The New Zealand White rabbit breed, which is distinguished by its white coat color, pink eyes, and great mothering abilities, can reach slaughter weight at an age of 12 to 13 weeks and weigh an average of 3 kg. When used for business, this breed weighs an average of 5 kg (El-Badawi *et al*., 2014; Badr *et al*., 2019). The meaty hip of the California white breed of rabbit is what gives it its reputation for meat. The US is where this commercial breed originated. Except for its nose, ears, tail, and feet, which are either dark grey or black, it is white and stockier. It is the optimum sire breed for mating with other breeds of rabbits to produce meat (Fadare, 2015).

One of the biggest rabbit breeds is the Flemish Giant, which may reach 7kg in weight. Most farmers don't want it because of its slow growth and high bone to meat ratio. It is mated with different breeds to assist it develop better traits (Daszkiewicz & Gugoek, 2020).

The French lop stands out for having short, stocky legs, huge ears that hang around the head, and a weight of above 5 kg. They are raised mostly as pets rather than for meat production (Ludwiczak *et al*., 2016). Chinchillas are short and stocky with a lovely rounded back and were originally bred for meat (Apori *et al*., 2014). The Standard, American, and Giant Chinchilla are the three chinchilla breeds (Bhatt *et al*., 2017). Domestic rabbits have fluffy, black, gray, or white fur; wild rabbits have a blend of coarser hair that is more grayish brown or tan in color. White will not be present at all on adult wild rabbits (Márquez, 2015). They have long, muscular hind legs and a compact body. Typically, a rabbit's fur is long and velvety, grey or brown in color, with white underparts and a short tail. Rabbits' protruding ears are perhaps an adaptation for percieving predators.

2.4 Growth characteristics of domesticated rabbit breeds

2.4.1 Litter size at birth of domesticated rabbit breeds crosses

Both domestic and wild rabbits have a wide range of litter sizes. Domestic rabbits often have litters of 6–10 babies. For cross-bred rabbits to produce meat effectively, the litter size is crucial. In order to develop crossbred females that are competitive enough to produce rabbit meat, the rabbit cross might be used. New Zealand white pure breeds attempt to increase the maximum productivity in rabbit production in terms of litter size and litter weight (Fayeye & Ayorinde, 2016).

New Zealand white crosses have the largest birth weights, although they also rely on the feeding schedule. According to Fayeye & Ayorinde (2016) and Mayamba *et al*. (2020), vegetation characteristic index is a significant element in explaining and forecasting animal species richness across the various study landscapes in regions with high to moderate rainfall.

The impact of litter size on the pre-weaning weight gain in rabbit kits up to the point of weaning is acknowledged by Fayeye & Ayorinde (2016). This is explained by the fact that rabbits raised in tiny litters consume more milk and put on more weight as a result of the doe mother (Nasr *et al*., 2017a). It is well established that in rabbits, litter size at delivery and newborn weight are negatively associated (Nasr *et al*., 2017a). This is because, in comparison to kits produced in greater litter sizes, those born in smaller litters have a somewhat higher share of milk per kit. According to Prunier *et al*. (2020) and Blavi *et al*. (2021), bigger litter sizes result in a lower proportion of milk per kit, which affects the body weight gain of competing animals. According to Blavi *et al*. (2021), the proportional share of milk consumed by each kitten falls as litter size rises at pre-weaning body weights.

According to Nasr *et al*. (2017a), litter size significantly affects the weight gain of suckling rabbit kittens up to the point of weaning and reduced litter size can help to achieve higher weaning weight and growth rate which also help to increase their individual birth weight. Maintaining high level of nutrition through the growth period of rabbits, result in growth and productive performances of the doe. Although it has been suggested that the adaptive activation of pre-partum mammogenes helps mammals' mothers regulate their milk production to changes in litter size (Ologbose *et al*., 2018). In their study on the pre- and post-weaning growth performance of rabbits

in a humid tropical setting, Ajayi *et al*. (2018) also found that individual birth weight decreased with growing litter size. Additionally, Ologbose *et al*. (2018) noted that despite the doe's milk production being positively correlated to litter size, rabbit kittens of larger litter sizes always have a lower weight at weaning than kittens of smaller litter sizes. This is because their body weight gain depends on the amount of milk consumed. Ajayi *et al*. (2018) and Ologbose *et al*. (2018), highlighted the importance of litter size in different species where an increase in the number of siblings/ kittens reduces the share of milk obtained by individuals thus influencing the weight gain. This result in a negative correlation between litter size and growth rates of dependent kits (Ajayi *et al*., 2018; Ologbose *et al*., 2018). Nasr *et al*. (2017a), indicated that there is a clear negative relationship between sibling number (per litter) and kitttes growth rates or average weaning weight in domestic breeds as well as in European rabbits living under natural breeding conditions.

2.4.2 Body weight of the domesticated weaners rabbit crosses

Rabbit production is now a minor agricultural enterprise throughout the world. It is most highly developed in Western European countries such as France, Italy and Spain. Rabbits are also raised in large numbers in China, which is the main exporter of rabbit meat. Increasing quantities of Chinese rabbit meat are being imported into the United States. Rabbits have a number of attributes which may result in their importance increasing in the future. They have the potential to become a major livestock species. Litter size contributes to body weight of weaners rabbit. Ologbose *et al*. (2018), notes that litter size at birth significantly influence the post birth body weight of rabbit kittens. Ajayi *et al*. (2018) and Ologbose *et al*. (2018) noted that genotype significantly affect body weight in rabbit crosses.

2.4.3 Growers body weight of domesticated rabbit crosses

Performance is a crucial factor in determining productivity and financial success in the production of animals. Maj *et al*. (2009) found that crossbred rabbits outgrew purebred rabbits in terms of development rate when they studied California White and New Zealand White rabbits. It was reported by Ajayi *et al*. (2018) and Ologbose *et al*. (2018) that genotype had an impact on rabbit body weight. For post-weaning growth traits in breed, Ologbose *et al*. (2018) found no breed differences that were statistically significant.

2.4.4 Sub adults body weight of rabbit crosses

Maj *et al*. (2009) highlighted factors affecting some rabbit traits which are of economic importance especially in a tropical environment. Litter size at birth in domestic rabbit was a determining factor correlating positively with individual rabbit birth weight. The differences in weight gain of rabbit within the same breed (Ologbose *et al*., 2018) or among different breeds (Ajayi *et al*., 2018; Ologbose *et al*., 2018). Ajayi *et al*. (2018) added that pre-weaning variables are major contributory factors affecting post weaning performance of rabbits.

2.4.5 Feed conversion efficiency of domesticated rabbit breeds

In animal husbandry, Feed Conversion Ratio (FCR) is expressed as the rate at which an animal body converts the food ingested to meat, milk or any desired output by the farmer or breeder. For animals like dairy cows, the animal is reared for milk production and the feed conversion is calculated as the amount of food offered and milk produced per ration. In the case of animals such a pig, fish, beef cows among others, the output is the flesh or meat which is calculated as the body mass per food ingested. In simple

terms, FCR is the mass of the input in which case is the food offered divided by the output which can be mass of flesh of meat, eggs or milk of the animal. Feed accounts for the largest part of the production costs in animal production. Feed efficiency, mostly expressed as FCR, is a key indicator to judge the performance and profitability of a farming system.

Breeding management as well as health status of animal, impacts greatly on the feed efficiency. According to Trocino *et al*. (2015), sex sometimes affect FCR in rabbits with female having lower FCR due to a relatively higher adipose tissue deposition than in male. In animal husbandry, the rule of thumb is that, the younger the animal, the higher the food conversion ration while the older the animal, the lower the FCR. Gidenne *et al*. (2020) adds that the FCR increases quickly with age especially when reaching maturity due to allometry tissue deposition. In terms of feed conversion efficiencies, age is a factor with weaners having the highest efficiency followed by growers and then sub adult. Slow or reduced growth rate is observed with relative stable feed intake. Gidenne *et al*. (2020) highlighted that the FCR of growing rabbits increases gradually with age noting that generally young and fast-growing animals such as in rabbits have a far more promising FCR in their early fattening stage than when near slaughter weight. Tissue deposition allometry becomes strong with age for adipose tissue adding high energy cost of synthesis.

In India, rabbits raised for meat had an FCR of 2.5 to 3.0 on high grain diet and 3.5 to 4.0 on natural forage diet, without animal-feed grain. Wanjala (2015) alluded that New Zealand rabbit crosses performs better when compared with other crosses such as those of California when fed with pure concentrate. This improvement can be attributed to progress in health control, nutritional factors and strategies, management and genetics.

To optimize rabbit farm FCR, the reproducing stock as well as the fattening unit must be considered. Low weight gain can be attributed to weaning shock in weaners as they adapt to feed from milk to solid food. Low growth rate with low food conversion efficiencies was observed and the findings were similar to those reported by Wanjala (2015).

Ajayi *et al*., (2018) and Ologbose *et al*. (2018), indicated the importance of feed intake and growth rate where they suggested that it is directly correlated in the weaners and sub adults but subsequently decreasing, with notable intake stabilizing at around the 12th weeks of age. The differences in feed conversion within the same breed or among different breeds can be attributed to variations in feeding regimes, environmental conditions as well as diseases. Wanjala (2015) noted the importance of environmental factors such as disease, nutrition, hormone and general management in determining the feed conversion efficiencies in rabbits. The findings also concur with those of (Ajayi *et al*., 2018; Ologbose *et al*., 2018), that pre-weaning variables are major contributory factors affecting post weaning performance of rabbits.

Similarly, to other mammals, the domestic as well as wild rabbits, regulates their feed intake according to their basal metabolic needs. For a closed unit in the case of fattening or breeding, the food conversion ratio can vary from one kg of meat for five kg of food offered. When the FCR is calculated in fatteners then the FCR is defined as the ratio of kg of feed consumed per kg weight gain of rabbits (finishing weight minus weaning weight). In addition to FCR, efficacy of the feed utilization is sometimes presented as feed efficiency. Feed efficiency is negatively correlated with dietary digestible energy (DE) content. A rabbit regulates its feed intake according to energy requirements, as for other mammals. Based on the relationship between dietary DE content and intake,

an improved FCR can be obtained with diets of high energy concentration. However, due to the dietary fibre requirements of rabbits and the low digestibility of different fibre classes, rabbit diets have a low energy content (DE or metabolizable energy) compared to poultry and pig diets.

High performing reproduction stock results in a lower FCR in maturity. The use of diets with nutrient levels to optimize digestive health, together with an appropriate feeding restriction after weaning, leads to minimal losses and has a large impact on the FCR. If the different fiber requirements are met, an increase of the dietary energy level, especially in the finishing stage, reduces the FCR. Gidenne *et al*. (2020) adds that the FCR increases quickly with age especially when reaching maturity due to allometry tissue deposition. Tissue deposition allometry becomes strong with age for adipose tissue adding high energy cost of synthesis. Additionally, breeding management as well as health status impact greatly on the feed efficiencies.

2.5 Genetic diversity of domesticated rabbits

The European bunny (*Oryctolagus cuniculus*) is the only ancestor (El Bayomi *et al*., 2016) of domestic rabbits recognising the presence of both the wild as well as the domestic forms occurring all over the globe. Geographic origin of the European rabbit can be drawn and traced to the regions of Iberian Peninsula; areas known to have history of coexistence of the two subspecies. There are two species of domestic rabbits with the first (*Oryctolagus cuniculus*) distributed widely in the Iberian Peninsula (north eastern portin) while the second (*Oryctolagus algirus*) is known to have been distributed in the same area but on the southern part. Movement of the European rabbit to south of France is thought to have happened 18,000 years ago after the last glacial traversing the wide Pyrenees and extended.

Over a thousand years, humans being have played a key role in changing characteristics of several living organisms more so on the phenotypic as well as the genetic composition with the end process transforming the wild species (El Bayomi *et al*., 2016) into already known domesticated species. From this well elaborated close association, domestic animals such as rabbits and others consequently came up to be vital representations in research fields. in addition, these domesticated animal species came to be of fundamental social cultural and of economic value (El-Aksher *et al*. (2017).

Genetic data supports a domestication origin in France and shows that domestic rabbits display a subset of the genetic variability found in the *O. c. cuniculus* French wild populations. The founding of most domestic rabbit breeds has not taken long. This process began in the late 18th century in the regions of Western Europe. Reporting of rabbit breed with different coat colour emerged in the early 16th century indicating the possibility of diversification process having started earlier than presumed. Rabbit breeds with wide purpose such as provision of fur, meat, pet animals, companion animals and therapeutic purposes has narrowed down to approximately 200 known rabbit breeds. The said traits come from breed exhibiting both phenotypic as well as genotypic diversification accumulated over surprisingly short period of time since the preliminary domestication.

The genetic determination of character variations is of dual interest to the selector and breeder: first: to exploit the genetic variability of animals of the same breed or population; and second, by crossing, to exploit the genetic variability between breeds and populations. El-Aksher *et al*., (2017), in their studies of Egyptian rabbit populations; they recorded the highest number of observed alleles at 10 and 13 and the lowest number at 3 and 5, with averages of 6.75 and 6.13 alleles, respectively.

Greater loss of genetic diversity has been attributed to rabbit domestication (Carneiro *et al*., 2014). There are phenotypic variations between the domesticated and wild rabbits with the typical phenotype of a wild rabbit from the subspecies *O. c. cuniculus* (Carneiro *et al*., 2014). Among the rabbit breeds, the strong human-driven selection has to lead to remarkable phenotypic changes in morphology, physiology and behaviour (Ballan *et al*., 2022). El Bayomi *et al*. (2016) reported that the observed number of alleles and effective number of alleles ranged between and among the breeds of Kenyan rabbit populations.

The structural changes have contributed to phenotypic variation by primarily altering transcriptional regulation, how alleles may differ by multiple substitutions affecting gene function and that mutations with moderate to large effects on multifactorial traits have often been enriched during the course of evolution of domestic animals (Andersson, 2016).

In regions, where recombination is restricted, then there would be higher differentiation between species and this is one of the distinct models where regional speciation enable divergence in the presence of a gene pool (Carneiro *et al*., 2014). But the selective sweeps occur when beneficial genetic variants increase in frequency due to positive selection together with linked neutral sequence variants. This results in genomic islands of reduced heterozygosity and increased differentiation between populations (Carneiro *et al*., 2014).

Wide analyses of genome differentiation results to new genetic understandings into the early stages of speciation (Carneiro *et al*., 2014) but the patterns of nucleotide variation in genomes are shaped by both intrinsic and extrinsic factors (Bourgeois *et al*., 2017). Even within a single isolated panmictic population, the interaction between

recombination, selection and historical variation in population size will lead to heterogeneous diversity along the genome. Carneiro *et al*. (2014), managed to identify the numerous regions of strong differentiation, suggesting that the genetic basis of reproductive isolation may be highly polygenic. Also, the architecture of differentiation indicated regions of small size and contained very few genes.

Although the field of functional genomics will no doubt identify additional genes underlying the phenotypic characteristics that differentiate wild and domestic animals, any research that is rooted on single trait gene model may ignore the possibility of a deeper molecular basis for domestication (Mohammad *et al*., 2016). Carneiro *et al*. (2014), noted that by deciphering the genotype of animal species allows for it to be domesticated and motivates the studies on the links between genotype and phenotype of the domesticated rabbits in Western Kenya Region.

Previous analyses have shown that genotype of a rabbit can be used to genetically separate rabbit breeds (Boucher *et al*., 2021). The observed differences between the molecular sequences of wild and domestic samples, therefore, are not a result of the process of domestication per se, but rather reflect (1) the variation already present in wild lineages before domestication began and (2) the secondary effects of isolation resulting from the isolation of wild and domestic populations (Petrescu-Mag *et al*., 2019; Boucher *et al*., 2021) .

According to Alves *et al*. (2015), there is a clear and detectable differentiation in genetic structure in domesticated rabbits level of differentiation in many domestic mammals being lower than in that of rabbits. Genetic studies have focuses both subspecies and has based on a few dozen nuclear markers revealing a loci of relatively high divergence (0.3–1.2%) between subspecies embedded in a genome otherwise characterized by low

levels of differentiation and high levels of bidirectional gene flow that likely facilitated by high effective population sizes, high dispersal, and relatively short generation time (Carneiro *et al*., 2014; Seixas *et al*., 2014b).

There are two noticeable genetic diversity major reductions in the recent past of the rabbit breeds (Alves *et al*., 2015). The first to be noted resulted from the wild population while the second was allied with breed establishment. They estimated that the primary domestication accounted for 21% losses in the initially present diversity of genetic levels in the wild. Other studies done by Boucher *et al*. (2021), indicated an 18% loss while Carneiro *et al*. (2014) and Seixas *et al*. (2014b), estimated a 40% loss. The discrepancy in the estimated loss of the pre-existing levels of genetic diversity of the wild population is traceable to; the higher mutation rate of microsatellites, the large number of breeds used in the study and the different properties of the summary statistics used (Alves *et al*., 2015).

Genome-wide data from populations with a history of extensive gene flow may provide insights into the genetic basis of reproductive isolation in nature (Carneiro *et al*., 2014. Alves *et al*. (2015), observed that on average the initial domestication of rabbits' breeds and the subsequent process of breed formation have culminated lead to a loss of 20% of genetic diversity that is present in the ancestral wild population and domestic rabbits as a whole. Several forces such as mutation, migration, genetic drift and selection are used to study genetic differentiation among local populations existing and adapting to the natural environment involves several forces (de Meij *et al*., 2014).

The wild rabbit populations in the native Iberian Peninsula reveal a high genetic diversity and the presence of two evolutionary divergent units, identified at both nuclear and cytoplasmic level that corresponds to the subspecies *Oryctolagus cuniculus*

cuniculus and *O. c. algirus* (Carneiro *et al*., 2014). Concerning the European rabbit (*Oryctolagus cuniculus), the CSN3* has previously been shown to possess two alleles (A and B), which differ deeply in their intronic regions (indels -insertions or deletions of bases of 100 and 1550 nucleotides in introns 1 and 4, respectively) (Mfuko, 2017). Carneiro *et al*., (2014), established heterozygote positions similar with a pseudoautosomal X chromosome location on the rabbit while Alda & Doadrio (2014), observed that the estimate of nucleotide diversity in the rabbit Y chromosome is the largest reported so far in any mammalian species. This is as a result of the occurrence of two highly divergent Y chromosome lineages that reflects the same molecular signature of strong population subdivisions of *Oryctolagus cuniculus cuniculus* and *O. c. algirus* (García *et al*., 2020).

Alves *et al*. (2015) established that rabbit breeds can be separated based on their genotype alone since they are genetically distinct. Thus, there is a clear connection between genetic polymorphism at these genes and the important production traits in a variety of domesticated species. In particular, the K-casein (*CSN3*) which is important in the stabilization of milk micelles and evidence showing that its relative concentration *versus* other casein proteins varies among allelic variants within each species (Carneiro *et al*., 2014). Empirical results by Boucher *et al*. (2021), demonstrated that there are significant differences between breeds as the differentiation level is higher in rabbits than in other mammals.

Thumiki (2018), observed the reduction in the overall genetic diversity of the breeds that are derived from a wild population and breed formation with the private alleles having low number in comparison to other breeds indicating that differentiation attributed to changes in frequencies in allele. Findings on a study on European rabbit

breeds indicated that the X chromosome plays a big role in propagative isolation in subspecies of rabbit (Carneiro *et al*., 2014).

The initial human intervention resulted in the slight decrease in allelic diversity (the mean number of alleles per locus per population ranging from 3.2 to 4 instead of 3.3 to 6.5) and the strong differentiation between domestic populations (Mfuko, 2017). Evidence suggests that intra-breed stratification is linked with demographic and discriminating causes such as the formation of strains, colour morphs within the same breed, or country/breeder of origin (Alves *et al*., 2015). It is difficult to identify the deletions that are unique to domestic rabbits based on the study of domesticated rabbit, however, some convincing duplications can be detected with striking frequency differences between wild and domesticated rabbit breeds (Thumiki, 2018). A survey by Carneiro *et al*. (2014), revealed the occurrence of new haplotypes in wild populations suggesting that intragenic recombination is important in creating genetic diversity at this locus.

The levels of recombination are exhibited in the chromosomal rearrangements in the centromeric regions which have also been associated with lower rates of gene flow in the European rabbit (Alves *et al*., 2015). As shown by empirical evidence the levels of diversity were the same for the autosomal and X-linked loci Carneiro *et al*. (2014), thus there is no proof of the contribution of the sex of the individual domesticated animals to the gene pool. But based on limited genomic sampling, (Alves *et al*., 2015), it is indicated that the differentiation among rabbit breeds appears most pronounced in centromeric regions and on the sex chromosomes.

From their experiment, Carneiro *et al*., (2014), found that the levels of nucleotide diversity were 0.2%, while the domesticated rabbits have 60%. Furthermore, there is a

higher level of population differentiation among the most strains and breeds but the majority of polymorphisms were shared and are transferable among breeds (Seixas *et al*., 2014b). A study by Neimanis *et al*. (2018), showed that the indigenous rabbit breeds in Tunisia exhibit high genetic diversity with heterozygosity (Ben *et al*., 2014). A study on Tunisian rabbit shows that the variation between and among the breeds with respect to regions decreased owing to change in geographical proximity between them (Badr *et al*., 2019). Carneiro *et al*. (2014), observed that by uncovering the genotype of animal species, the humans were able to domesticate it and by extension motivate the studies on the understanding the genetic diversity.

2.5.1 Population and structure of domesticated rabbits

Genetic diversity has been thought to have been influenced by animal domestication with proof on domesticated rabbits (Badr *et al*., 2019; Ben *et al*., 2014). Study of genetic diversity in animals is very important in animal breeding programmes. These help farmer's stakeholders in animal breeding such a farmer to make informed decisions and choose animals with the desirable characteristics thus increase in productivity.

The population structure of a rabbit species is based on the successful DNA analyses which shed more light on genealogy but the recent advances in phylogenetic methodologies offer more insights (Andrews *et al*., 2018). The European rabbit (*Oryctolagus cuniculus*) bids an exceptional phylogeographic framework owing to a well-documented history that allows the efficiency test using diverse genetic markers to evaluate evolutionary history (Alda & Doadrio, 2014; Rafati *et al*., 2018). For example, numerous studies have effectively applied microsatellite markers in a profounded phylogeographical context as well as across species boundaries (Fontanesi *et al*., 2021). This is based on the relative temporal scale inferred from the hierarchy of

haplotype position in a phylogenetic tree, where the most interior haplotypes are the oldest and those with outer positions are younger (Alda & Doadrio, 2014; Ferreira *et al*., 2015).

The phylogeographical pattern suggests that two groups of populations were isolated for a certain time and later expanded and overlapped (Mutisya, 2014; Seixas *et al*., 2014b). These breeds vary extensively in weight, body conformation, fur type, coat colour, and ear length, and this visible morphological variation dramatically exceeds the phenotypic diversity of their wild counterparts (Carneiro *et al*., 2014). An inventory of existing genetic resources allows for a better understanding of the abilities of breeds that could include great variability in body size, diversification of carcass weight (Mfuko, 2017). The patterns of production could be diversified, and, with more adapted breeds, leading to a more extensive way of rearing rabbits for a part of the production.

According to Maroja *et al*. (2015) the effect of initial human interaction is summarized by the slight decrease in the allelic diversity and the strong differentiation between the domestic populations. The modification of genomes under artificial selection has aided in improving the understanding the cultural and historical conditions, in line with biological requirements, fundamental for the change of domesticated relative from a wild species (Carneiro *et al*., 2014; Seixas *et al*., 2014b). Other studies (Maroja *et al*., 2015) have shown the existence of well-defined breed structure dictated by a phylogenetic tree that clusters individuals same individuals together (Alves *et al*., 2015). Studies by Alves *et al*., (2015) indicated that the phylogeny of domestic rabbit breeds presented a wide-ranging absence of subdivision in bottomless branches.

Empirical studies on rabbit breeds show that domesticated breeds have a high genetic homogeneity which is a representation of a small subset of the genetic diversity of the

species at different levels of analysis from the mitochondrial DNA sequence variation, microsatellites, protein electrophoretic polymorphisms, and immunogenetic markers (Carneiro *et al*., 2014). Thus, breeds conventional from the aforementioned local populations are currently dissimilar by a standard based on exterior appearance while a strain resembles to a impartially homogeneous assemblage of individuals exposed to artificial assortment for a concert trait and usually descend from a mixture of a few breeds such as New-Zealand White, Californian among others (Boucher *et al*., 2021).

Thus, the domesticated rabbit is characterized by the exceptionally high phenotypic diversity with more than 200 breeds worldwide (Carvalho *et al*., 2022). In Europe, more than 60 breeds are described by the national associations of rabbit breeders (Alda & Doadrio, 2014; Seixas *et al*., 2014b; Fontanesi *et al*., 2021). Natural populations and laboratory crosses used in studying rabbit breeds have revealed that in male heterogametic systems, there is a disproportionally accumulation of X chromosome of the loci that contribute to reproductive isolation (Carneiro *et al*., 2014). In addition, there is non-established occurrence of two highly deviating maternal lineages resulting in mitochondrial DNA polymorphism analysis of the native range of the European rabbit (*Oryctolagus cuniculus*) (Alda & Doadrio, 2014; Gall-Reculé *et al*., 2017).

A genealogical study on the rabbit breeds by García *et al*. (2020), showed the existence of two centromeric loci with low levels of variability, high levels of linkage disequilibrium, and little introgression between subspecies while the two telomeric loci show high levels of variability, low levels of linkage disequilibrium, and considerable introgression between subspecies. These genealogical patterns varied considerably among loci with reciprocally monophyletic genealogies being observed at some loci,

whereas the great majority displayed variable levels of shared variation (Carneiro *et al*., 2014).

Other genotypic studies at genomic level have focused on describing its genetic diversity and geological distribution with conflicting results ranging from a strong phylogeographical pattern based on two highly divergent but overlapping *mt*DNA of the *Oryctolagus cuniculus cuniculus* and *O. c. algirus* (Valvo *et al*., 2017) to the lack of complete population structures as derived by the study of autosomal microsatellites. According to (Carneiro *et al*., 2014), the extensive gene flow between subspecies resulted in, some portions, high levels of introgression of the genome. These introgressed regions were therefore already present in wild rabbit populations before the onset of wild rabbit domestication. (Carneiro *et al*., 2014), observed that the analysis of introgression of genomic regions between divergent populations provides an excellent opportunity to determine the genetic basis of reproductive isolation. The long tails of introgression are often detected indicating that the populations are not genetically pure. Thus, introgression seems not only to affect a large portion of the genome but frequently occurs through the entire range of parental populations (Carneiro *et al*., 2014).

This differentiation in the rabbit breeds is led by the allele frequencies changes followed by a gap in artificial selection together with up-to-date breeding practices that tend to close the genetic pools into strongly differentiated genetic compartments (Alves *et al*., 2015). Deletions unique to domestic rabbits are also difficult to identify because of the genome assembly is based on a domestic rabbit, but some convincing duplications were detected with striking frequency differences between wild and domestic rabbits (Carneiro *et al*., 2014).

Speciation of a species through isolation also leads to the changes in the population structure. This is identifiable through the reduced levels of introgression (Carneiro *et al*., 2014). This naturally hybridizing approach provides suitable generations leading to documentation of hybrid unsuitability that have been naturally tested. de Meij *et al*. (2014), considered the lack of specific selection strategies, founder effects, genetic drift and geographical isolation of the study area may have contributed to the moderate level of differentiation among the Tunisian rabbit populations investigated.

A study by Badr *et al*. (2016) found that Egyptian rabbit breeds share common phylogeny with the European rabbit breed, the *O. c. algirus*. The genetic distance can then be compared with geographical or ecological distance (Bourgeois *et al*., 2017). In a phylogenetic study done in Egypt, Badr *et al*. (2016) observed that the local rabbit breeds were polymorphic with observed heterozygosity was 0.527, ranging between 0.477 and 0.581, While a study on the rabbit population in Italy by Valvo *et al*. (2017) were able to detect 75 variables sites from a total of 954 nucleotides. The results showed locations of some of the microsatellite loci indicating shared lineage.

Mutations with large favorable effects have been under strong positive selection in domestic animals and the same mutation is often found in different breeds all over the world (Andersson, 2013). In regions, where recombination is restricted, then there would higher differentiation between species and this is one of the distinct models where regional speciation allows deviation in the presence of a genetic factor (Carneiro *et al*., 2014). Strain of domestic rabbit breeding is expected to cause the forfeiture of alleles over founder effects and genetic drift (Boucher *et al*., 2021). Though it is difficult to identify the deletions that are unique to domestic rabbits based on the study of domesticated rabbit, some convincing duplications can be detected with striking

frequency differences between wild and domesticated rabbit breeds (Mutsami & Karl, 2020). Carneiro *et al*. (2014) and Mfuko (2017) indicated that the empirical models supporting speciation are still fairly scarce but can be derived from mapping experiments, therefore the current study aims and examining the population structure and distribution of the domesticated rabbits in Western Kenya Region using *mt*DNA genetic marker.

2.5.2 Phylogeny and microsatellite variations in rabbits

The most common approach to assessing the genetic diversity of domesticated animals is through the use of microsatellite markers (Lai *et al*., 2018). Microsatellites have been used for rabbit biodiversity studies, parentage studies, and genetic mapping by enrichment of linkage groups as well as anchoring and orientation onto rabbit chromosomes (Badawy *et al*., 2018). The use of microsatellites in mapping genetic diversity and population structure of rabbit breeds is widespread with different researchers using different loci. For instance, in East Anglia, UK, the researcher used 4 microsatellite loci to identify 5 wild rabbit populations, while their counterparts in Europe used 9 loci (Boucher *et al*., 2021). The study on autosomal microsatellite is useful in studying genetic diversity but fall short on studying in population structure (Carneiro *et al*., 2014). The use of autosomal microsatellites helps in highlighting the very strong phylogeographical pattern of two highly divergent *mt*DNA clades (Badr *et al*., 2019; Fontanesi *et al*., 2021).

The study of variation in these genome markers across natural populations has deepened the understanding of how population history and selection act on genomes (Bourgeois *et al*., 2017). The strength and appropriateness of applying microsatellites to more recent evolutionary questions are highlighted by the fact that both mtDNA and

protein markers have the requisite allelic diversity necessary to properly evaluate the Geo diversity of the rabbit breeds (Rödel, 2022). Experimentally, mtDNA is relatively easy to amplify because it appears in multiple copies in the cell. Mitochondrial gene content is strongly conserved across animals, with very few duplications, no intron, and very short intragenic regions (Maroja *et al*., 2015). Molecular markers are a powerful tool for assessing genetic diversity within and between the rabbit populations and for identifying the genetic loci linked to different traits (Lai *et al*., 2018). The microsatellites are effective markers in detecting genetic diversity and relationship among and within animal populations. Use of all microsatellite markers tends to illustrate high polymorphism (Ben *et al*., 2014).

The result of *mt*DNA analysis has demonstrated that the process of domestication and allowed for the characterization of breeds of both domestic and wild animal species (Badawy *et al*., 2018). *mt*DNA maternal inheritance, high mutation rates and availability in large quantities in the cell are the three main features that warrant it to be an attractive marker for studying diversity and origin (Owuor *et al*., 2019). The high mutation rates enable accountability for the variation that a species undergoes over time, and maternal inheritance enables tracing all the animals to their ancestor(s). *mt*DNA is a maternally inherited non-recombinant molecule and therefore, in species that hybridize, only provides information on the ancestry of the female lineage (Badr *et al*., 2016; Schneider and Meyer, 2017).

Genetic markers are also powerful tools to assess genetic variation within and between domestic stocks in a conservation programmed for genetic resources (Larbi *et al*., 2014). The genetic diversity and population structure of the rabbit breeds can be

established through the use of data on the polymorphism of immunoglobins (Alda and Doadrio, 2014).

Microsatellites are the greatest prevalent genetic markers for responding to an extensive range of biological queries at the intra-specific level, despite continued dispute concerning the mode and mechanisms of their evolution (Alves *et al*., 2015). Several studies on the genetic polymorphism of domestic rabbit haptoglobin (HP) and haemopexin (HPX) have been performed in the past. Nevertheless, both the separation and detection methods used are far from being efficient for large population phenotyping and resolving power for the detection of cryptic variation (Alves *et al*., 2015).

2.6 Carcass and meat quality traits of domesticated rabbit breeds

2.6.1 Carcass characteristics of domesticated rabbits

The domesticated rabbit originate from the European wild rabbit, *Oryctolagus cuniculus* (Johansson *et al*., 2015). Nowadays, the rabbit is to some extent raised in all countries worldwide, either for industrial purposes such as meat production or as pets (Ben *et al*., 2014; Alves *et al*., 2015). The major producers in Europe are Italy, France and Spain where rabbit meat is considered an economically attractive alternative to the meat from larger livestock. Worldwide rabbit meat production increased by 13% from 2006 to 2016 with China being the world leading rabbit meat producer (Nasr *et al*., 2017a; Cullere & Dalle Zotte, 2018; Ballan *et al*., 2022). In European countries rabbit production is decreasing while in Africa and America the production has been relatively constant in recent years (Karikari and Asare, 2009; Elamin *et al*., 2012; Nasr *et al*., 2017a; Rödel, 2022). The number of slaughtered chickens in Europe is approximately

60 times higher than rabbit, cattle – is 200 times higher and the number of slaughtered pigs is almost 2000 times higher than rabbits (Márquez, 2015; Fayeye & Ayorinde, 2016; Boucher *et al*., 2021).

Rabbit's production directly relies on their reproductive performance ; Ludwiczak *et al*., 2016; Nasr *et al*., 2017a; Daszkiewicz and Gugołek, 2020). Many factors affect the reproductive performance such as age, weight at first service, longevity of the doe breed and season combined with several traits which are considered as an indication of the mothering capability of the doe such as age at first service, kindling intervals, conception and kindling rates and litter size at birth and weaning (Dalle Zotte and Paci, 2013; Fayeye and Ayorinde, 2016; K. Ogolla *et al*., 2017; Ajayi *et al*., 2018; Ologbose *et al*., 2018). Genetic diversity is enhanced among some local and different standard exotic breeds (New Zealand White and Californian) through crossbreeding experiments to improve doe reproductive performance, milk production, post-weaning growth, carcass and other traits (Maj *et al*., 2009; El-Badawi *et al*., 2014; Somerville and Sugiyama, 2021). Rabbit meat productivity is based on selection of pure breeds for meat traits and on their crosses (Nasr *et al*., 2017a; Khan *et al*., 2018; Daszkiewicz and Gugołek, 2020).

The main traits of economic importance in rabbit production are feed conversion rate, litter size, and carcass yield (Nasr *et al*., 2017a; Macias-Fonseca *et al*., 2021). The latter, varies directly by the weight of the carcass and, the possibility of predicting its value, would produce valuable information to guarantee the viability and sustainability of the production system (Karikari and Asare, 2009; Cullere and Dalle Zotte, 2018).

New Zealand White and the Californian are the most important rabbit breeds for meat production. They have white fur that is difficult to see if a few pieces are stuck to the

carcass, and they have higher meat-to-bone ratios. The New Zealand White is considered the best breed overall, considering mothering ability and carcass characteristics (Maj *et al*., 2009; Fadare, 2015; Macias-Fonseca *et al*., 2021). However, crossing male Californians to female NewZealand White and then breeding the female from this cross back to male Californians results in larger litter sizes and heavier fryers than using straight New Zealand White. Other meat breeds include Californian white and Flemish Giant, but these may not receive a premium price because of their colored fur.

In recent years, there has been rising awareness on the advantages of rabbit meat production in developing countries as an alternative means of alleviating world's food shortage. This basic understanding is largely attributed to the rabbit's high fecundity and growth rates, early maturity, high genetic potential, efficient feed and land utilization, limited competition with human for similar food and high-quality nutritious meat (Maj *et al*., 2009; Alves *et al*., 2015; García *et al*., 2020). In Nigeria of recent, interest in the domestic rabbit production has increased tremendously that people want to know more about all the intricacies of the business particularly the prospect of commercial operations (Maj *et al*., 2009; Alves *et al*., 2015)

Rabbits were used in some parts of Nigeria to produce meat quickly to help in the nutrition of those that lost their crops and animals in the early 1970's. The carcass of the domestic rabbit has long shown its importance in the supply of meat for human consumption in densely populated countries (Mailafia *et al*., 2010; Baruwa, 2014; Fayeye & Ayorinde, 2016).

Rabbit meat has high biological value with high protein (21%), low fats (10%), low cholesterol and low sodium contents (Alves *et al*., 2015; Macias-Fonseca *et al*., 2021).

Rabbit grows rapidly and their growth rate is comparable to that of broiler chicken (Alves *et al*., 2015; Macias-Fonseca *et al*., 2021; Ballan *et al*., 2022). In Nigeria, a lot of effort had been utilised in the nutrition and physiology of rabbits` production to improve in growth rates and attain higher weight gains (Mailafia *et al*., 2010; Fayeye and Ayorinde, 2016).

The assessment of productive, reproductive and success indexes in rabbit farms can help in the calculation of their latent performance (Alves *et al*., 2015; Macias-Fonseca *et al*., 2021). New Zealand White and Californian white breeds have far much great important as pure breeds, make best use of the fraction of heterosis in their crosses in the creation of genetic lines (Mailafia *et al*., 2010; Baruwa, 2014; Fayeye and Ayorinde, 2016). They possess muscle conformation which is good for meat production, growth rate and high prolificacy (Alves *et al*., 2015; Macias-Fonseca *et al*., 2021). Heterosis between New Zealand White and Californian white breeds crosses present good and outstanding reproductive characteristics than in growth characteristics, demonstrating itself in a superior number of kits at weaning.

Domestic rabbit sex (Mailafia *et al*., 2010; Baruwa, 2014; Fayeye and Ayorinde, 2016) did not influence the assessed characteristics as far as reproduction traits were concerned. Samkol and Lukefahr, (2008) and Apata *et al*. (2012) indicated that sex impacts the weight and parts of the cadaver at slaughter when the live weight of the rabbit is greater than 2.5 kg. Rabbits are slaughtered before puberty with an average weight of 2.1 kg (Wanjala, 2015; Nuamah *et al*., 2019; Macias-Fonseca *et al*., 2021). The results obtained are similar to those reported by Nasr *et al*. (2017), who registered a killing weight of 1.998 g for New Zealand and 2040 g for California white rabbit

breeds and shows the reputation of heterosis in the crossbreeding of rabbits, whose reported weights were 2160 g at the end of fattening in a New Zealand cross.

2.6.2 Primal cut-up parts of rabbit crosses carcass (Mean ± SE)

Crossbreeding is one of the fast tools offered to breeders to improve many qualities and to establish gains in the performance in farm animals (Wanjala, 2015; Nuamah *et al*., 2019; Macias-Fonseca *et al*., 2021) and to increase production, produce superior crosses and to combine different characteristics in which the crossed breeds were premium through the explosion of heterosis (Harrison and Larson, 2016).

Primal cut up parts of rabbit crosses carcasses do not differ among the crosses in respect to environmental conditions. Ludwiczak *et al*. (2016) highlighted that the type of feed as environmental conditions offered to the animals has statistically significant effects on the rabbit crosses carcass parameters. Nuamah *et al*. (2019) found no significant differences in all parameter assessed as far as primal cut-up parts of rabbit crosses carcass are concerned.

2.6.3 Meat to bone ratio

The New Zealand white is well recognized as a dam breed based on its outstanding maternal capabilities (Wanjala, 2015; Nuamah *et al*., 2019; Macias-Fonseca *et al*., 2021) owing to its general mothering ability. Meat to bone ratio evaluation is a good predicator of which cross breed to keep for meat production (Ludwiczak *et al*., 2016). Nuamah *et al*. (2019) reported non-significant difference in bone to meat ratio in the Crossbreed of Californian White and New Zealand White.

2.6.4 Influence of domestic rabbit breed crosses on the organoleptic properties of meat

In rabbit farming, meat quality is the most important aspect to consider (Apata *et al*., 2012). All meat quality is described by its physical appearance, chemical components, and sensorial qualities, as the utmost critical attributes for the final animal protein consumer (Wanjala, 2015; Nuamah *et al*., 2019; Macias-Fonseca *et al*., 2021). Rabbits' meat contains high protein and less fat in comparison with other farm animal reared for meat. High levels of monounsaturated acids are similarly high in Rabbit meat in addition to remarkably low cholesterol level 45-85 mg/100 g (Szendrő *et al*., 2012; Serem *et al*., 2013; Daszkiewicz and Gugołek, 2020). In terms of calorific content, Rabbit meat has about 1380 to 1820/ kg. in terms of minerals, rabbit meat is loaded with rich amounts of sodium, iodine, phosphorus, calcium, iron and potassium (Apata *et al*., 2012; Nuamah *et al*., 2019). As in all slaughter animals, the colour of rabbit meat may be indirectly influenced by environmental factors related to management conditions (Dal *et al*., 2002), preslaughter stress as well as the housing system (Szendrő *et al*., 2012; Serem *et al*., 2013; Daszkiewicz & Gugołek, 2020).

The juiciness of any meat is alleged in two ways, first the feeling or sensation. Flavour contributes to meat aroma which is related to compounds which are soluble in water determines consumer suitability of meat. The soluble compounds (amino acids, sugars and nucleotides) in the meat muscle are common to different species. Phospholipids likewise play an important role in the flavour of meat.

Domestic rabbit weight as well as age, significantly influences the quality of meat as reported by Apata *et al*., (2012), while food provided to rabbit has a profound restraining effect (Dalle Zotte & Paci, 2013). Maj *et al*., (2009) highlighted the

importance of climate on rabbit meat quality with attributed significant effect of season on the meat quality. Daszkiewicz & Gugołek (2020) likewise reported rabbit meat quality effects as determined by production systems (intensive or extensive). On the other hand Wanjala, (2015) highlighted the importance of stress in influencing meat quality of rabbits. Rabbit meat consumers, are known to go for meat which is of high nutritive content, tender and soft with inclined positive impact on human health (Karikari and Asare, 2009; Nasr *et al*., 2017; Khan *et al*., 2018).

Rabbit meat is usually considered as low fat meat compared with red meats (Dalle Zotte and Paci, 2013). However, information available from chemical composition of rabbit meat is extremely variable, lipid composition ranging from 3.6% (Nasr *et al*., 2017) to 8% (Hungu, 2011). This could be due to the study of different parts of the carcass in the different investigations. Chemical meat composition is studied in the Longissimus dorsi (LD) muscle, where colour (Apata *et al*., 2012; Nasr *et al*., 2017; Nuamah *et al*., 2019), collagen (Hungu, 2011), texture (Szendrő *et al*., 2012; Serem *et al*., 2013; Daszkiewicz and Gugołek, 2020) and sensorial analysis are often measured. In other cases, the meat comes from the dissection of the hind leg, previously dissected to estimate the meat to bone ratio of the carcass. Moreover, carcasses analysed could be from animals of different weight and age (Daszkiewicz *et al*., 2012), Szendrő *et al*., 2012; Serem *et al*., 2013; Daszkiewicz and Gugołek, 2020), breed, sex or degree of maturity.

Fadare (2015), highlighted the importance of weight and food restrictions at a certain age, influencing on rabbit meat quality and impacting greatly on consumer acceptability. Similarly, Szendrő *et al*., 2012), Serem *et al*.,2013) and Daszkiewicz and Gugołek, (2020), noted that production systems either intensive or extensive, influences

meat quality and quantity of rabbits. Fadare (2015), in addition highlighted the importance of stress in its influence in pH, color or darkness as well as tenderness of rabbit meat. In a cross between New Zealand white and Palomino brown, meat with least flavor was produced (Fadare, 2015).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location

Clearance for this research was granted by NACOSTI permit number NACOSTI/P/21/7936. The study was carried out in the North Rift and Western Kenya which comprise of Counties of Elgeyo–Marakwet, Nandi, Trans-Nzoia, and Baringo in North Rift region and Bungoma, Busia, Kakamega, Vihiga in Western Kenya. Onsite study was conducted at the University of Eldoret (UoE) Farm (rabbitry section), Animal Science and the Biological laboratory in Uasin Gishu County, Kenya located in latitude 0°34'26.21"N and longitude 35°18'11.01"E (Figure 3.1).

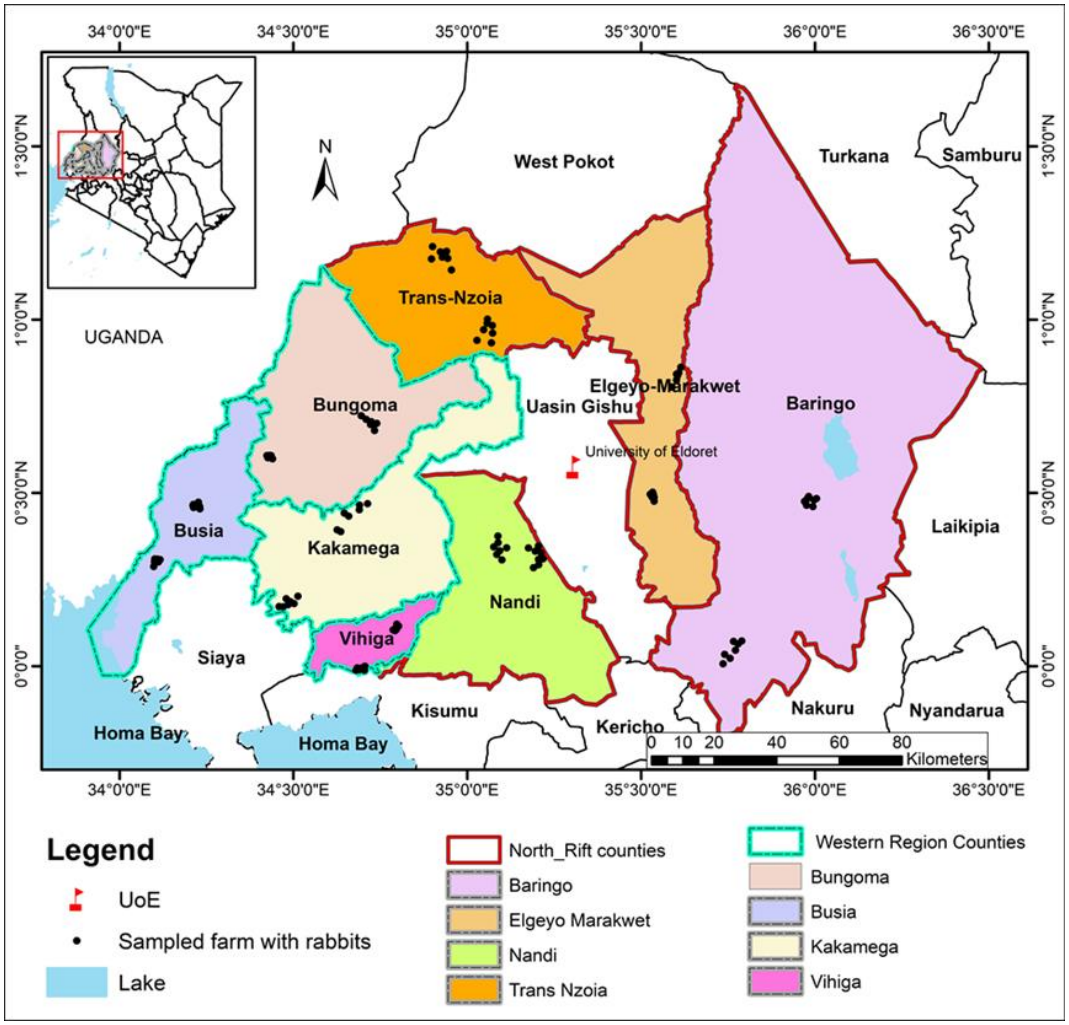

Figure 3.1: Generated map of the study areas

3.1.2 Climate

The climate is mainly tropical, with variations due to altitude in Western Kenya. Kakamega County is mainly hot and wet most of the year, while Bungoma County is drier but just as wet. Busia County is the warmest, while the hilly Vihiga County is the coldest. The entire region experiences very heavy rainfall (>1000mm) all year round, with the long rains in the earlier months of the year (Ochenje *et al*., 2016).

For the North Rift Region, Kenya, the wet season is overcast, the dry season is mostly cloudy, and it is hot year-round. Over the course of the year, the temperature typically

varies from 18°C to 34°C and is rarely below 15°C or above 36°C. They have a unimodal type of rainfall with recorded averages of 1000mm to 1520 mm per year. The long rains were experienced from March to August while the short rains were from November. A notable dry period was experienced from January to March. The average temperature of the site was 25.08^{o}C. (Barasa *et al*., 2020).

3.1.3 Topography and geology

Western Kenya has diverse and prominent physical features, ranging from notable hills of northern Bungoma County to the rolling plains bordering Lake Victoria in Busia County. The highest altitude is the peak of Mount Elgon and the lowest at Lake Victoria. For the North Rift region, the extinct Volcanoes, Lake Baringo, Lake Bogoria, the Suguta Valley, and Lake Turkana are some of the important geographic features.

3.1.4 Economic activity

Farming is the main economic activity in the region with many large factories such as Mumias Sugar, Pan Paper Mills and chemical processors present. Maize, sorghum and pearl millet are mostly for subsistence and sugar, pine trees as cash crops. Dairy farming and poultry keeping is widely practiced. Most parts in Western region practice rabbit farming as compared with North Rift. In the North Rift Kenya, the main economic activity includes rearing of cattle, goats, sheep and camels especially in Turkana, Baringo and part of Elgeyo-Marakwet Counties. The animals are reared mostly for traditional reasons and a sign of wealth and a symbol of respect in the communities. In Trans-Nzoia, maize farming is the main economic activity. Rabbit keeping is practiced though not a major enterprise.

3.2 Research design

The study used the exploratory research design to generate the required information. exploratory design allows the investigator to make an all-inclusive inference about the investigated variables in the target population. This was employed while sourcing rabbits as well as rabbit farmers. Sample size for rabbit farmers was determined using Cochran method for unknown population where a sample size of 138 farmers was established.

$$n_0 = \frac{Z^2 pq}{e^2}$$

p (population proportion) = 0.1; q (1-p) =1-0.1 = 0.9; e (margin of error) = 0.05; z (z test) =1.96; n (sample size) =138 farmers

3.2.1 Sampling procedures and sample selection for evaluation of production characteristics of domesticated rabbit breeds

The study targeted 112 rabbit farmers who comprised 56 from Western and the other 56 farmers from North-Rift region of Kenya. Study used both stratified and systematic sampling where population was divided into clusters (North Rift and Western-Rift regions) before sampling. The regions were chosen because of their different agro-climatological zones which were assumed to determine the phenotype of the rabbit breeds in the country. The regions were subdivided into smaller clusters (sub-counties). In each sub county (stratum), seven rabbit farmers were selected through snow balling technique which involved identifying a rabbit farmer who would in turn identify others. By obtaining referrals in succession in the region where rabbit farmers were distributed, this process was carried out in waves and all rabbit farmers were identified and used in

the analysis. A total of 112 rabbit farmers were identified and this was used as the sample for the study.

3.3 Assessment of domestic rabbit farming

Face-to-face interviews were held with household member of either sex above the age of 18 years who was responsible for the farm management and marketing of rabbits as an enterprise. These interviews were conducted by a well-trained team of independent field assistants. Carefully pre-tested open and closed-ended structured questionnaires were used. The information therein was intended to capture issues related with rabbit production constraints, source and selection of rabbit breed stock, farm characteristics, rabbit production system and feeding, and rabbit house hygiene practices. All information was captured was what had been done within a period of the previous 12 months.

To supplement and authenticate the information gathered from the farmers' interviews were carried out on key informants from Ministry of Agriculture, community leaders, farmer associations and representatives from Livestock and Fisheries departments in the sub-counties.

3.3 Body measurements and indices for morphometric characteristics of domesticated rabbit breeds

3.3.1 Sourcing the experimental animals

The sampling design was divided into two. First, the regions in which the rabbit breeds were sourced represented different agro ecological zones. The second part represented the different rabbit breeds. The breeds were assumed to have a wide range of

phenotypes as well as genotypes and with historical records indicating mostly old and distinct origin. The justification behind this mode of choice was that higher genetic divergence may be reflected by high phenotypic divergence and that reservoirs of genetic diversity may be represented by older rabbit breeds. Rabbit breeds (Agouti, Chinchila, Dutch, Flemish giant, New Zealand white, Palomino, Rex and Silver fox) were sourced from the two regions (North Rift and Western Counties) in Kenya. The Counties in the said regions were Nandi, Elgeyo Marakwet, Baringo and Trans Nzoia in the North Rift Kenya and Bungoma, Busia, Kakamega and Vihiga counties in the Western Kenya of Kenya.

The rabbit does and bucks from farmers in the North Rift and Western Kenya were obtained through snow balling sampling technique / chain referral sampling technique. The rabbits selected were of a random population between five to six months old. One or two rabbits were sourced from farmers for each breed. The identified breeds were transported to University of Eldoret rabbitry section where they were allowed to acclimatize before being weighed and body linear body measurements taken.

3.**3.2 Animal housing, feeding and health management**

The rabbits' parent stock consisted of 24 females and 8 males aged between 6-7 months old local rabbits. They were sourced and bought from 8 different Counties in North Rift and Western Kenya to assure a high and divergent level of genetic variation (Appendix II). Pure breeds (NewZealand White) from KALRO Research station Naivasha, consisted of one male and three females. These animals were randomly divided into groups, each consisting of three does and one buck care was taken to avoid mating rabbits from different areas. Through permitted mating using diallel cross design, a total

of two hundred and sixteen (216) kittens were reproduced and denoted as the first generation (F1).

Sufficient rooms (18x 24 x30 or 18 x 24 x24) inches were provided for the rabbit breeds with standard requirements for does and bucks depending on the breed or size of rabbit to reduce stress, fighting and injury (Clauss and Hatt, 2017). Each rabbit breed was housed individually in an all-wire metallic cage, fitted with a gutter to a slatted floor designed for easy collection of faeces and urine.

General health, hygiene and husbandry practices for the animals were taken care of. The rabbit house and cages were thoroughly cleaned with clean water and disinfectant (Kupacide) before placing the rabbits in the cages and followed by routine hygiene. Earthen bowls were used as feeders and drinkers and were routinely washed with clean water before new feed or water was offered.

3.3.3 Morphometric characterization of the rabbit breeds

The morphometric characterization of the rabbit breeds from farmers in North Rift and Western Kenyan regions were made according to Clauss and Hatt (2017) and included life body weight of mature (6-7 months old) adult does and bucks, the conformation of body, head, legs, neck, eyes, ears and the respective coat colours on a total number of 112 mature rabbits. The rabbit breeds were weighed using an electronic digital weighing balance in kilograms, model 50kg*10g and body measurements taken at predefined anatomical points using a measuring tape (cm), (GB™ weight measuring tape). Anatomical lengths of the rabbits involved laying them on a table and the measurements taken by the same person for consistency.

Briefly, the body length of each rabbit was measured and recorded in a data sheet by use of tape measure from atlas bone all the way to the first coccygeal bone. Rabbit radial chest (in cm) was measured from back of the rabbit shoulder while the abdominal circumference was measured within the seventh lumbar vertebrae located at the bottom section of the vertebral column inferior to the rib cage and superior to the pelvis and sacrum. Measurement of the ear width was from the widest part from left right margins at the distance of 2 cm from the top. Rabbit ear length was taken from the bottom (head) to the top (peak) while the foot length was measured from fingers / tarsus to tail. Measurement was repeated if the process was disturbed. Measurements were replicated twice and their means taken for statistical analysis (Clauss and Hatt, 2017).

Figure 3.2: Some of the measurements taken on the rabbits in Kenya (Source : Author, 2022)

3.3.4 Chemical composition analysis (g/kg) of rabbit pellets diet

Rabbits were provided with water and feed ad-libitum daily at 08:30 and 15:30 h. The diet was a standardized meal of 40% pellets and 60% hay, Samkol & Lukefahr (2008), (Table 3.1).

Table 3.1: Chemical composition analysis (g/kg) of rabbit pellets diet

Item	Rabbit pellets diet
Dry matter	923
Crude protein	133
Crude fibre	145
Ether extract	40
Ash	88
Neutral detergent fibre	280
Acid detergent fibre	175
Acid detergent lignin	32
Gross energy (MJ/kg)	16

3.4 Growth and performance characteristics of domesticated rabbit breeds and their crosses in North Rift and Western Kenya

The growth and performance characteristics of domesticated rabbit breeds and their crosses in North Rift and Western Kenya experiment was carried out following the European Union, (2003) recommendations for the care and protection of live animals used for experimental purposes at the University of Eldoret.

To establish growth and performance characteristics of domesticated rabbit breeds and their crosses in North Rift and Western Kenya, a total of seventy-one (71) kittens generated from the nine (9) groups were used for this experiment from the initial 216. Identification of the kittens was done as described by Quick and Knauer (2019).

Sufficient room space measuring 18 x 24 x 24 or 18x 24 x 30 inches as well as kindling boxes (Hungu, 2011) were provided. Feeding was done twice a day at 08:30 and 15:30 hrs with a standardized meal of 40% pellets adlibitum and 60% hay. Each rabbit was provided with 25 grams per kilogram body weight of good rabbit pellets per day. Hay was given at 170 grams per kg of body weight and adlibitum. Fresh green vegetables were given in small amounts at 110 grams per kg body weight per day. The data collected on the domestic rabbits was; Initial body weight at birth (BW0), initial body

weight at week 1, 2, 3 and 4 for pre weaners, 5, 6, 7 and 8 weeks of age for weaners, 9, 10, 11 and 12 weeks for (growers) and 13, 14, 15 and 16 weeks (sub adults). Amounts of feed taken and remainders as well as corresponding weight of rabbit crosses were done using an electronic digital weighing balance in kilograms.

3.5 Genetic diversity of domesticated rabbit breeds in North Rift and Western Kenya

3.5.1 Preparation for patterns of genetic variation within and among the rabbit breeds

In order to investigate patterns of domestic rabbit genetic variation among and within the rabbit breeds, individual does from each County for each of six different breeds (Palomino, Silver fox, New Zealand White, California, Dutch and Rex) were used. In order to improve on the generalization, the breeds included reflected the various phenotypic characteristics representing different agro-ecological zones in North Rift and Western Kenya.

The rabbit does from farmers in the North Rift and Western Kenya were used. The experimental design based on the principle that mitochondrial DNA (*mt*DNA) is almost exclusively maternally inherited and is an essential tool to assign animals to a precise maternal lineage (Owuor *et al*., 2019). The rabbits were of a random population between six months old and were used for breeding to obtain the hybrids. A pure New Zealand white breed was sourced from KALRO, Naivasha for control purposes.

3.5.2 Blood Sample Collection and Genomic DNA Extraction

Whole blood was collected aseptically by saphenous rear leg venial puncture of the rabbits using 1ml sterile syringe. A total of 2 ml blood was transferred into serum tubes containing 1 ml ethylene di-amine-tetra acetic acid (EDTA) tubes shaken gently for mixing and stored at - 4^0C until use.

Rabbits are known to suffer from hematoma formation if venipuncture is not done with care. The maximum volume of blood that should be collected at one time was 1 ml/100 g body weight. The activity was done by first restraining the animal well, extending it neck a little bit and drawing 1ml of rabbit blood. To ensure that blood did not continue to leak from the puncture as well as to prevent infections, cotton wool soaked in alcohol was placed over the venipuncture site and clipped to hold it for some few minutes.

Genomic DNA extraction was done using a Quick-gDNA MiniPrep kit (Catalog NO: D3025) from Qiagen Limited following manufacturers' recommendations. Briefly a total of 400ul of genomic lysis buffer was added to 100ul of whole blood in a microcentrifuge tube. This was mixed completely by vortexing for 6 seconds and then allowed to stand for 10 min at room temperature. The mixture was transferred to mini-spin columns in a collection tube and then centrifuged at 10000g for 1 min. The collection tube with the flow-through was discarded.

The mini spin column was then transferred to a new collection tube and 200ul of DNA pre-wash buffer was added to the Spin column and then centrifuged at 10,000 rpm for 1 min. The Spin column was transferred to a clean collection tube and 500ul of gDNA wash buffer was added to the spin column and centrifuged at 10,000g for 1 min. The spin column was transferred to a clean microcentrifuge tube and 50ul of DNA elution

buffer was added to the spin column, incubated at room temperature for 5 min, and then centrifuged at top speed for 30 seconds to elute the genomic DNA. The DNA was then stored at -20^{0}C until use for further molecular-based applications.

3.5.3 DNA quantification

The purity and concentration of the isolated DNA were determined using NanoDrop 2000c spectrophotometer (Thermo Scientific) and Agarose gel electrophoresis. Nanodrop spectrophotometry involved the determination of the concentration of DNA from the absorbance of DNA at 260 nm (1OD (A260) = 50 µg for double-stranded DNA/µl). The purity of the DNA sample was determined by the A260:A280 ratio (1.6±1.8 for pure DNA).

Agarose gel electrophoresis involved running the extracts in a 1% agarose gel (1g agarose and 100ml TBE buffer) pre-stained with Ethidium bromide staining dye at a voltage of 100 Volts and a current of 400mA for 30 minutes. The extracts were visualized on a UV Trans illuminator. The presence of DNA in the sample was visualized by the presence of a band while DNA quantity in the sample was assessed by the brightness of the band. The sharpness of the bands indicates the quality of the isolated DNA (Sharp bands indicate good quality, while smears indicated sheered DNA).

3.5.4 Polymerase Chain Reaction (PCR) and microsatellite genotyping

Seven microsatellite markers (SAT3, SAT8, SAT12, SOL 3, SOL 8, SOL 28, and SOL 30) used in the study are tabulated (El-Aksher *et al*., 2016) (Table 3.1). The markers were selected because they are uniformly distributed across the rabbit genomes and

have been associated with growth and meat yield traits. Microsatellite markers (SAT3, SAT8, SAT12, SOL 3, SOL 8, SOL 28, and SOL 30) were selected in this study.

Table 3.2: Rabbit microsatellite (SSR) markers

Locus	Primer Sequence	Temp (ºC)	Polymorphic Information Content (PIC)
SAT3	F: 5'GGAGAGTGAATCAGTGGGTG3'	60	0.72
	R: 5' GAGGGAAAGAGAGAGACAGG3'		
SAT8	F: 5'CTTGAGTTTTAAATTCGGGC3'	55	0.68
	R: 5'GTTTGGATGCTATCTCAGTCC3'		
SAT12	F: 5'GGATTGGGCCCTTTGCTCACACTTG3'	58	0.8
	R: 5'ATCGCAGCCATATCTGAGAGAACTC3'		
SOL3	F: 5'ATTGCGGCCCTGGGGAATGAACC3'	58	0.78
	R: 5'TTGGGGGGATATCTTCAATTTCAGA3'		
SOL8	F: 5'CAGACCCGGCAGTTGCAGAG3'	60	0.77
	R: 5'GGGAGAGAGGGATGGAGGTATG3'		
SOL28	F: 5'TACCGAGCACCAGATATTAGTTAC3'	52	0.81
	R: 5'GTTGCCTGTGTTTTGGAGTTCTTA3'		
SOL30	F: 5'CCCGAGCCCCAGATATTGTTACCA3'	52	0.78
	R: 5'TGCAGCACTTCATAGTCTCAGGTC3'		

Rabbit genetic diversity SSRs (El-Aksher *et al*., 2016)

PCR amplification of isolated DNA was carried out to amplify the selected loci. Briefly, the PCR mix was prepared in a 25.0µl volume which contained 1.0µl of DNA template, 2.0µl of 10 × DNA amplification buffer, 6.0ul Master Mix, and 16.0µl distilled water. Denaturing temperature of 94°C (1 minute) and annealing temperature for the seven microsatellite primers ranged from 52°C - 60°C (Table 3.1). The initial extension was at 72°C (1 minute) (Bourgeois *et al*., 2017).

3.6 Carcass traits of the crosses of domesticated rabbit breeds in North Rift and Western Kenya

3.6.1 Slaughter and carcass measurements

The rabbits were sacrificed at rooster age (16 weeks) and with an average slaughter weight of 2.8±0.13 kg. Slaughtering of the rabbits was carried out at the University of Eldoret Laboratory as recommended by World Rabbit Science Association (WRSA) followed by the cutting of the carotid arteries and jugular veins. The slaughtered rabbits were bled and blood was collected in a container for weighing. Weight of blood was obtained by getting weight of container in grams, then subtracting from that of the blood and the container. The skin and paws, genital organs, urinary bladder, and full gastrointestinal tract were removed and individually weighed. The carcasses, with the head, thoracic cage organs (heart, lungs, thymus, trachea, and oesophagus – HLTTO), liver, kidneys, the perirenal and scapular fat, were weighed 30 minutes after slaughter (hot carcasses – HC), and then chilled at +4 °C for 24 h in a ventilated room. The chilled carcasses (CC) were weighed. The head, HLTTO, liver and kidneys were removed from each carcass to obtain the reference carcasses (RC), which included the meat, bones and fat deposits.

3.6.2 Experimental design for slaughter and carcass measurements

The completely randomized research design (CRD) was employed with the equation;

$$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$$

Where:

Y_{ijk} = the total observation on the j^{th} sampling unit of the i^{th} treatment.

μ = overall population mean

α_i = effects due to i^{th} treatment

ε_{ij}= random error associated with Y_{ij}

3.6.3 Carcass quality and yield

At the end of the experiment (16 week of rearing) 33 (thirty three) rabbit crosses were randomly selected and sacrificed according to the procedure used by Khan *et al*. (2018). Before slaughtering, the rabbits were tagged, fasted for 12h and weighed to determine the final live weight. The fur was removed by scalding. Evisceration (removal of viscera and intestines) was carried out immediately. For weights assessment of different organs, the intestines (viscera) were carefully separated to prevent puncturing the intestines (both small and large), liver, bile gland spleen, pancreases and kidneys. Weights were taken for each part separated from the viscera and percentage weight to hot carcass weight determined. The hot dressed carcass was weighed before chilling 24 hours at-4^0 C. After chilling, primal cuts were made which included loin, chest, hind legs and their weight taken separately. The thigh muscles from the thigh legs were later used for sensory evaluation and laboratory analyses. The weight of the carcass, head and internal organs, pelt and tail were taken and recorded.

3.6.4 Sensory evaluation of domestic rabbits crosses meat

In preparation for sensory evaluation of domestic rabbit crosses meat a total of twenty-two (22) participants within age group of 18 to 25 years were randomly sourced from the School of Consumer Science, Food Science Department in University of Eldoret. To avoid gender biasness, equal number of male and female student was used in this study. Individuals with underlying respiratory diseases such as cough, common cold and tuberculosis were excluded. Selection and training of the candidates was carried

out using British Standard Institution guidelines to evaluate the products (Lawson *et al*., 2014). The rabbit meat from thigh muscles was defrosted sliced into small pieces (about 2cm) and grilled in a 70°C in an electric oven (Turbofan, Blue seal, UK). The cooked pieces were then packed in oblique aluminum foils before being presented to panelists alongside bottled water and a tuscan bread that served as neutralizers between products from different rabbit crosses. A five-point hedonic scale was used to evaluate sensory evaluation of domestic rabbits' meat across the breed crosses as summarized in Table 3.3.

Table 3.3: A five-point hedonic scale used to evaluate the sensory characteristics of rabbit breed crosses meat

Attribute	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5
Colour:	Very pale	Pale	Intermediate	Dark	Very dark
Off-odour:	Very weak	Weak	Intermediate	Strong	Very strong
Juiciness:	Very juicy	Juicy	Intermediate	Dry	Very dry
Flavour intensity:	Very weak	Weak	Intermediate	Strong	Very strong
Flavour-liking:	Like very much	Like	Intermediate	Dislike	Dislike very much
Overall acceptability:	Like very much	Like	Intermediate	Dislike	Dislike very much

3.7 Statistical analysis

Data collected was analyzed with the help of Statistical Package for Social Science (SPSS version 20). Data collected through questionnaires was coded, analyzed using the chi-square test to determine whether expected frequencies differ from the actual frequencies.

Rabbits breed distribution was analyzed using cross tabulation chi squares (χ^2). Means as well as least square means for body weight and organ as well as for different carcass weights were estimated using the Generalized Linear Modeling (GLM) procedure. Significant differences between the populations were separated by Duncan test and least significant different test by Fishers Test.

Least square means for body weight and body dimension measurements were estimated using the GLM procedure of SAS version 9.1.3 (SAS Institute Inc., Cary, NC, USA). The model used was Yij=μ+Pi+eij, where Yij=any observation of rabbit within ith populations (P), μ=overall mean, Pi=the effect of the populations, i=1, 2, and 3, and eij=the random error. Significant differences between the populations were defined by Duncan test.

Genetic diversity was evaluated by calculating the observed and effective number of alleles (No and Ne), heterozygosity observed and expected (Ho and He) using GENALEX software version 6.0 (Muzzalupo *et al*., 2014). CERVUS software version 3 was used to determine the Polymorphic information content (PIC). GENEPOP software version 3.4 was used to calculate Pairwise FST in addition to F-statistics (FIS, FST, and FIT) for populations (GENEPOP (version 1.2). Genetic distances among the studied populations was evaluated by Reynolds genetic distance (Touma *et al*., 2020). A neighbor-joining (NJ) Dedrogram was constructed based on the Reynolds genetic distance in POPULATIONS version 1.2.30 and CLUMPP software for runs (Touma *et al*., 2020).

DISTRUCT software was used to plot the clustering pattern with the highest H value for the selected K value (Jakobsson & Rosenberg, 2007).

The carcass yield (carcass weight as % of SW) was expressed as either the hot carcass (HC) or the chilled carcass (CC) weights, and the ratio of the carcass traits and the organs to both the SWs and the CC weights were calculated as required. The perirenal fat, scapular fat and other dissectible fat, and the hind legs and loin joint (between the 1st and the 7th lumbar vertebra) were dissected.

Standard genetic diversity statistics; allelic frequencies, observed heterozygosity (Ho), expected heterozygosity (HE), the mean number of alleles (MNA), and Hard-Weinberg equilibrium were estimated using Popgen version 2.03 Software. Inter and intrapopulation diversity were estimated by Analysis of Molecular variance executed in GenAlEX 6.41 software. Rabbit population genomic structure was determined using, Discriminant Analysis of Principal Components (DAPC) computed in DARwin 6.021 software.

CHAPTER FOUR

RESULTS

4.1 Domestic rabbit farming techniques and problems associated in North Rift and Western Kenya

4.1.1 Characteristics of the respondents

There were one hundred and twelve (112) questionnaires administered to the local residents who kept and reared rabbits from North Rift and Western Kenya. Majority of the respondents (56.3%) were males. A large proportion (52.7%) was aged below 36 years with those above 36 years comprising only 47.3%. The majority of the respondents (96.4%) had formal education, with 54.5% having attained certificate of secondary level education (Table 4.1). On occupation, unemployed local residents constituted the highest respondents (64.3%). Majority (86.6%) of the respondents were residents by birth. Those respondents who had stayed for more than 18 years (81.3%) in the study area were the majority. Those who practiced mixed farming (keeping animals and crops) represented 82.1% while 16 (14.3%) practiced livestock rearing. Few respondents (3.6%) practiced other forms of land use such as small businesses enterprises (e.g. quarrying) as illustrated in Table 4.1.

Table 4.1: Respondent's socio-demographic profile

Variable	Respondents	Frequency (f)	Percentages (%)
Gender	Male	52	46.4
	Female	60	53.6
	Total	112	100.0
Age	<18 yrs.	10	8.9
	18-25 yrs.	25	22.3
	26-35 yrs.	24	21.4
	36-45 yrs.	27	24.1
	46-55 yrs.	17	15.2
	Above 56 yrs.	9	8.0
	Total	112	100.0
Education	None	4	3.6
	Primary	28	25.0
	Secondary	61	54.5
	Tertially	12	10.7
	University	7	6.3
	Total	112	100.0
Occupation	Employed	9	8.0
	Self employed	31	27.7
	Un employed	72	64.3
	Total	112	100.0
Residence	Birth	97	86.6
	Immigrant	15	13.4
	Total	112	100.0
Period of residency	<18 yrs.	21	18.8
	18-25 yrs.	35	31.3
	> 25 yrs.	56	50.0
	Total	112	100.0
Forms of land use	Livestock keeping	16	14.3
	Mixed farming	92	82.1
	Others	4	3.6
	Total	112	100.0

4.1.2 Farm characteristics and rabbit production system

The interviewed farmers who kept and reared rabbits indicated that they kept other types of livestock, (89.3%) kept chicken, (49.1%) kept cattle and a few (10.7%) kept sheep with a significant difference (χ^2 = 145.15, d.f.=4, p<0.0001) as shown in Figure 4.1. In Western Kenya, majority of farmers kept chicken followed by cattle which was not significantly different from farmers in North Rift region (χ^2 = 20.00, d.f.=16, p=0.2202). Only 8 (15.4%) farmers in the regions surveyed highlighted that rabbit enterprise was not their main type of land use activity as it was a project owned by young boys in the family.

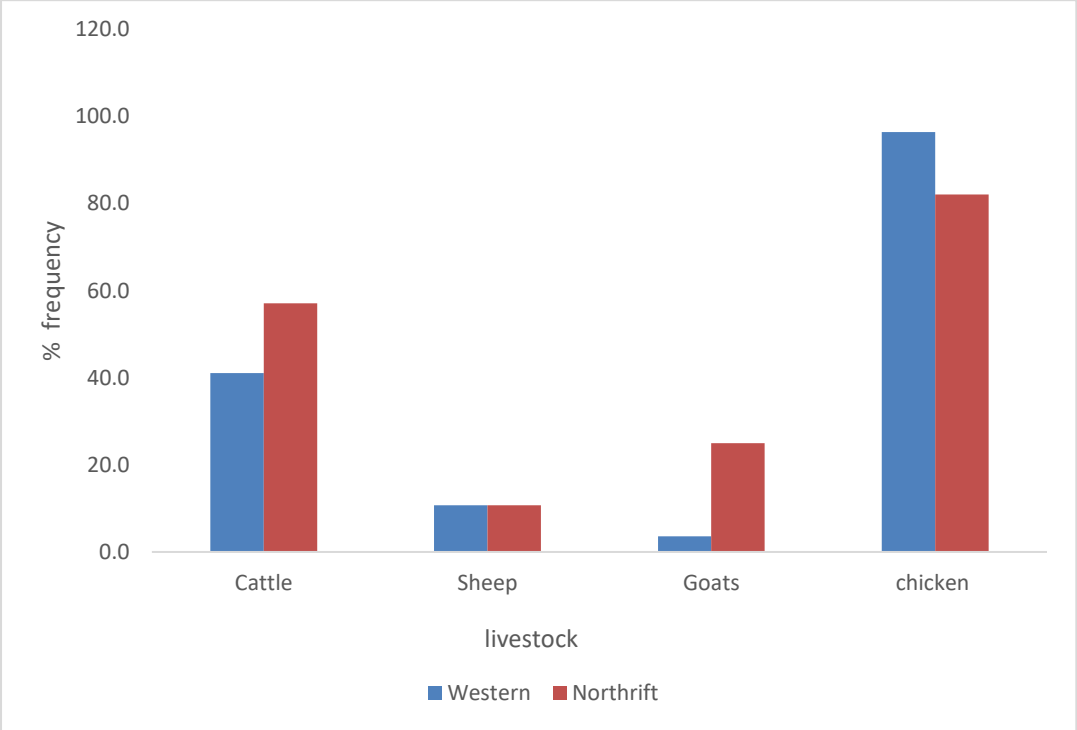

Figure 4.1: Other types of livestock kept by respondents

4.1.3 Types of rabbits reared by farmers and reasons for having rabbits

A large proportion (74.0%) of the respondents had kept rabbits for a period of less than five years while the rest 26% had reared so for a period of over 10 years with a significant difference (χ^2 = 28.96, d.f.=3, p<0.0001). Most farmers 62 (59.6%) did not know the breeds of rabbits they reared (χ^2 = 4.00, d.f.=1, p= 0.0455) but distinguished them by coat and eye colour (χ^2 =47.66, df=2, p< 0.0001). For those who knew the breeds they reared, majority had New Zealand White 48 (43.6%) followed by Flemish Giant 22 (20.0%) while Palomino was least kept with a statistically significant difference (χ^2 = 84.24, d.f.=6, p<0.0001) (Table 4.2). In cross tabulation with education level, respondents who had secondary and tertiary level of education knew breeds` name of the rabbits they reared in their farms (χ^2 =54.89, df=2, p=0.0002). Rabbits were kept for various purposes such as meat provision 40 (38.5%), as pets (31.7%), sale

(21.2%) while few were kept for skin and fur 5 (4.8%) as well as for breeding purposes (6.7%) (Table 4.2). There was a significant difference in the reasons provided for rearing of rabbits (χ^2 = 41.85, d.f.=4, p<0.0001).

Table 4.2: Types of rabbits reared by farmers and reasons

Question	Attribute	f	% f	Chi square (χ^2)
Period in which farmers had kept rabbits	Less Than 1 Year	33	31.7	χ^2= 28.96 d.f.=3 p = 0.0000
	2- 5 Years	44	42.3	
	6- 10 Years	21	20.2	
	Over 10 Years	6	5.8	
	Total	104	100.0	
Do you know the breed you keep?	Yes	42	40.4	χ^2= 4.0 d.f.=1 p = 0.0455
	No	62	59.6	
	Total	104	100.0	
if no, how do you distinguish them	Eye Colour	11	10.6	χ^2= 47.66 d.f.=2 p= 0.0000
	Coat Colour	25	24.0	
	Both	68	65.4	
	Total	104	100.0	
if yes, which breed (name)	New Zealand White	48	43.6	χ^2= 84.24 d.f.=6 p = 0.0000
	Chinchilla	3	2.7	
	Dutch	10	9.1	
	Rex	7	6.4	
	Silver fox	8	7.3	
	Agouti	12	10.9	
	Flemish Giant	22	20.0	
	Total	110	100.0	
Why do you rear rabbits in your home?	Pets	30	28.8	χ^2= 41.85 d.f.=4 p = 0.0000
	Meat	40	38.5	
	Skins And Fur	5	4.8	
	Breeding Purposes	7	6.7	
	Sales	22	21.2	
	Total	104	100.0	

4.1.4 Rabbit housing

The proportion of respondents who at least indicated they reared their rabbits in cages 90 (86.5%) was high (χ^2 = 205.29, d.f.=3, p< 0.0001) and was found to be significantly different (Table 4.3) as compared to those who reared in an indoor rabbitry 10 (9.6%)

free range 2 (1.9%) and both 2 (1.9%). The measurement of the rabbit house was 1.5m by 1.5m and above (68.3%) with statistically significant difference (χ^2 = 2.24, d.f.=2, p = 0.3263). Majority of the structures were raised (99.0%) about a meter from the ground (χ^2 = 96.04, d.f.=1, p< 0.0001) as anti-predation precaution (50.3%) against dogs and mongooses (χ^2 = 44.24, d.f.=1, p<0.0001). The average number of rabbits housed per structure ranged from 10 and above 26 (50.0%) with the highest record of 200 individual rabbits in one enclosure (χ^2 = 14.66, d.f.=2, p= 0.0005).

Table 4.3: Rabbit housing

Question	Attribute	f	% f	Chi square (χ^2)
Which type of structure do you house your rabbits in?	Rabbit cage	90	86.5	χ^2= 205.28 d.f.=3 p< 0.0001
	Indoor rabbitry	10	9.6	
	Free range	2	1.9	
	Both	2	1.9	
	Total	104	100.0	
Approximate size of the rabbit house/. Structure	1m by 1m	33	31.7	χ^2= 2.24 d.f.=2 p = 0.3263
	1.5m by 1.5 m	29	27.9	
	Over 1.5m by 1.5m	42	40.4	
	Total	104	100.0	
Nature	Raised	103	99.0	χ^2= 96.04 d.f.=1 p< 0.0001
	Unraised	1	1.0	
	Total	104	100.0	
If raised, reasons	Against predation	79	50.3	χ^2= 44.24 d.f.=2 p < 0.0001
	For hygiene purposes	75	47.8	
	None	3	1.9	
	Total	157	100.0	
Number of rabbits per structure	1 per structure	20	19.2	χ^2= 14.66 d.f.=2 p= 0.0007
	2-10 per structure	32	30.8	
	10 and above	52	50.0	
	Total	104	100.0	

4.1.5 Source of rabbit breeds

Most farmers (85.5%) indicated that they sourced breeding stocks from local farmers/ breeders which was significantly different (χ^2 =125.78, df=2, p< 0.0001) with emphasis focusing on size and beauty of the breed 57 (56.4%) and advice from farmers 25

(24.8%) with a statistically significant difference (χ^2 =23.66, d.f.=2, p<0.0001) as indicated in Table 4.4. Majority of farmers (46.8%) indicated that they provided six females to one male for mating purposes (χ^2 =36.44, df=3, p<0.001) with a significant difference between the regions. There was no significant difference (χ^2= 0.82, d.f.=1, p=0.3652) as a large proportion of respondents 61 (54.5%) indicated that they provided pregnant does with nesting boxes where approximately between 6 and 10 young ones per female rabbit doe 102 (95.3%) were born with a significant difference (χ^2= 171.43, d.f.=2, p<0.0001). Females were recorded to eat some of the weak young ones by majority of farmers but this did not deter many to reach market age 83 (76.1%) where they were sold to individuals 109 (94.8%). Majority of rabbits were sold when at an age of more than three months but less than five months 57 (52.3%) as illustrated in Table 4.4. Farmers indicated that they sold mature rabbits for a price ranging from 200 to 1200 Ksh with majority selling at an average of 200 to 500 Ksh with a significant difference from those who sold at an average of above 800 Ksh (χ^2 = 47.63, d.f.=3, p = 0.0000).

Table 4.4: Source and selection of rabbit breed stock

Question	Attribute	f	% f	Chi square (χ^2)
Where did you source your parent	From other farmers or breeders	100	85.5	χ^2= 125.78 d.f.=2 p< 0.0001
	Fromm accredited rabbit breeders	4	3.4	
	My own stock	13	11.1	
	Total	117	100.0	
How did you select the breeding parent	By breed performance	19	18.8	χ^2= 23.66 d.f.=2 p< 0.0001
	Advice from other rabbit farmers	25	24.8	
	According to size and Colour	57	56.4	
	Total	101	100.0	
How many females to male rabbits did you keep?	1 female	7	6.3	χ^2= 36.43 d.f.=3 p< 0.0001
	2-5 females	20	18.0	
	6- 10 females	52	46.8	
	More than 10 females	32	28.8	
	Total	111	100.0	
Do you provide nesting boxes for pregnant does?	Yes	61	54.5	χ^2= 0.82 d.f.=1 p=0.3652
	No	51	45.5	
	Total	112	100.0	
How many young ones are born per one doe?	Less than 5	1	0.9	χ^2= 171.43 d.f.=2 p< 0.0001
	6-10 young	102	95.3	
	More than 10 young ones	4	3.7	
	Total	107	100.0	
Approximate number of young ones that reach maturity of marketable age per doe?	Less than 5	1	0.9	χ^2= 146.16 d.f.=3 p < 0.0001
	6-10.	21	19.3	
	More than 10.	4	3.7	
	All	83	76.1	
	Total	109	100.0	
Where do you sell your rabbits	To individual farmers	109	94.8	χ^2= 273.32 d.f.=3 p < 0.0001
	Nearby market	1	0.9	
	To hotels	1	0.9	
	None	4	3.5	
	Total	115	100.0	
Age at which rabbits were sold	Less a month old	6	5.5	χ^2= 35.12 d.f.=2 p<0.0001
	3- 5 months old	57	52.3	
	Above 5 months old	46	42.2	
	Total	109	100.0	
Price of a mature rabbit	< 200 ksh.	5	4.7	χ^2= 47.63 d.f.=3 p< 0.000
	200-500 ksh.	55	51.4	
	500-800 ksh.	31	29.0	
	> 800 ksh.	16	15.0	
	Total	107	100.0	

4.1.6 Rabbit house cleaning practices

Farmers indicated their major sources of water to their farm. A large proportion 57 (52.8%) of them indicated that they relied on shallow wells. Those who fetched water from rivers / lakes were 39 (36.1%) while those who relied on seasonal ponds were 5 (4.6%) majority of whom came from North Rift Kenya with a significant difference (χ^2 = 105.75, d.f.=4, p< 0.0001). The proportion of farmers who stated that they never cleaned rabbit houses were 57 (50.9%). For those who cleaned, few did it three times a week 5 (4.5%) with majority practicing manure removal were 46 (70.8%), followed by those who sprinkled ash (*jivu*) as a disinfectant 8 (12.3%) and addition of more fresh straw 5 (7.7%) with a significant difference (χ^2 = 162.95, d.f.=4, p<0.0001) (Table 4.5).

Table 4.5: Rabbit house cleaning practices

Question	Attribute	f	% f	Chi square (χ^2)
Where do you source your water for use?	Tap water	4	3.7	χ^2= 105.75 d.f.=4 p < 0.0001
	River/ lake	39	36.1	
	Well	57	52.8	
	Rain water	3	2.8	
	Seasonal ponds	5	4.6	
	total	108	100.0	
How many times per week do you clean the rabbit houses?	Daily	16	14.3	χ^2= 68.5 d.f.=4 p < 0.0001
	Once a week	25	22.3	
	Twice weekly	9	8.0	
	Thrice weekly	5	4.5	
	Never	57	50.9	
	Total	112	100.0	
What cleaning practice do you follow?	Sweeping alone	3	4.6	χ^2= 162.95 d.f.=4 p < 0.0001
	Adding more straw	5	7.7	
	Manure removal only	46	70.8	
	Use of disinfectant (ash)	8	12.3	
	All of the above	3	4.6	
	total	65	100.0	

4.1.7 Rabbit feeding

Majority 92 (86.8%) of farmers never gave rabbits drinking water as they do not take it 73 (68.9%) said rabbis don`t take water, and 19 (20.7%) said they feared might die of diarrhoea with a significant difference (χ^2= 29.96, d.f.=1, p<0.0001). Varieties of feeds given to rabbits ranged from Commercial pellets to kitchen left-overs. Majority of rabbits were fed purely vegetables plucked or uprooted from farms 68 (60.7%) while others were fed with commercial pellets 30 (26.8%) and kitchen remains 3 (2.7%) with a significant difference (χ^2 = 80.36, d.f.=3, p<0.0001). Commercial pellets were sourced from nearby agrovets (Shops that sell both Agricultural and Veterinary items) (100.0%) with advice on how to feed rabbits being sourced from other local rabbit farmers as illustrated in Table 4.6.

For those who were fed with green vegetables, the vegetables were mainly collected from individual farms 61 (89.7%). the vegetables were first wilted in the sun (16.4%) and fed the following day at intervals 82 (74.5%) by young boys 68 (60.7%) but while in school, all this was done by parents/ farmer 30 (26.8%) with a significant difference (χ^2 = 30.57, d.f.=2, p<0.0001). This was done to prevent diarrhoea in rabbits as respondents added.

Table 4.6: Rabbit feeding

Question	Attribute	F	% f	Chi square (χ^2)
Do you give your rabbits water to drink	Yes	14	13.2	χ^2= 54.76 d.f.=1 p < 0.0001
	No	92	86.8	
	Total	106	100.0	
If no, why	They do not drink	73	79.3	χ^2= 29.96 d.f.=1 p < 0.0001
	They will diarrhoea	19	20.7	
	Total	92	100.0	
Mention the rabbit feed types you use for your rabbits	Commercial Pellets	30	26.8	χ^2= 80.36 d.f.=3 p < 0.0001
	Vegetables	68	60.7	
	Left over foods	3	2.7	
	All	11	9.8	
	Total	112	100.0	
If Commercial Pellets, where do you buy the?	Agro-Vet	23	76.7	χ^2= 29.16 d.f. =1 p< 0.0001
	Suppliers	7	23.3	
	Total	30	100.0	
If vegetables, where do you get them?	From individual as well as neighbours farm	61	89.7	χ^2= 64.0 d.f.=1 p < 0.0001
	Market vendors	7	10.3	
	Total	68	100.0	
Do you use wet vegetables as food for your rabbits?	Yes	11	16.4	χ^2= 46.24 d.f.=1 p < 0.0001
	No	56	83.6	
	Total	67	100.0	
How often do you feed your rabbits per day?	Continuous / ad libitum	28	25.5	χ^2= 24.02 d.f.=1 p < 0.0001
	Intervals	82	74.5	
	Total	110	100.0	
Who takes care of your rabbits (feeding, house cleaning)?	Farmer	30	26.8	χ^2= 4.99 d.f.=1 p < 0.0253
	Employee	14	12.5	
	Children	68	60.7	
	Total	112	100.0	

4.1.8 Production problems and diseases

Rabbit farmers indicated that they encountered problems while practicing rabbitry. These problems were diseases like diarrhoea and skin diseases 12 (10.7%) and predators such as dogs and mongooses 68 (60.7%), thieves (from other rabbit keepers) 14 (14.3%), mortality of the rabbits/ sudden deaths, and high costs of building materials

such as nails and iron sheets with a significant difference (χ^2 = 121.8180, d.f.=4, p< 0.0001) (Figure 4.2).

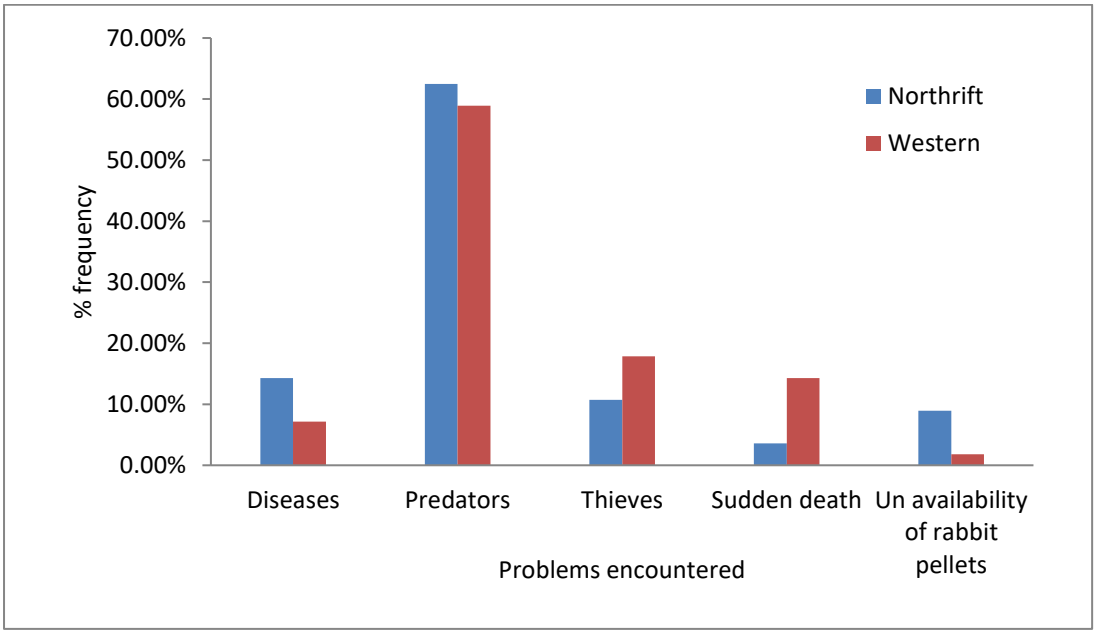

Figure 4.2: Rabbit production problems and diseases

For the management of diseases, most rabbit farmers indicated that they sought advice from other rabbit farmers (57.5%), agrovet staff (22.0%) and both (30.5%) with a significant difference (χ^2 = 19.1545, d.f.=2, p= 0.0001). Administration of drugs was done by farmers in their own premises. Not a single rabbit farmer was a member of a rabbit group organization in both regions (Figure 4.2).

4.2 Distribution and morphometric characteristics of domesticated rabbit breeds in North Rift and Western Kenya

4.2.1 Rabbit breeds distribution

There were eight rabbit breeds whose morphometric characteristics were explored. These were Agouti, Chinchilla, Dutch, Flemish giant, New Zealand white, Palomino,

Rex and Silver fox sourced from North Rift and Western Kenya. The two regions had same breeds of rabbits (χ^2=9.422, df=7, p=0.2240) (Figure 4.3). For the counties within the regions in which the breeds were collected, New Zealand white was found predominant with largest percentage in Baringo County (92.86%). Flemish giant was the second most predominant breed with the largest proportion collected from Vihiga (35.71%) and Nandi (35.71%) Counties. The least populous breed was Palmino which was only recorded in Bungoma County as illustrated in Figure 4.3. Significance difference was between the counties in the regions in which the breeds were collected (χ^2=77.1940, df=49, p=0.0060).

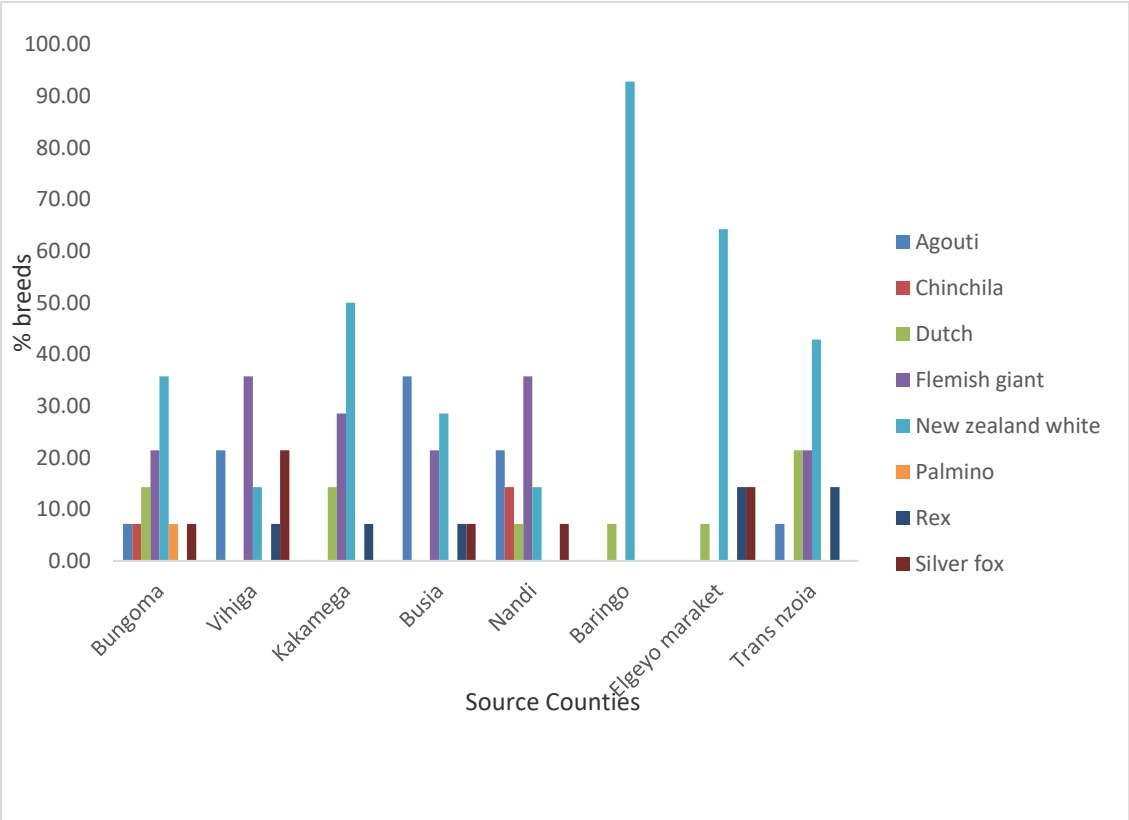

Figure 4.3: Distribution of rabbit breeds in various counties.

4.2.2 Morphometric characteristics of rabbit breeds

All morphometric measurements did not differ between the regions for breed ($p>0.05$). Body weight characteristic of the rabbit breeds was compared to establish if there was any significant difference in respect to the two regions. For Agouti (2.189±0.41) and Flemish Giant (2.27±0.33) breeds, sampled from Western Kenya had body weight as compared to those from Western Kenya ($p>0.05$). For Dutch (2.36±0.33), New Zealand white (2.16±0.37), Rex (2.25±0.57) and Silver Fox (2.58±0.35) breeds from Western Kenya had higher significant mean weight in kg compared with those from North Rift region ($p<0.05$) as illustrated in Table 4.7.

Table 4.7: Body weight characteristic of the rabbit breeds from the two regions

Breed	Region	Average±Sd	t- test	p- value
Agouti	North	1.77±0.22	-1.6223	0.1357
	West	2.189±0.41		
Chinchila	North	2.47±0.00	-	-
	West	2.73±0.81		
Dutch	North	1.61±0.29	-3.7498	0.0056
	West	2.36±0.33		
Flemish Giant	North	2.02±0.51	-1.4070	0.1740
	West	2.27±0.33		
New Zealand White	North	1.66±0.38	-4.4612	0.0001
	West	2.16±0.37		
Palmino	North	-		
	West	2.55±0.00		
Rex	North	1.49±0.44	-2.4587	0.0301
	West	2.25±0.57		
Silver Fox	North	1.65±0.52	-3.5748	0.0033
	West	2.58±0.35		

Analysis was carried out to determine if there was a significant difference in morphometric characteristics in rabbit breeds. Majority of characteristics did not differ between male and female rabbits. Female Agouti rabbits had larger ear length than males ($t = 2.3378$, $p= 0.0393$). New Zealand white females had significant larger weights than males ($t = 2.4226$, $p= 0.0194$). Chinchilla rabbit breed (51.00±4.15) had

higher significant body length (F=2.49, p=0.0356) than Flemish giant (43.43±3.27) (Table 4.8). In males' weight, Palomino (2.55±0.12) had the highest followed by Silver fox (2.49±0.57), New Zealand white and Dutch (1.92±0.48). There was a significant difference in males` weights (F=2.51, p=0.0274). For females, Chinchila (3.31±0.48) had the highest weight with a significant difference compared with other female breeds (F=2.87, p=0.0179) as illustrated in Table 4.8.

Table 4.8: Morphometric characteristics of rabbit breeds

	Category	Agouti	Chinchila	Dutch	Flemish giant	New Zealand white	Palomino	Rex	Silver fox	F	p-value
Body length (cm)	Male	45.83± 3.37	45.50± 0.71	45.50± 1.91	44.44± 4.88	43.07± 3.62	48.00± 0.00	46.00± 5.29	43.75± 2.22	1.01	0.4371
	Female	45.71± 4.15	51.00± 0.00[a]	46.67± 3.01	43.43± 3.27	46.74± 2.62	-	42.25± 6.13[b]	42.25± 6.85[b]	2.49	0.0356 *
	All	45.77 3.76	48.25± 0.71	46.08± 2.46	43.94± 4.08	44.90± 3.12	48.00± 0.00	44.13± 5.71	43.00± 4.53	1.102	0.367
Girth (cm)	Male	27.83± 1.60	26.50± 2.12	25.75± 1.71	24.33± 3.00	24.83± 2.45	23.00± 0.00	26.00± 1.73	26.50± 5.07	1.42	0.22
	Female	28.00 4.76	31.00± 0.00	29.00± 4.10	29.14± 4.82	28.37± 4.06	-	24.75± 6.95	28.00± 3.46	0.57	0.7498
	All	27.92± 3.18	28.75± 2.12	27.38± 2.90	26.74± 3.91	26.60± 3.25	23.00± 0.00	25.38± 4.34	27.25± 4.27	0.734	0.644
Belly (cm)	Male	27.67 3.88	28.00± 2.83	27.75± 3.40	24.44± 6.11	26.14± 3.90	25.00±0 .00	26.33± 2.31	26.00± 8.12	0.35	0.93
	Female	29.00±3. 00	42.00± 0.00	25.67± 3.27	26.57± 5.91	27.32± 4.66	-	24.00± 3.92	26.00 4.32	2.34	0.0463 *
	All	28.33 3.44	35.00± 2.83	26.71±3 .33	25.51±6. 01	26.73±4.2 8	25.00± 0.00	25.17±3 .11	26.00±6 .22	1.254	0.281
Leg (cm)	Male	7.50± 1.05	8.50± 0.71	8.75± 1.47	8.00± 1.32	7.86± 0.88	7.00± 0.00	8.00± 1.00	7.50± 1.73	0.80	0.5912
	Female	8.71± 1.98	8.00± 0.00	8.17± 1.47	7.14± 0.86	8.05± 1.43	-	8.00± 1.63	6.75± 0.96	1.18	0.3329
	All	8.11± 1.51	8.25± 0.71	8.46± 1.47	7.57± 1.09	7.96± 1.15	7.00± 0.00	8.00± 1.32	7.13± 1.34	1.285	0.265
Ear width (cm)	Male	5.33± 0.52	6.00± 1.41	5.75± 0.50	5.78± 1.20	5.97± 1.18	6.00± 0.00	5.67± 0.58	5.75± 0.50	0.08	0.9991
	Female	6.14± 1.07	6.00± 0.00	5.83± 0.41	6.21± 1.25	5.84± 0.83	-	5.50± 1.29	4.75± 0.96	1.29	0.2803
	All	5.74± 0.79	6.00± 1.41	5.79± 0.45	6.00± 1.23	5.90± 1.01	6.00± 0.00	5.58± 0.93	5.25± 0.73	0.642	0.72
Ear length (cm)	Male	8.83± 1.72	9.00± 1.41	10.50± 1.73	9.78± 0.67	9.31± 1.00	10.00± 0.00	10.67± 0.58	9.25± 0.50	1.63	0.1486
	Female	10.43± 0.53	11.00± 0.00	9.83± 1.33	9.21± 1.31	9.89± 1.15	-	9.50± 1.29	10.00± 1.15	1.62	0.1635
	All	9.63± 1.13	10.00± 1.41	10.17± 1.53	9.50± 0.99	9.60± 1.08	10.00± 0.00	10.08± 0.93	9.63± 0.83	0.474	0.851
Weight (kg)	Male	2.08± 0.42	2.32± 0.22	1.90± 0.56[b]	2.08± 0.56	1.73± 0.38[b]	2.55± 0.00[a]	2.11± 0.67	2.49± 0.57	2.51	0.0274 *
	Female	1.93± 0.57[b]	3.31± 0.00[a]	1.92± 0.48[b]	2.26± 0.29	2.03± 0.51	-	1.49± 0.44[c]	2.13± 0.52	2.87	0.0179 *
	All	2.01± 0.49	2.81± 0.22	1.91± 0.52	2.17± 0.43	1.88± 0.44	2.55± 0.00	1.80± 0.56	2.31± 0.54	3.035	0.006*

*p- values with * are significant*

4.3 Growth performance and feed conversion of domesticated rabbit breeds in North Rift and Western Kenya

4.3.1 Litter size at birth of domesticated rabbits breeds crosses

When the litter size at birth was determined it was established that the average litter size for the crosses was 7.10±1.44 kits per cross. NZW*KALRO had the highest litter size of 10 kits followed by NZW*DR (8) while NZW*SF, NZW*R, and NZW*FG had a litter size of 6 in each with a significant difference ($F_{0.05\,(9,\,20)}$ =5.87, p=0.0005). Litter size had significant effect on domesticated rabbit breeds crosses body weight at all ages.

4.3.2 Body weight of domesticated rabbit crosses from birth to four weeks old (BW0-BW4)

At birth, NZW*KALRO cross had the highest body weight (53.00±4.83) g followed by NZW*DR (50.00±0.00) g, NZW*R (50.00±0.00) g and NZW*P (50.00±0.00) g while NZW*FG cross had the lowest weight (38.57±13.45) g at birth with a significant difference ($F_{0.05\,(9,\,63)}$ =8.05, p<0.0001). Crosses differed in mean weights BW1 age, with NZW*KALRO (81.90±4.53) having the highest while NZW*SF (60.00±0.00) cross having the lowest weight with a significant difference ($F_{0.05\,(9,\,61)}$ =3.30, P<0.0001). In BW2 significant difference was observed between NZW*SF and NZW*R (p<0.05) in BW3 and BW4, but no significant difference in mean was recorded between the crosses as illustrated in Table 4.9.

Table 4.9: Pre-Weaning Body Weight of domesticated rabbit breed crosses

Crosses	BW0	BW1	BW2	BW3	BW4
NZW*FG	38.57± 13.45^{a}	61.67± 7.53^{abc}	84.33± 11.87^{ab}	131.00± 3.22^{a}	163.33± 24.47^{a}
NZW*SF	40.00± 0.00^{b}	60.00± 0.00^{ab}	88.50± 3.99^{a}	128.33± 0.82^{b}	208.33± 0.82^{bcd}
NZW*DR	50.00± 0.00^{c}	80.00± 0.00^{d}	113.00± 0.00^{bcd}	148.00± 0.00^{ab}	228.00± 0.00^{cd}
NZW*R	50.00± 0.00^{c}	80.00± 0.00^{d}	114.43± 0.98^{bcd}	149.14± 1.07^{ab}	229.43± 0.98^{d}
NZW*P	50.00± 0.00^{c}	78.57± 3.78^{cd}	110.43± 6.80^{bc}	145.43± 6.80^{ab}	192.86± 81.67^{abc}
NZW*KALRO	53.00± 4.83^{cd}	81.90± 4.53^{bcd}	110.40± 36.28^{ab}	149.30± 25.02^{a}	230.30± 36.21^{d}
F-Ratio	8.05	3.30	5.14	0.86	3.32
p-Value	0.0000	0.0000	0.0000	0.5791	0.0023

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Agricultural and Livestock Research Organisation, SF- silver fox, P- Palomino, DR- Dutch. Means with similar superscripts within each column do not differ significantly at 0.05.

4.3.3 Body weight of domesticated rabbit crosses for Wk5 to Wk8 in grams

Assessment of weaners body weight for the BW5 age showed that NZW*R cross had the highest body weight (434.33±94.04) followed by NZW*P (326.25± 30.91). Cross NZW*SF (256.67±4.08) recorded the lowest body weight with a significant difference ($F_{0.05\ (9,\ 55)} = 19.24$, $p < 0.0000$) as illustrated in Table 4.10. Crosses did not differ in mean body weight for BW6, BW7 and BW8 ages as shown in Table 410.

Table 4.10: Weaners age body weight (BW5-BW8) in grams of domesticated rabbit breed crosses

Crosses	n	BW5	n	BW6	n	BW7	n	BW8
NZW*FG	6	284.83± 5.31^{abc}	6	284.83± 5.31^{abc}	6	453.50± 32.63^{bc}	6	587.67± 6.31^{ab}
NZW*SF	6	256.67± 4.08^{a}	7	255.00± 4.47^{a}	6	273.33± 157.41^{a}	6	560.00± 5.48^{a}
NZW*DR	6	301.67± 33.48^{bcd}	9	301.67± 33.48^{bc}	6	461.67± 33.48^{bc}	6	606.67± 33.48^{abc}
NZW*R	6	434.33± 94.04^{f}	6	434.33± 94.04^{e}	6	590.17± 94.70^{e}	6	735.17± 87.48^{d}
NZW*P	7	308.00± 3.65^{cd}	7	308.00± 3.65^{c}	7	469.14± 1.07^{bc}	7	612.29± 5.50^{abc}
NZW*KALRO	7	274.29± 1.89^{ab}	9	274.29± 1.89^{ab}	9	406.43± 50.64^{b}	7	554.29± 45.96^{a}
F-Ratio		19.24		24.36		13.59		7.65
p-Value		< 0.0001		< 0.0001		<0.0001		<0.0001

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.
Means with similar superscripts within each column do not differ significantly at 0.05

4.3.4 Growers body weight (Wk9-Wk12) in grams of domesticated rabbit crosses

Domestic rabbit crosses (Growers BW9-BW12) were assessed for body weight in grams. NZW*R weight (834.00±10.96) at age BW9 differed significantly ($F_{0.05(9, 55)}$ = 8.48, P<0.0001) with those of other crosses except NZW*R cross (847.67±94.04) as illustrated in Table 4.11.

Table 4.11: Growers body weight (BW9-BW12) in grams

Crosses	n	BW9	n	BW10	n	BW11	n	BW12
NZW*FG	6	733.17± 5.31^{abc}	6	879.00± 5.10^{abc}	6	1027.67± 6.31^{ab}	6	1177.67± 6.31^{ab}
NZW*SF	6	705.00± 4.08^{ab}	6	849.17± 6.65^{ab}	6	998.33± 5.16^{ab}	6	1214.17± 164.57^{abc}
NZW*DR	6	748.33± 33.48^{bcd}	6	896.67± 33.48^{bcd}	6	1046.67± 33.48^{abc}	6	1196.67± 33.48^{ab}
NZW*R	6	847.67± 94.04^{f}	6	992.67± 80.83^{e}	6	1147.67± 98.77^{de}	6	1291.00± 82.31^{bc}
NZW*P	7	758.71± 3.65^{cd}	7	904.43± 98.21^{cd}	7	1054.43± 0.98^{bc}	7	1204.43± 0.98^{ab}
NZW*KALRO	7	699.29± 18.9^{a}	7	844.29± 45.96^{a}	7	992.14± 47.77^{a}	7	1229.29± 232.91^{abc}
F-Ratio		8.48		12.33		8.09		1.54
p-Value		<0.0001		<0.0001		<0.0001		0.1557

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.
Means with similar superscripts within each column do not differ significantly at 0.05

4.3.5 Sub adults body weight (BW13-BW16) in grams

There was a significant difference in BW13 age in weight with NZW*R cross recording the highest weight (1406.00±143.84) while NZW*SF recorded the lowest (1301.67±5.16) with a significant difference ($F_{0.05\,(9,\,55)}$ =4.45, p=0.0002). The same trend was observed at the age of 15th week with NZW*R crosses (1806.33±190.69) recording the highest while NZW*FG (1717.67±23.91) recorded the lowest with a significant difference ($F_{0.05\,(9,\,55)}$ =2.20, p=0.0342). NZW*SF and NZW*R crosses had the highest mean body weights at BW15 age. Domestic rabbit crosses sub adults body weight did not differ significantly at BW14 ($F_{0.05\,(9,\,55)}$ =1.93, p=0.0651) and BW16 ($F_{0.05\,(9,\,55)}$ =2.00, p=0.0565) ages (Table 4.13).

Table 4.13: Sub adults body weight (BW13-BW16) in grams

Crosses	n	BW13	n	BW14	n	BW15	n	BW16
NZW*FG	6	1336.00± 17.41^{ab}	6	1537.33± 20.56^{ab}	6	1717.67± 23.91^{a}	6	1899.33± 73.33^{a}
NZW*SF	6	1301.67± 5.16^{a}	6	1665.00± 255.66^{ab}	6	1746.67± 33.47^{a}	6	1899.00± 5.47^{ab}
NZW*DR	6	1346.67± 33.48^{ab}	6	1546.67± 33.48^{ab}	6	1746.67± 33.48^{a}	6	1946.67± 33.48^{ab}
NZW*R	6	1406.00± 143.84^{b}	6	1589.33± 163.20^{ab}	6	1806.33± 190.69^{ab}	6	2088.00± 322.27^{bc}
NZW*P	7	1354.43± 0.98^{ab}	7	1554.43± 0.98^{ab}	7	1754.43± 0.98^{a}	7	1954.43± 0.98a^{ab}
NZW*KALRO	6	1305.83± 10.68^{a}	6	1505.83± 10.68^{ab}	6	1705.83± 10.68^{a}	6	1905.83± 10.68^{ab}
F-Ratio		4.45		1.93		2.57		2.27
p-Value		0.0002		0.0651		0.0141		0.0307

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.
Means with similar superscripts within each column do not differ significantly at 0.05

4.3.6 Feed conversion of domesticated rabbit cross breeds

Initial mean body weight was recorded for NZW*R crosses with an average weight of 434.33±94.04 while NZW*FG and NZW*SF crosses recorded the lowest average weights of 284.83±5.31 and 256.67±4.08 g respectively. There was a significant difference in initial mean body weight of weaners rabbits' ($F_{0.05\ (9,\ 55)}$ =19.24, p <0.0001). Final body weight gain was highest in NZW*R and NZW*P crosses with averages of 735.17±87.48 and 612.29±5.50 respectively and lowest in NZW*KALRO (554.29±45.96) with a significant different ($F_{0.05\ (9,\ 55)}$ =7.65, p <0.0001). Weekly mean weight gains among the crosses did not differ significantly (p>0.05) irrespective of NZW*KALRO cross recording the lowest average of 280.00±21.89 (Table 4.14). Similarly, the mean daily weight gain, 100% mean daily feed intake and Feed conversion efficiency did not differ significantly among the weaners rabbit crosses as illustrated in the Table 4.14.

Table 4.14: Feed conversion ratio of weaners rabbits on concentrate ration

	NZW*FG	NZW*SF	NZW*DR	NZW*R	NZW*P	NZW*KALRO	p-value
Initial mean body weight	284.83± 5.31^{abc}	256.67± 4.08^{a}	301.67± 33.48^{bcd}	434.33± 94.04^{f}	308.00± 3.65^{cd}	274.29± 1.89^{ab}	0.00
final body weight	587.67± 6.31^{ab}	560.00± 5.48^{a}	606.67± 33.48^{abc}	735.17± 87.48^{d}	612.29± 5.50^{abc}	554.29± 45.96^{a}	0.00
Weekly mean weight gain	302.84± 41.31^{a}	303.33± 30.08^{a}	305.00± 32.48^{a}	300.84± 34.04^{a}	304.29± 30.65^{a}	280.00± 21.89^{ab}	>0.05
mean daily weight gain	10.82± 0.42^{a}	10.83± 0.31^{a}	10.89± 0.80^{a}	10.74± 0.65^{a}	10.87± 0.44^{a}	10.00± 0.20^{a}	>0.05
100% mean daily feed intake	31.37± 1.00^{a}	29.25± 2.12^{ab}	30.50± 3.16^{a}	31.16± 6.70^{a}	29.34± 3.21^{ab}	31.00± 6.70^{a}	>0.05
Feed conversion efficiency	2.90± 0.04^{a}	2.70± 0.02^{a}	2.80± 0.03^{a}	2.90± 0.05^{a}	2.70± 0.05^{a}	3.10± 0.02^{ab}	>0.05

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.
Means with similar superscripts within each row do not differ significantly at 0.05

For growers, Initial mean body weight differed among the crosses with NZW*R (847.67±94.04) having the highest average weight followed by NZW*P (758.71± 3.65) while NZW*KALRO recorded the lowest weight of 699.29±18.9 ($F_{0.05\ (9,\ 55)}$ =19.24, $p<0.0001$). Final body weight showed the same trend with NZW*R, NZW*P and NZW*KALRO having the highest average weights of 1291.00±82.31, 1204.43±0.98, 1204.43±0.98 and 1229.29±232.91 respectively with no significant difference with those that had the lowest average weights ($p>0.05$). Mean daily weight gain, 100% mean daily feed intake and Feed conversion efficiency were all significant among the rabbit crosses ($p<0.05$) as illustrated in Table 4.15.

Table 4.15: Feed Conversion Ratio of Growers rabbits on concentrate ration

	NZW*FG	NZW*SF	NZW*DR	NZW*R	NZW*P	NZW* KALRO	F-Ratio
Initial mean body weight	733.17± 5.31abc	705.00± 4.08ab	748.33± 33.48bcd	847.67± 94.04f	758.71± 3.65cd	699.29± 18.9a	<0.0001
Final body weight	1177.67± 6.31ab	1214.17± 164.57abc	1196.67± 33.48ab	1291.00± 82.31bc	1204.43± 0.98ab	1229.29± 232.91abc	0.1557
Mean weight gain	444.50± 5.62	509.17± 5.51	448.34± 6.00	443.33± 5.85	445.72± 5.64	530.00± 5.40	>0.05
Mean daily weight gain	15.88± 4.97	18.18± 5.12	16.01± 6.16	15.83± 6.70	15.92± 3.21	18.93± 6.70	<0.0001
100% mean daily feed intake	68.26± 13.04	80.01± 12.78	80.06± 13.92	66.50± 13.57	60.49± 13.08	115.46± 12.53	<0.0001
Feed Conversion Efficiency	4.30± 0.04	4.40± 0.08	5.00± 0.06	4.20± 0.05	3.80± 0.09	6.10± 0.02	<0.0001

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.
Means with similar superscripts within each column do not differ significantly at 0.05

Feed conversion was assessed for all crosses at 16th week. Initial body weight was high in NZW*R (1406.00±143.84) followed by NZW*P (1354.43±10.98) and NZW*DR (1346.67±33.48) and low by NZW*KALRO (1305.83±10.68) and NZW*SF (1301.67±5.16) with a significant difference ($F_{0.05\ (9,\ 55)} = 4.45$, $p = 0.0002$). Mean significant difference was between NZW*SF and NZW*R as summarized in Table 4.16.

The assessed final weight gain was high in NZW*R with average mean weight of 2088.00±322.27 followed by NZW*P with a mean of 1954.43±0.98 while the lowest mean was recorded for NZW*FG (1899.33±73.33) and NZW*SF (1899.00±5.47) with a significant difference ($F_{0.05\ (9,\ 55)} = 2.27$, $p = 0.0307$). There was a significant difference between NZW*R, NZW*FG. For the mean weight gain, NZW*P recorded the highest of 682.00±16.80 followed by NZW*DR (642.33±18.80) and NZW*SF (610.71±12.44) while NZW*FG (600.00±10.00), NZW*R (600.00±10.00) and NZW*KALRO (563.33±19.81) recorded the lowest weight gain with no significant difference ($F_{0.05\ (9,\ 55)} = 0.69$, $p = 0.7111$).

NZW*P and NZW*DR cross breeds had the highest mean daily weight gain of 24.36±9.17 and 22.94±2.46 while NZW*KALRO (20.12±3.21), NZW*FG (21.43±0.00) and NZW*R (21.43±0.00) had the lowest non significant mean daily weight gain ($F_{0.05\ (9,\ 55)}$ =0.69, p =0.7111). The assessed mean daily feed intake was highest in NZW*R (122.92±5.00) followed by NZW*DR (121.17±4.50) and NZW*SF (118.70±5.50) but significantly low in NZW*P (103.61±4.50) cross breed ($F_{0.05\ (9,\ 55)}$ =105.10, p =0.7111).

For the Feed Conversion Efficiency, all the cross breeds did not differ significantly in irrespective of NZW*FG, NZW*SF, NZW*D, NZW*R and NZW*KALRO having conversion efficiencies of more than 5.00 as summarized in Table 4.16.

Table 4.16: Feed Conversion Ratio of Sub adults' rabbits on concentrate ration

	NZW*FG	NZW*SF	NZW*DR	NZW*R	NZW*P	NZW*KALRO	p -value
Initial mean body weight	1336.00± 17.41ab	1301.67± 5.16a	1346.67± 33.48ab	1406.00± 143.84b	1354.43± 10.98ab	1305.83± 10.68a	0.0002
final body weight gain	1899.33± 73.33a	1899.00± 5.47ab	1946.67± 33.48ab	2088.00± 322.27bc	1954.43± 0.98ab	1905.83± 10.68ab	0.0307
mean weight gain	600.00± 10.00a	610.71± 22.44ab	642.33± 18.80b	600.00± 10.00a	682.00± 16.80c	563.33± 19.81d	0.0111
mean daily weight gain	21.43± 0.00a	21.81± 0.80a	22.94± 2.46a	21.43± 0.00a	24.36± 9.17ab	20.12± 3.21a	0.7111
100% mean daily feed intake	114.50± 6.00a	118.70± 5.50ab	121.17 4.50b	122.92± 5.00b	103.61± 4.50a	115.95± 7.00b	0.00
Feed Conversion Ratio	5.34±0.04	5.44±0.05	5.28±0.03	5.73±0.05	4.25±0.45	5.76±0.03	>0.05

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.
Means with similar superscripts within each row do not differ significantly at 0.05

4.4 Genetic diversity of domesticated rabbit breeds in North Rift and Western Kenya

4.4.1 Marker Genotyping

The summary statistics of genetic diversity are presented in Table 4.17 indicated that the observed number of alleles for all the microsatellites was 2.0 while the effective number of alleles ranged between 1.357 and 1.916 for markers SOL30 and SAT3 respectively with a mean value of 1.65. The mean values of Ho and He recorded in the study were 0.903 and 0.89 respectively. Ho and He values above 50 percent, highlight higher genetic diversity across the studied rabbit ecotypes, and inform that the genetic fidelity of the rabbit populations is well managed and the rate of genetic erosion is low. Nei's genetic diversity indices varied from 0.335 to 0.578 for markers SOL30 and SAT8 respectively with a mean of 0.353. All the microsatellite markers used in the study were polymorphic and polymorphic indices ranging between 0.651 and 0.98 for markers SAT3 and SAT8 respectively with a mean of 0.808. These high microsatellite polymorphism values are an indicator that the markers used in the study have a higher resolution for segregating closely related ecotypes (Table 4.17).

Table 4.17: Summary statistics of genetic diversity and Microsatellite polymorphism

Locus	Sample size	na*	ne*	h*	I*	Ho	He	PIC
SAT3	64	2	1.733	0.523	0.614	0.824	0.865	0.651
SAT8	64	2	1.916	0.578	0.671	0.633	0.898	0.982
SAT12	64	2	1.496	0.283	0.457	1.000	0.971	0.678
SOL3	64	2	1.882	0.469	0.661	1.000	0.893	0.816
SOL8	64	2	1.544	0.508	0.486	1.000	0.892	0.915
SOL28	64	2	1.600	0.375	0.562	1.000	0.836	0.784
SOL30	64	2	1.357	0.335	0.261	0.867	0.913	0.832
Mean	***64***	***2***	***1.647***	***0.439***	***0.530***	***0.903***	***0.890***	***0.808***
Std dev	***0***	***0***	***0.178***	***0.094***	***0.124***	***0.121***	***0.036***	***0.102***

**na = Observed number of alleles; * ne = Effective number of alleles; * h = Nei's (1973) gene diversity; * I = Shannon's Information index (Lewontin (1972), Ho = Observed Heterozygosity; He = Expected Heterozygosity; PIC = Polymorphic information content.*

4.4.2 Genetic differentiation among and within the population

Results of the Analysis of Molecular Variance, (AMOVA) summarized in Table 4.18 shows that the genetic differentiation measured among Counties was 4%, while 96% of the genetic variation was attributed to within county genetic diversity.

Table 4.18: Genetic differentiation among and within the population

Source	Df	MS	Est. Var	%
Among counties	7	4.361	0.027	4
Within counties	7	4.033	0.142	96
Total	14		3.919	100

Df= Degree of freedom; MS= Mean square; Est. Var = Estimated variance.

4.4.3 Factorial analysis

Genetic segregation of the individuals and population structure of the rabbit ecotypes within and between the counties was analyzed using factorial analysis. Factorial coordinates of the individuals were derived from the dissimilarity matrix that was calculated from raw SSR gel scores “1” and “0” matrix. Factorial analysis segregated the samples into three main groups without any pattern as illustrated in Figure 4.4. Majority of the samples segregated at one matrix and these were those that came from BN, BS, EM, BR, KR, TN. A small group consisted of KK, KR and BN, although they segregated far apart.

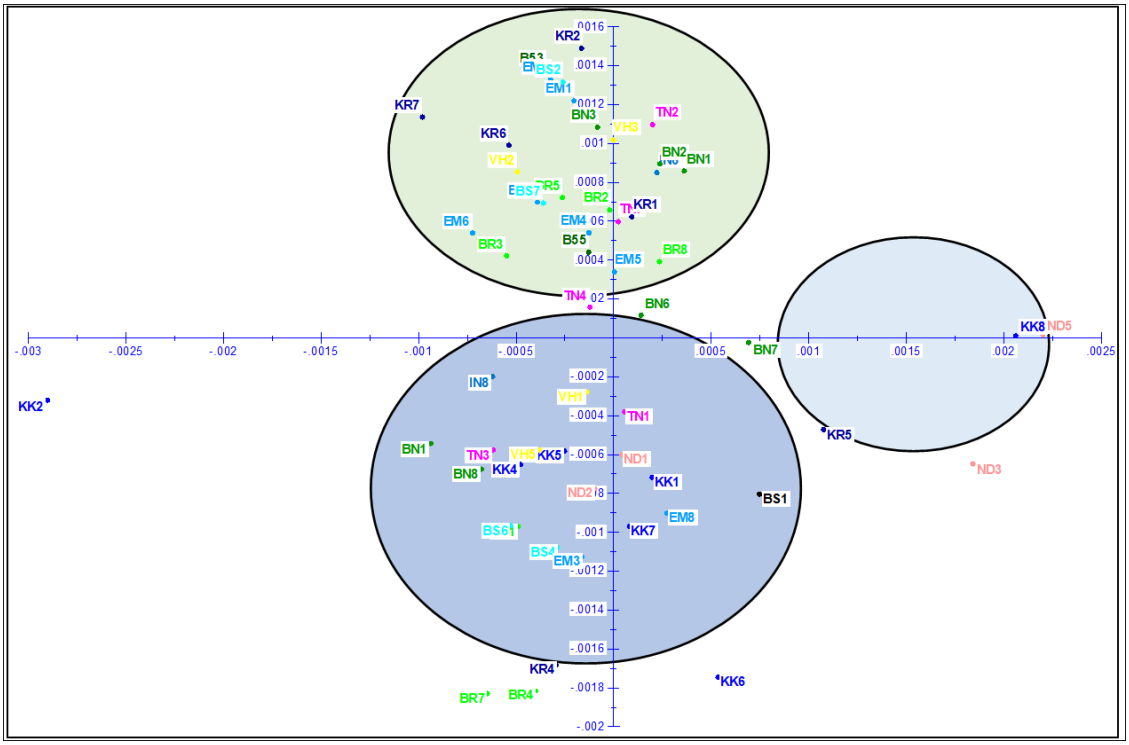

Figure 4.4: Factorial analysis

4.4.4 Neighbour joining tree for phylogenetic relationships among samples of *Oryctolagus cuniculus*

Alleles of *Oryctolagus cuniculus* samples from eight locations in Kenya (BN; Bungoma, ND; Nandi, TR; Trans Nzoia, BS; Busia, KK; Kakamega, VH; Vihiga, and EM; Elgeyo Marakwet) were used to identify three genetic groupings (Figure 4.5).

4.4.5 Phylogenetic Analysis

A dendrogram was constructed using the Unweighted Neighbor-Joining method with 1000 bootstrap replicates in Darwin 6.0.21. The minimum dissimilarity value recorded in the study was 1.5 while the maximum value was 2. Basing on similarity coefficient of 1.8 Phylogenetic analyses grouped the 64 ecotypes into four clusters without regard to the county of collection. This may be explained by inbreeding and transfer of the rabbits across counties. Cluster 1 comprised of the BR and BN population also included

haplotypes from cluster three. The second cluster comprised haplotypes of all population. Cluster 3 comprised BN, BR and KK and included samples from cluster one. Both factorial and dendrogram population analyses showed that the genetic background of the rabbits in Kenya is mixed as illustrated in Figure 4.5.

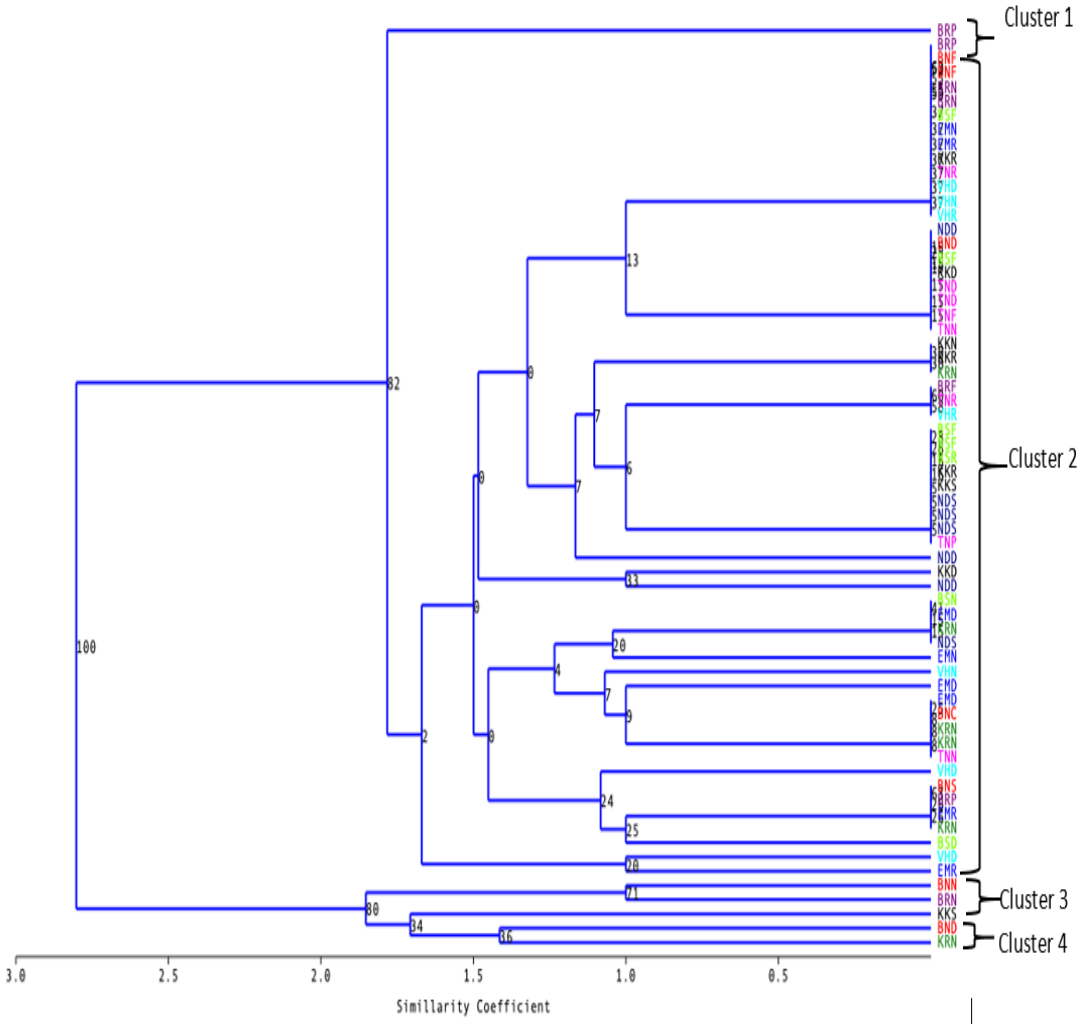

Figure 4.5: Dendrogram showing clustering of Kenya rabbit ecotypes

4.5 Domestic rabbit (*Oryctolagus cuniculus*) crosses' carcass and meat quality traits

4.5.1 Carcass characteristics of rabbits crosses

Live weights before fasting were non significantly high in NZW*SF (2319±164) and low in NZW*FG (2188±156). Live weight of rabbits after 12hrs fasting (pre slaughter weight followed the same trend (Table 4.19). Fasting loss did not significantly differ among the crosses. The weight after breeding determined showed the highest non-significant weight ($p>0.05$) was recorded for NZW*SF (2203±206) with the lowest recorded in NZW*FG (2066±151). In terms of hot carcass weight, NZW*R (1083±96.0) cross had non significant higher weight in comparison to other crosses. Giblets- liver heart and kidneys weight did not differ among crosses irrespective of NZW*P (89.5±7.65) having a higher weight. A higher dressed weight of the head was recorded for NZW*SF (147±16.2) non significantly different with other crosses ($p>0.05$). Similarly, total edible parts, dressing yield, carcass %, carcass with giblets and dressed head, % inedible parts, pelt, feet and tail, spleen, lungs and trachea, inedible parts of the head and the ratio between inedible and edible did not differ among the crosses as illustrated in Table 4.19.

Table 4.19: Carcass characteristics of rabbit crosses (Mean ± SE)

Parameters (weight grams)	NZW*FG	NZW*SF	NZW*DR	NZW*R	NZW*P	NZW*KALRO
Live weight before fasting,	2188 ±161	2319±214	2253 ± 128	2267 ± 195	2273 ± 284	2270 ± 164
Fasted Rabbit weight (g) before slaughter	2129 ± 156	2270 ± 213	2200 ± 127	2218 ± 194	2218 ± 280	2218 ± 163
Fasting loss,	58.3±5.87	49.2 ± 2.01	48.8 ± 1.75	48.3 ± 3.07	55.0 ± 5.00	51.7 ± 2.97
	(2.65±0.13)	(2.25±0.21)	(2.45±0.13)	(2.26±0.20)	(2.63±0.28)	(2.44±0.17)
Weight after bleeding, g	2066 ± 151	2203 ± 206	2135 ± 123	2154 ± 187	2158 ± 272	2156 ± 158
Edible parts						
Hot carcass,	1012 ± 72.1	1070 ± 114	1041 ± 64.9	1083 ± 96,0	1050 ± 138	1067 ± 80.1
	(47.6±0.22)	(46.9±0.92)	(47.2±0.46)	(48.9±1.34)	(47.1±0.68)	(48.0±0.76)
Giblet – liver, heart and kidneys,	81.0 ± 7.69	87.8 ± 8.41	84.4 ± 5.53	84.8 ± 5.64	89.5 ± 7.65	87.0 ± 4.58
	(3.77±0.11)	(3.89±0.15)	(3.83±0.09)	(3.88±0.16)	(4.28±0.47)	(4.08±0.25)
Dressed head,	127 ± 5.02	147 ± 16.2	137 ± 8.65	143 ± 13.5	134 ± 11.8	139 ± 8.65
	(6.07±0.33)	(6.70±0.92)	(6.38±0.48)	(6.49±0.29)	(6.27±0.36)	(6.38±0.22)
Total edible parts,	1220 ± 83.4	1305 ± 122	1262 ± 71.5	1311± 113	1274 ± 155	1292 ± 91.7
	(57.4±0.33)	(57.5±0.47)	(57.4±0.27)	(57.3±2.13)	(57.7±0.61)	(57.5±1.06)
Dressing yield						
Carcass, %	47.6 ± 0.22	46.9 ± 0.92	47.2 ± 0.46	48.9 ± 1.34	47.1 ± 0.68	48.0 ± 0.76
Carcass with giblet, %	51.9 ± 0.90	50.8 ± 0.88	51.4 ± 0.62	52.8 ± 1.44	51.4 ± 0.43	52.1 ± 0.74
Carcass with giblet and dressed head, %	57.1 ± 0.25	57.5 ± 0.33	57.3 ± 0.26	59.3 ± 1.59	57.7 ± 0.61	58.5 ± 0.85
Inedible parts						
Blood,	63.2 ± 4.29	67.0 ± 7.17	65.1 ± 4.03	63.9 ± 6.90	60.5 ± 8.29	62.2 ± 5.17
	(2.97±0.05)	(2.85±0.12)	(2.91±0.06)	(2.8 ±0.08)	(2.70±0.07)	(2.78±0.05)
Pelt,	179 ± 14.4	205 ± 20.9	192 ± 12.7	214 ± 27.6	195 ± 24.3	205 ± 17.7
	(8.37±0.10)	(9.03±0.42)	(8.70±0.23)	(9.47±0.56)	(8.93±0.46)	(9.20±0.35)
Feet and tail,	80.0 ± 1.50	89.5± 3.07	84.8 ± 2.17	92.7 ± 4.64	82.8 ± 4.38	87.8 ± 3.39
	(3.88±0.34)	(4.12±0.42)	(4.00±0.26)	(4.31±0.34)	(4.17±0.70)	(4.24±0.37)
Spleen,	1.67 ± 0.25	2.33 ± 0.36	2.00 ± 0.23	1.83 ± 0.10	1.75 ± 0.33	1.79 ± 0.17
	(0.08±0.01)	(0.11±0.01)	(0.09±0.01)	(0.08±0.002)	(0.08±0.01)	(0.08±0.004)
Lungs and trachea,	17.5 ± 1.67	18.3 ± 2.20	17.9 ± 1.32	14.8 ± 1.25	18.3 ± 1.82	16.6 ± 1.18
	(0.82±0.03)	(0.80±0.04)	(0.81±0.02)	(0.67± 0.23)	(0.86±0.08)	(0.77 ± 0.05)
G.I. tract full,	249 ± 27.2	255 ± 15.7	252 ± 15.0	268 ± 11.3	245 ± 18.17	257 ± 10.8
	(11.5±0.64)	(11.4±0.39)	(11.5± .36)	(12.5± 0.90)	(11.7±1.00)	(12.1± 0.65)
Inedible parts of head,	74.8 ± 4.85	88.83± 12.8	81.8 ± 6.84	76.2 ± 7.89	72.3 ± 9.70	74.3 ± 5.99
	(3.54±0.11)	(3.84± .22)	(3.69± .13)	(3.41 ± 0.18)	(3.30±0.22)	(3.35± 0.14)
Total inedible parts,	675 ± 44.8	726 ± 57.2	703 ± 34.1	732 ± 55.2	673± 57.4	702± 39.0
	(31.8±0.38)	(32.2±0.69)	(32.0±0.38)	(33.3±0.92)	(31.6±2.05)	(32.4± .10)
Inedibles:	1: 1.82 ± 0.02	1: 1.79 ± 0.04	1: 1.80 ± 0.02	1: 1.79 ± 0.08	1: 1.86 ± 0.10	1: 1.82 ± 0.06

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.Numbers in the parenthesis are in mean grams of live weight before slaughter (fasted weight). Figures in parenthesis indicate weight of organs in percentage (%) of live weight before fasting.

4.5.2 Primal cut-up parts of domestic rabbit crosses carcass

Primal cut up parts of rabbit crosses carcasses were established. For the initial hot carcass weight, NZW*SF (1070.56±114.53), NZW*R (1083.85±96.05) and NZW*KALRO (1067.36±80.15) had the highest weight significantly different in comparison with other crosses as illustrated in Table 4.20. NZW*KALRO (165.71 ±18.26) and NZW*R (160.44 ± 17.27) and had the highest weights of two shoulders significantly ($p<0.05$) different with others crosses. Thorax weight of NZW*KALRO was significantly low in comparison with other crosses ($p<0.05$) as illustrated in Table 4.20. NZW*R (351.87 ± 29.60), NZW*P (321.42±32.01) and NZW*KALRO (318.36±28.09) had the highest mean loin weight in comparison with the other crosses while NZW*P (364.35 ± 43.12) and NZW*SF (352.24±54.79) had higher mean leg weights as illustrated in Table 4.20.

Table 4.20: Primal cut-up parts of rabbit crosses carcass

	NZW*FG	NZW*SF	NZW*DR	NZW*R	NZW*P	NZW*KALRO
Hot carcass weight, g	1012.67± 72.14a	1070.56± 114.53b	1041.45± 64.98ab	1083.85± 96.05c	1050.62± 73.45a	1067.36± 80.15b
Two shoulders, g	146.24 ± 14.69a (14.43± 4.21)	152.32± 17.72ab (14.21± 2.52)	147.21 ± 13.81a (14.12± 3.28)	160.44 ± 17.27c (14.77± 2.19)	149.32 ± 16.45a (14.19± 3.00)	165.71 ± 18.26c (15.46± 2.88)
Thorax, g	218.67± 22.44a (21.54± 2.56)	222.64± 22.34ab (20.75± 2.33)	227.76 ± 22.11ab (21.81± 3.21)	216.99 ± 19.33a (19.94± 2.87)	215.66 ± 20.13a (20.48± 2.63)	209.56± 19.89c (19.53± 3.56)
Loin, g	321.11± 19.10a (31.5± 0.69)	319.09± 26.23a (29.8± 1.32)	339.56 ± 31.56ab (30.7± 0.76)	351.87 ± 29.60c (33.3± 1.01)	321.42± 32.01c (29.7± 1.44)	318.36± 28.09c (31.5± 0.99)
Two legs, g	313.02± 23.84a (30.93± 2.29)	364.35 ± 43.12b (34.02± 3.13)	339.65 ± 24.71c (32.56± 3.56)	344.59 ± 35.06c (31.76± 4.84)	352.24 ± 54.79b (33.52± 3.74)	348.56± 31.04bc (32.61± 3.76)
Cutting loss, g	14.21± 1.23a (1.38± 0.98)	13.34± 1.56a (1.21± 0.95)	12.00 ± 2.86a (1.15± 0.56)	12.78± 3.81a (1.11± 0.22)	13.26 ± 2.99a (1.241± 0.61)	27.55± 4.02b (2.53± 0.33)

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.
(Figures or numbers in the bracket indicate mean % and SE of hot carcass weight)

4.5.3 Meat bone ratio of rabbit crosses carcass (Mean ± SE)

Weight of hind leg muscle was determined for all crosses. For the weight of the two hind legs, NZW*SF (364 ± 43.1) had non-significant higher weight (p>0.05) followed by NZW*P (352.2 ±54.7) while NZW*FG (313±23.8) had the lowest weight. Muscle weight did not differ among the crosses (p>0.05) irrespective of NZW*P having the weight of 26.59±1.96 in comparison with that of NZW*FG (24.80±1.99). None significantly higher bone ratio was recorded in NZW*KALRO (5.98:1) followed in NZW*D with a ratio of 5.78:1 while NZW*FG had the lowest ratio of 5.31:1 as illustrated in Table 4.21.

Table 4.21: Meat bone ratio of rabbit crosses carcass (Mean ± SE)

	NZW*FG	NZW*SF	NZW*Dr	NZW*R	NZW*P	NZW*KALRO
Weight of two hind legs (g)	313.02±23.8	364.35 ± 43.1	339.65 ± 24.7	344.59 ± 35.0	352.24 ±54.7	348.56 ± 31.0
Weight of one hind leg (g)	156.50±14.91	182.00±17.4	169.50±15.62	172.00±13.41	176.00 ±14.21	174.00±16.31
Muscle weight (g)	131.70±12.11	155.00±13.21	144.50±14.28	145.58±15.44	149.41 ±16.02	149.08±13.51
Bone weight (g)	24.80±1.99	27.00±2.31	25.00±2.00	26.42±3.10	26.59±1.96	24.92±2.51
Meat bone ratio	5.31	5.74	5.78	5.51	5.62	5.98

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.

4.6 Influence of domestic rabbit breed crosses on the organoleptic properties of meat

The ranking of the flavour, tenderness, juiciness, texture, colour as well as acceptability of meat from New Zealand cross with other breeds was not statistically significant (P>0.05). NZW*P meat was ranked high in Texture (6.74±2.21), while NZW*FG was ranked high in tenderness (6.78±1.85). Ranking of color was high in NZW*P

(2.47±1.03) and low in NZW*R (1.87±0.74). General acceptability was ranked high in NZW*SF (7.08±2.27) (Table 4.22).

Table 4.22: Influence of domestic rabbit breed crosses on the organoleptic properties of meat

Organoleptic	NZW*R	NZW *FG	NZW *KALRO	NZW *SF	NZW*P	NZW*DR	F	Sig.
Meat Flavour	6.16± 2.46	6.40± 2.67	6.45± 2.34	6.72± 2.41	6.04± 2.66	6.22± 2.47	0.459	0.807
Meat Tenderness	6.55± 2.08	6.78± 1.85	6.74± 2.14	6.80± 2.19	5.98± 2.85	6.12± 2.44	1.228	0.296
Meat Juiciness	5.89± 2.61	6.12± 2.63	6.44± 2.51	7.00± 2.26	5.96± 2.71	6.44± 2.19	1.303	0.263
Meat Texture	6.74± 2.21	6.71± 1.95	6.78± 2.24	6.98± 1.96	6.27± 2.62	6.31± 2.63	0.758	0.581
Meat Acceptability	6.53± 2.69	6.76± 2.69	7.08± 2.27	7.22± 2.29	6.43± 2.82	6.86± 2.32	0.71	0.616
Meat Colour	1.87± 0.74	2.10± 1.01	2.24± 1.01	2.23± 0.99	2.47± 1.03	2.22± 0.90	1.711	0.132

NZW- New Zealand white, R-rex, FG-Flemish giant, KALRO-Kenya Livestock and Agricultural Research Organisation, SF- silver fox, P- Palomino, DR- Dutch.

CHAPTER FIVE

DISCUSSION

5.1 Domestic rabbit farming techniques and problems associated in North Rift and Western Kenya

5.1.1 Farm characteristics and rabbit production system

From the findings, farmers kept other species of livestock such as chicken, cattle and sheep, and specified that rabbit rearing was not their major interest as it was a project owned by young boys in the family essentially a family business whose revenues are fueling the young boys' cash. The findings are consistent with those of Chah *et al*. (2017), who attributed it to low demand for rabbit meat thereby discouraging farmers from large scale production.

Most farmers were not aware of the breeds' name of the rabbits they reared but distinguished them by coat and eye colours. Of the few that knew the breeds they reared, majority acknowledged rearing New Zealand White and Flemish Giant because of their large mature weight. The findings are in agreement with those of Olagunju *et al*. (2018), that the most common domestic rabbits reared in Kenya include; New Zealand White breeds, Californian White, Chinchilla, Flemish Giant and their crosses. The same findings were reported by Hungu, (2011) and ascribed the reason to the good white meat production as the primary objective of the Kenyan rabbit farmers.

Findings showed that rabbit farming had a reason attached to it. Surveyed farmers reared domestic rabbit for meat whether for sale or for home consumption, as pets, for skin and fur and for manure. The findings are in line with those of Mbutu (2013), that rabbits have been associated with several benefits such as meat provision as the main

focus of consumption and sales with extensive test showing that rabbit meat is among the most nutritious meat. In addition, other useful by products from domestic rabbits include skin, wool and organic manure.

5.1.2 Rabbit housing

Housing constitutes one of the most important factors in rabbit production (Mbutu, 2013). High proportion of respondents indicated they reared their rabbits in cages rather than free range system. This was for protection from predators such as birds of prey (Courchamp *et al*., 2000), mongooses among others. The most popular measurements of the rabbit house was 1.5m by 1.5m and above which agrees with Hungu (2011). The measurements were larger than those specified by Mailafia *et al*. (2010) as more than one rabbit is housed in the same structure. Majority of the structures were raised about a metre from the ground as anti-predation measure against dogs, cats and mongooses (King, 2019). These findings acknowledges FAO guidelines in Szendrő *et al*. (2012) on the rabbit hutches construction which can be modified to suit the taste of the farmer.

5.1.3 Source of Rabbit Breed

Most farmers indicated that they sourced breeding stocks from other local farmers with emphasis focusing on size and beauty of the breed and advice from farmers. This is due to the fact that there is low awareness of rabbit farming in both regions and local agricultural extension officers are insufficient in numbers in the areas for advices to the farmers. This trend was observed by Oseni & Lukefahr (2014), thus disadvantaging farmers from access to a diverse range of important genetic material. In addition, Mbutu (2013), adds that traditionally in Meru community, adults do not discuss rabbits' issues,as it is small boys' business.

Majority of farmers indicated that they provided six females to one male for breeding purposes. This is in consistence with Hungu (2011), findings that 1 male (buck) served approximately 5 females (bucks). This is within the recommended ratio more so in subsistence rabbit farming where one male is suitable to serve up top 10 females (Mbutu, 2013).

A large proportion of respondents provided pregnant does with nesting boxes where approximately 8 kits per doe were born. The investigation by Dalle Zotte & Paci, (2013), reported a mean number of total born rabbits 7.2 per birth for 95.1% of farmers concerned. The findings are in line with those of Hungu, (2011), where in their study observed an average litter size of 7 kits. Matics *et al*. (2014), on a local population in traditional breeding, reported a litter size at birth varying from 5 to 8 total born with 7 to 7 live births. Females were recorded to eat some of the weak young ones by 87 of farmers. Rabbits may eat their young kits because of stress, rejection, or inexperience with having kits even though not very often (Marai & Rashwan, 2003). Majority of rabbits were sold when at an age of more than three months but less than five months which concurred with Karikari & Asare (2009), and with a market price ranging from 200 to 1200 Ksh with majority selling at an average of 200 to 500 Ksh.

5.1.4 Rabbit house cleaning practices

A large fraction 57 (52.8%) of farmers indicated that they relied on dug out wells while few relied on seasonal ponds as their sources of water. In parts of North Rift Kenya, communities relied on seasonal ponds (*tabar*) for domestic water supply due to ASAL climatic conditions that do not favour free continous flowing water such as in rivers. A large proportion of farmers 57 (50.9%) indicated that they never cleaned the rabbit houses, this is at variances with farmers in central region of Kenya who cleaned the

rabbit houses on a regular basis by removing waste, sweeping and disinfecting (Hungu 2011). However, in this study, 46 (70.8%) rabbit farmers practiced manure removal only followed by those who sprinkled ash (*jivu*) on the manure as a disinfectant and those who addi more fresh straw to the manure.

5.1.5 Rabbit feeding

Some of the farmers reported that they never gave water to the rabbits either they believed they don`t drink or that doing so would lead to death of rabbits from diarrhoea. Varieties of feeds were given to rabbits ranging from commercial pellets to kitchen left overs. Other farmers fed rabbits with vegetables plucked or uprooted from farms. Samkol & Lukefahr (2008), indicated that rabbit feeding is not expensive as they can be fed from forage and garden waste grown in the surrounding areas. A large proportion of farmers avoided commercial rabbit feed attributing it to high cost. In addition, farmers not trusting feed companies as Hungu (2011), indicated the reason too. The rabbit enterprise being carried out by youths who are in school and cannot afford money to buy commercial feed could also have contributed to rabbits being fed mainly with vegetables.

5.1.6 Production challenges and diseases

Farmers encountered many challenges in rabbit rearing like diarrhea and skin diseases, predators such as dogs and mongooses, thieves (from other rabbit keepers) among others were encoutered. Domestic rabbits are prone to predators such as dogs and this drives farmers to build raised cages about one meter from the ground. High mortalit and high costs of commercial food (pellets), building materials such as nails and iron

sheets also constraints the enterprises. This was aslo noted by Kumar *et al*. (2012) and Hungu (2011).

5.2 Distribution and morphometric characteristics of domesticated rabbit breeds in North Rift and Western rift regions, Kenya

5.2.1 Rabbit breeds distribution

There were eight different rabbit breeds whose morphometric characteristics were explored. The explored breeds were Agouti, Chinchilla, Dutch, Flemish giant, New Zealand white, Palomino, Rex and Silver fox sourced from North Rift and Western Kenya. The findings indicated that the two regions had similar breeds of rabbits. The findings concur with those of other workers that the common rabbit breeds in Kenya are New Zealand White, Angora, French Ear lop, Californian White, Chinchilla, Flemish giant, Kenya White and their crosses (Olagunju *et al*., 2018,Serem 2014).

New Zealand white was found in all Counties probably because New Zealand White is the principal breed for commercial meat production in Kenya with meaty haunches and extensive, deep shoulders. Indeed, New Zealand White rabbit is the commonest breed of domestic rabbits all over the world incuding China, United States and Africa bred for meat in Commercial rabbitries.

Flemish Giant was the second most common breed. This breed is known for its high returns by industries that practice commercial rabbit meat production (Hawthorne, 2021). However, this rabbit breed does not perform best in meat production for commercial purposes (). Another rabbit breed that was most noted was New Zealand white indicating that both breeds are recognized for their high profit margins in both

subsistence as well as in commercial rabbit meat production which agrees with findings of Hawthorne (2021) and Wanjala (2015).

5.2.2 Morphometric characteristics of rabbit breeds

None of the morphometric measurements differed significantly between the regions for breed. However, body weight characteristic of the rabbit breeds for Dutch, New Zealand white, Rex and Silver Fox breeds from Western Kenya had higher significant mean weight compared with those from North Rift region. This can be attributed to the fact that the Western Kenya belongs to Agro Ecological Zone 2 and 3 (high and medium potential) which receives adequate amount of rainfall,.in comparison, North Rift region which is in Zone 4 and 5 refereed as ASAL areas. This concurs with findings of Mayamba *et al*. (2020) that areas that receive high to moderate rainfall have a high normalized difference vegetation index (NDVI), an important vegetation characteristic index in explaining and predicting species richness across different study landscapes. Chidodo *et al*. (2020) added that crop type in a region is associated with food availability for an organism. The rabbit characteristics did not differ between male and female rabbits. This concurs with Harcourt-Brown (2012), that sex does not affect all linear body measurements in rabbits stating that traits that are significantly affected include heart girth in males being higher in estimates as well as fore limb length, abdominal circumference and tail length.

5.3 Growth and performance characteristics of domesticated rabbit breeds and their crosses in North Rift and Western Kenya

5.3.1 Litter size at birth of domesticated rabbit breeds crosses

Results established that KALRO X KALRO (control) had the highest litter size. KALRO X KALRO is and improved breed crosses that aims at improving maximum productivity in rabbit production more so litter size and litter weight the findings are similar with those of (Fayeye & Ayorinde, 2016).

Crosses that had highest weights came from Western Kenya which belongs to Agro Ecological Zone 2 and 3 (high and medium potential). This zone receives adequate amount of rainfall thus high amounts of food for rabbits. Crosses that had significantly low weights came from North Rift Kenya which belongs to Zone 4 and 5 (having some areas which are arid and semi-arid) that limits amount of food available for rabbits. The findings concur with those of Fayeye & Ayorinde, (2016) and Mayamba *et al*., (2020), that areas that receive high to moderate rainfall have a vegetation characteristic index important in explaining and predicting species richness across different study landscapes.

Litter size had significant effect on body weight of domesticated rabbit breed crosses at all ages. This is due to the fact that kits born in smaller litters have a relative higher share of milk per kit as compared to those born of larger litter size. Similar findings were also reported by Blavi *et al*. (2021) and Prunier *et al*. (2020), that larger litter size reduces share of milk per kit thus affecting their body weight gain out of competition. Blavi *et al*. (2021) adds that relative share of milk per kit decreases as the litter size increased at pre-weaning body weights. Ajayi *et al*. (2018) also noted in their

research on pre weaning and post weaning growth performance of rabbits in a humid tropical environment that individual birth weight declined with increased litter size. In addition, Ologbose *et al*. (2018), pointed out that rabbit kittens of larger litter size always have a lower weight at weaning than the corresponding weight for kittens of smaller litter size due to the fact that their body weight gain depends on the quantity of milk consumed irrespective of doe's milk production being positively correlated to litter size.

5.3.2 Body weight of the domesticated rabbit crosses for Wk5 to Wk8 in grams

Assessment of weaners body weight for the BW5-BW8 age indicated that NZW*R cross had the highest body weight followed by KALRO X KALRO. Crosses NZW*SF recorded the lowest body weight. The results indicated that a cross between superior breed (KALRO) and a larger but inferior breed contributes to body weight at Wk5 to Wk8. Litter size in addition was a contributing factor to body weight at Week5 to Week8. The findings are in agreement with those of Ologbose *et al*. (2018), that litter size at birth significantly influence the post birth body weight of rabbit kits. The findings concur with those of Ajayi *et al*. (2018) and Ologbose *et al*. (2018), that genotype significantly ($P<0.05$) affect body weight in rabbit crosses across the weeks considered.

5.3.3 Growers body weight (Wk9-Wk12) in grams of domesticated rabbit crosses

In Week9 age, KALRO X KALRO (control) and NZW*R crosses had the highest weight significantly different from all other crosses. From the findings, genotype significantly ($P<0.05$) affects body weight. The same findings were recorded by Ajayi

et al. (2018) and Ologbose *et al*. (2018) on their work on effect of genotype on the body weight of rabbits.

5.3.4 Sub adults body weight (BW13-BW16) in grams

There was a significant difference in BW13 age in weight with NZW*R cross recording the highest weight while NZW*SF recorded the lowest. The same trend was observed at BW15 age with NZW*R crosses recording the highest while NZW*FG recorded the lowest. The differences in weight gain of domestic rabbit sub adults within the same breed or as well as among different breeds could have been due to contribution of different environmental factors such as presence of disease, differences in provided nutrition, differing hormonal levels resulting from stress and general management. These findings concur with those of Ajayi *et al*. (2018) and Ologbose *et al*. (2018), that pre-weaning variables are major contributory factors affecting post weaning performance of rabbits.

5.3.5 Feed conversion efficiency of domesticated rabbit breeds

Findings established that NZW*R and NZW*P crosses had the highest Initial and final mean body weight with the same mean weight gain among the crosses. Similarly, the mean daily weight gains and feed conversion efficiency did not differ significantly among the weaners rabbit crosses. This could have been attributed to the fact that cross breeds of New Zealand are known to be of high performance. The findings are in line with those of Wanjala (2015) who observed similar growth of rabbits across the breeds. Wanjala (2015) also alluded that New Zealand rabbit crosses perform better when compared with other crosses such as those of California when fed with pure concentrate. The observed growth rate from weaners, to growers to sub adults followed a pattern of

low, high to low weight again. Low weight gain can be attributed to weaning shock in weaners as they adapt to feed from milk to solid food. Low growth rate with low food conversion efficiencies was observed and the findings were similar to those reported by Wanjala (2015).

In terms of feed conversion efficiencies, age was a factor with weaners having the highest efficiency followed by growers and then sub adult. Slow or reduced growth rate is observed with relative stable feed intake. The findings agree with those of Gidenne *et al*. (2020) whostated that the FCR of growing rabbits increases gradually with age noting that generally young and fast-growing animals such as in rabbits have a far more promising FCR in their early fattening stage than when near slaughter weight. Gidenne *et al*. (2020) adds that the FCR increases quickly with age especially when reaching maturity due to allometry tissue deposition. Tissue deposition allometry becomes strong with age for adipose tissue adding high energy cost of synthesis. Additionally, breeding management and health status impact greatly on the feed efficiencies. According to Trocino *et al*. (2015), sex sometimes affects feed conversion ratio in rabbits with female having worse FCR due to a relatively higher adipose tissue deposition than in males.

5.4 Genetic diversity of domesticated rabbit breeds in North Rift and Western Kenya

The high allelic richness obtained in the study confirms that the populations of the rabbit in the selected counties are genetically diverse and is also indicative of the population's long-term adaptability and resilience (Ozdemir and Cassandro 2018). Similar results for the observed number of alleles and effective number of alleles were highlighted by El-Aksher *et al*., (2017), in their studies of Egyptian rabbit populations; where they

recorded 10 and 13 (highest number) of observed and alleles 3 and 5 as the lowest numbers, with an average of 6.75 (highest) and 6.13 (lowest) alleles, respectively..

In this study, observed values were lower than the He values for all studied microsatellite loci the across the studied ecotypes. The mean values of Ho and He recorded in the study were 0.903 and 0.89 respectively. The Ho and He figures recorded in the study are similar but comparatively lower than those recorded by Badr *et al*. (2019), for Egyptian rabbit breeds (0.35 to 0.84). Ho and He values above 50 percent, highlight higher genetic diversity across the studied rabbit ecotypes, and inform that the genetic fidelity of the rabbit populations is well managed and the rate of genetic erosion is low.

The average polymorphic information content (PIC) value calculated in this study was higher than reported by Badr *et al*. (2019) (0.689) and El Bayomi *et al*. (2016), who evaluated 10, 8 and 16 loci across Egyptian rabbit populations. The higher values observed in the present study suggest the usefulness of used markers for genetic diversity evaluation and linkage mapping of Kenyan rabbit ecotypes. These high PIC values are an indicator that the markers used in the study have a higher resolution for segregating closely related ecotypes.

The overall genetic differentiation among populations (FST) was low (6%). This implies that 94% of the total genetic variation was attributed to individual variability. This level of differentiation is slightly higher than those reported by Badr *et al*. (2019), in Kenya, Ben Larbi *et al*. (2014) for in Tunisia (1.1%), Badr *et al*. (2019) in Egypt (0.318) and Alves *et al*. (2015c) for European rabbit populations (12% - 16%). The studies used distinct rabbit breeds and concentrated on intensively rearing method and this could explain the low levels of differentiation. Touma *et al*. (2020), recorded higher FST

values because they used mtDNA profiling which is a more sensitive platform than microsatellites. Alves *et al*. (2015c) on the other hand studied both domestic and wild rabbit populations and used a significantly larger sample size which may be the reason for higher FST values.

Factorial analysis and phylogenetic analysis showed that the ecotypes were randomly found in the selected Kenyan counties. Additionally, Discriminant analysis of Principal Components revealed that the admixture level of an individual rabbit was not pure (Figures 1, 2 and 3). This observation may indicate random mating among the ecotypes. Similar results were reported by Badr *et al*. (2019), who studied rabbit haplotypes for rabbit population in South Eastern Nigeria, and Alves *et al*. (2015c) for domestic and wild European rabbit populations.

5.5 Carcass and meat quality traits of the crosses of domesticated rabbit breeds in North Rift and Western Kenya

5.5.1 Carcass characteristics of rabbits' crosses (Mean ± SE)

The findings indicated that various carcass weight characteristics including; live weight (before domestic rabbit fasting), pre-slaughter loss weight, weight after bleeding, edible parts weights, hot carcass weight, dressed head, liver, lungs, kidneys weight, total edible parts, dressing yield, carcass with giblet, carcass with giblet and dressed head, inedible parts, blood, pelt, feet and tail, spleen, lungs and trachea, gastral intestinal tract full, inedible parts of head and total inedible parts weight before fasting was not significantly different across the rabbit crosses. This could be due to the fact that the rabbits were kept in the same environment, fed with the same amount and type of feeds.

The recorded average slaughter weight of New Zealand White rabbits crosses were in line with those of Nuamah *et al*. (2019), who stated that in general, breed and sex do not significantly affect rabbit crosses traits. The results obtained are similar to those reported by Macias-Fonseca *et al*. (2021), who registered a slaughter weight of 1998g for New Zealand breeds showing the importance of heterosis in the crossbreeding of rabbits. Meanwhile, according to Nuamah *et al*. (2019), the type of feed offered to the animals has statistically significant effects on the rabbit crosses carcass parameters. The findings concur with those of Nasr *et al*. (2017), that rabbit crosses carcass traits are influenced by the adult weight at slaughter, farming practices and the maturity of rabbits at the age of slaughter. They also noted that only in a few cases where significant differences were observed between crosses.

In another study by Macias-Fonseca *et al*. (2021), evaluated characteristics of carcass in ascertaining Productive performance was not influenced by Gender of California and New Zealand white rabbits and their crosses. On the other hand, Khan *et al*. (2018) highlighted influences of sex on the weight and parts of the carcass at slaughter weight of more than 2.5 kgs.

5.5.2 Domestic rabbit primal carcass cut-up parts

Primal cut up parts of rabbit crosses carcasses did not differ significantly among the crosses. This could be explained by the fact that environment in which the crosses were brought up was the same (University of Eldoret Farm). This concurred with the findings of Ludwiczak *et al*. (2016) that the type of feed as environmental conditions offered to the animals has statistically significant effects on the rabbit crosses carcass parameters. Comparable results were also noted by Nuamah *et al*. (2019), where they found no significant differences in all parameters assessed as far as primal cut-up parts of rabbit

crosses carcass are concerned. Another study by Fadare (2015), indicated that the New Zealand breed cross had the highest fore parts weight followed by California breed with no significant differences in thorax parts, with genetic origin influencing the dressing out percentage.

In respect to carcass parts, the results were similar with those of Macias-Fonseca *et al*. (2021), who found that loin and legs, were representing 16% and 24% of the carcass, respectively considering that they are the most economically important of the carcass.

5.5.3 Meat bone ratio of rabbit crosses carcass

The meat-to-bone ratio of rabbit carcasses was calculated using the weights of the hind leg flesh and bone. According to Ludwiczak *et al*. (2016), muscle and bone from the rear legs is a good predictor. The meat-to-bone ratio did not differ between rabbit carcass crosses ($p>0.05$). This is in line with Ouyed *et al*. (2011), who found that the crossbreed had a somewhat higher meat-to-bone ratio.

5.5.4 Influence of domestic rabbit breed crosses on the organoleptic properties of rabbit meat

The effect of breed on organoleptic traits was assessed. The ranking of the colour, flavor, tenderness, juiciness, texture as well as acceptability of meat from New Zealand cross with other breeds was not significant irrespective of general acceptability ranked high in NZW*SF. Initial selection of meat by consumer is basically through colour which is highly and mainly related to myoglobin pigments concentration and its chemical state on the meat surface. Additionally, pigmentation dictates the muscle proteins structure and physical state (Apata *et al*., 2012; Fadare, 2015). The findings

are in line with those of Fadare (2015), who found no outstanding significant difference in rabbit meat colour from crosses of New Zealand white with California rabbits, Havana black rabbits and Palomino rabbits. The chemical state of myoglobin according to Apata *et al*., 2012), is responsible for meat colour which is directly affected by cofactors and presence of substrates, the concentration of pH, partial pressure of O_2, tissue structure, temperature, light, lipid oxidation and the activity of reducing enzymes. According to Fadare (2015), weight and food restrictions of rabbits at a certain age greatly influences on quality of rabbit meat directly influencing consumer acceptability.

Daszkiewicz & Gugołek (2020) added that meat quantity and quality can also be influenced by production system such as either intensive or extensive. Fadare (2015), in addition pointed out that pH, as well as tenderness influence color of rabbit meat. In another study, a cross between New Zealand white and Palomino brown produced meat with least flavor (Fadare, 2015).

Results established no significant differences in meat flavor among the rabbit crosses. This could have been influenced by the fact that all the crosses were under the same production management system. The findings agrees with those of Fadare (2015) who highlighted non-significant difference on the flavor of rabbit meat among crosses using meat from New Zealand white male rabbits and Palomino brown female crosses.

The findings showed non-significant difference in meat tenderness. According to Bízková & Tůmová (2010), tenderness of the meat is one of the most important sensory and physical characteristics of rabbit meat. Postmortem changes affect proteins such as myofibrillar on the connective tissue that is responsible for meat toughness and tenderness. In addition, just like meat color, tenderness is also influenced by pH, as well as stress during slaughter (Ballan *et al*., 2022; Nuamah *et al*., 2019). According to

Fadare (2015), colour, tenderness and flavor as organoleptic characteristics of domestic rabbit meat can moderately be influenced by rabbit genetic type.

For juiciness, all the rabbit breed crosses assessed in this research recorded similar level of juiciness. Ballan *et al*. (2022) and Nuamah *et al*. (2019) recorded that New Zealand white male rabbit and other breeds female crosses meat were alike in juiciness and texture as well as colour. They also added that small amounts of intramuscular fat lubricate the muscle fibers, thus affecting juiciness and flavor of rabbit meat.

The results indicated non-significant difference in rabbit meat texture of the meat samples from different rabbit crosses. Meat texture according to Bízková & Tůmová, (2010) mainly and highly depends on the rabbit meat slaughter changes as well as on the structure of the meat muscle. Texture dictated how hard or soft the meat is. Hard meat is linked with higher collagen level and low amounts of fat as compared to soft meat. The findings disagrees with those of Fadare (2015) who indicated high levels of texture in New Zealand breed crosses as compared with that of California. Fadare (2015), in addition highlighted the effect of genotype on the rabbit meat texture confirming no significant effect.

The research established an overall acceptability of domestic rabbit meat. According to Omojola & Adesehinwa (2006), the acceptability of any livestock meat is dependent on both processing method and general qualities which can be physical, chemical or organoleptic The findings are in line with those of Fadare (2015), that there is no significant difference in rabbit meat overall acceptability among New Zealand rabbit breed meat. According to Apata *et al*. (2012) sex may influence organoleptic properties of rabbit meat with male rabbit meat samples having better flavour, meat colour, juiciness, tenderness and texture. In another study on rabbit meat organoleptic

characteristics assessment, a high positive correlation was noted between flavour (Bízková & Tůmová, 2010) and juiciness (Fadare, 2015) in rabbit meat samples from New Zealand crosses was recorded. Other studies from various scholars highlighted positive correlation between organoleptic traits and overall acceptability (Apata *et al*., 2012; Fadare, 2015; Omojola & Adesehinwa, 2006).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- Rabbit farming is not a priority and has been mostly left to young boys in the family.
- Most rabbits for breeding are bought from other farmers with size and beauty being the most critical criteria.
- Rabbits are kept for meat, sales and manure.
- Cleaning was done by removing accumulated manure and ash was sprinkled as a disinfectant. The encountered problems were diseases like diarrhoea and skin diseases, predators such as dogs and mongooses, thieves (from other rabbit keepers) among others. Mortality of the rabbits/ sudden deaths, and high costs of commercial food (pellets) building materials such as nails and iron sheets also constraints the enterprise.
- The research established eight rabbit breeds sourced from North Rift and Western-Rift Regions of Kenya; these were Agouti, Chinchilla, Dutch, Flemish giant, New Zealand white, Palomino, Rex and Silver fox.
- New Zealand white was found in all counties attributed to the fact that it is the principal breed for commercial meat production in Kenya with meaty haunches and extensive, deep shoulders. Flemish giant was the second most populous breed especially in Vihiga and Nandi Counties. Flemish giant and New Zealand white were the most populous breeds reared by the communities owing to their high profit margins in subsistence as well as in commercial rabbit meat production. The findings indicated that morphometric measurements did not

differ between the regions for breed but body weight characteristic for Dutch, New Zealand white, Rex and Silver Fox breeds from Western Kenya had higher significant mean weight compared to those from North-rift region which was attributed to the fact that the Western Kenya belongs to Agro Ecological Zone which receives adequate amount of rainfall thus high amounts of food for rabbits as compared to the North Rift region which has some areas that are semi-arid.

- Litter size had significant effect on domesticated rabbit breeds crosses body weight at all ages. This is due to the fact that kits born in to smaller litters have a relative higher share of milk per kit as compared to those born of larger litter size. It is recognized that larger litter size reduces share of milk per kit thus affecting their body weight gain out of competition. This concluded that rabbit kittens of larger litter size always have a lower weight at weaning than the corresponding weight for kittens of smaller litter size due to the fact that their body weight gain depends on the quantity of milk consumed irrespective of doe's milk production being positively correlated to litter size.
- The results indicated that a cross between superior breed (KALRO) and a larger but inferior breed contributes to body weight. Litter size in addition was a contributing factor to body weight. This concludes that superior breed (KALRO) can still be used to improve the local breeds and increase productivity.
- Low weight gain can be attributed to weaning shock in weaners as they adapt to feed for milk to solid food. Low growth rate with low food conversion efficiencies was observed. In terms of feed conversion efficiencies, age was a

factor with weaners having the highest efficiency followed by growers and then sub adult.

- The higher values observed in the present study suggest the usefulness of used markers for genetic diversity evaluation and linkage mapping of Kenyan rabbit ecotypes. These high polymorphic information content (PIC) values are an indicator that the markers used in the study have a higher resolution for segregating closely related ecotypes. The overall genetic differentiation among populations (FST) was low (6%). This genetic differentiation (FST) among populations (6%) implies that 94% variation of the total genetic was explained by specific variability. The studies used distinct rabbit breeds and concentrated on intensively rearing method and this explains the low levels of differentiation. Factorial analysis and phylogenetic analysis showed that the ecotypes were randomly found in the selected Kenyan counties. Additionally, Discriminant analysis of Principal Components revealed that the admixture level of an individual rabbit was not pure indicating a random mating among the ecotypes. The results reported in the study confirmed that microsatellites possess applicability and genetic diversity assessment efficiency and advising conservation urgencies for Kenyan rabbit ecotypes. The information generated in this study will form an initial guide for expansion of genetic enhancement and preservation programmes for Kenyan rabbit genetic resources.

The findings indicated that various carcass characteristics weights were not significantly different across the rabbit crosses. This could be due to the fact that the rabbits were kept in the same environment, fed with the same amount and type of feeds.

6.2 Recommendations

Following the results of this study, the following recommendations are advanced:

1. Farmers may benefit from higher production of meat yields if they use the superior rabbit breed, New Zealand for upgrading their local breeds. This should be achieved through extension services and awareness campaign. From the findings, farmers kept other types of livestock and rabbit farming was not their main type of farming. This need to be addressed and more awareness created on the need to keep rabbits for meat provision, manure skin and fur as well as for commercial purposes as they occupy small space in comparison to other livestock.
2. High proportion of respondents reared their rabbits in cages. It was observed that the cages were not well constructed and materials were not up to standards. This could be the reason as to why rabbit farmers indicated that the constraining factor for rabbit farming was predator and diseases. More awareness should be created to educate farmers on the need to offer proper housing to rabbits and follow the FAO recommendations.
3. Managerial practices and marketing strategies` training are required by the rabbit farmers in the regions. There is need to Subsidize commercial feed to ensure quality rabbit feed affortability. This will eventually bring an increase in rabbit farming in the two regions that will increase meat yields for food security and sustainability. By so doing, the households in the nation will adopt the practice and the outcome will boost their families both health wise and increase in income from the yields of rabbit meat.

4. Some breeds in Western Kenya weighed more than those from the North Rift Kenya attributed to more food due to the type of agro-ecological zone. This research work recommends more studies be conducted on morphometric characterization of indigenous rabbit at pre-determined ages (juveniles, sub adults as well as in adults) including genetic, molecular, and immunological characterization and genetic parameter estimation. It is also recommended that breeding programs be carried out to improve production performance of local rabbits.
5. This study has shown that genotype significantly influences the body weight of rabbits both at the pre-weaning and post weaning stages. The research recommends more work to be done to establish if factors such as environmental conditions, diseases, feeding regimes as well as housing structures contributes significantly to body weight differences in rabbits both at the pre-weaning and post weaning stages.
6. In terms of feed conversion efficiencies, only age and the effects of cross breed was assessed to determine its influence. This research recommends more work to be done to assess the effects of forage and concentrate on feed conversion ratio and efficiencies, the influence of age, health status, management regimes as well as comparison of pure and cross breed of domesticated rabbits.
7. The results presented highlighted high genetic variability within and between Kenyan local rabbits. Microsatellites revealed clear sub-structuring between studied local populations, substantiating their local adaptation to respective Agro-Ecological Zones. Genetic erosion in the Kenyan rabbit population is still minimum and unnoticeable using the genetic testing platform applied. Thus,

future breeding programs should seek to maintain the status and control possible genetic dilution.

8. Microsatellite profiling highlighted that the Kenyan rabbits can be assigned to three major clusters with a single potential lineage. In response to the research findings, it is recommended that genetic diversity testing platforms with high resolution such as Genome Wide Sequencing (GWAS), and Metagenomic sequencing should be applied to rabbit diversity studies because they can detect more diversity than microsatellites.
9. The study also assessed various carcass characteristics weights including; live weight, fasting loss, weight after bleeding, carcass with giblet and dressed head, inedible parts, blood, pelt, feet and tail, spleen, lungs and trachea, gastral intestinal tract full, inedible parts of head and total inedible parts among others in different domesticated rabbit crosses only. More work needs to be done to compare the rabbit crosses with pure breed in terms of carcass characteristics. Additionally, effects of feed distribution mode, management, gender and age need to be tested to ascertain their influences in carcass characteristics.
10. The ranking of the flavor, tenderness, juiciness, texture, color as well as acceptability of meat from New Zealand cross with other breeds was tested and found to be non significant across the domesticated rabbit breed crosses. More work is needed to be done to compare the crosses` meat organoleptic characteristics with those of pure breed.

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APPENDICES

Appendix I: Questionnaire

Questionnaire for assessing domestic rabbit farming techniques and associated problems in the rural North Rift and Western Kenya

Section A. Farm attributes

Date visited.....
GPS Location of the farm.....
Approximate farm size (acres).....

Section B. Farmer's demographic characteristics

i. Gender
   - Male ( )
   - Female ( )

ii. Age
   - < 18 years ( )
   - 18-25 yrs. ( )
   - 26-35 yrs. ( )
   - 36-45 yrs. ( )
   - 46-55 yrs. ( )
   - Above 56 yrs. ( )

iii. Education
   - None ( )
   - Primary ( )
   - Secondary ( )
   - Tertially ( )
   - University ( )

iv. Occupation
   - Employed ( )
   - Self-employed ( )
   - Un employed ( )

v. Residence
   - Birth ( )
   - Immigrant ( )

vi. Period of residency
   - 16-20 yrs. ( )
   - 5-10 yrs. ( )
   - 11-15 yrs. ( )
   - 16-20 yrs. ( )
   - > 25 yrs. ( )

vii. How are you related with the rabbit owners?

Rabbits are mine ( )
Wife, husband ( )
Daughter/son ( )
Worker ( )
Others ( )

Section C. Characteristics of the farm where rabbits are reared

1. Forms of land use
   a) Agriculture ( )
   b) Livestock keeping ( )
   c) Bee keeping ( )
   d) Mixed farming ( )
   e) Others ( )
2. If livestock keeping, please indicate the type of livestock you keep in your farm
   a. Cattle ( )
   b. Sheep ( )
   c. Goats ( )
   d. Rabbits ( )
   e. chicken ( )
   f. others ( )
3. If rabbitry is one of livestock kept, is it the main type of farming?
   a. Yes ( )
   b. No ( )
4. If yes in the statement above, why do you keep them?
   a. Pets ( )
   b. Meat ( )
   c. Skins and Fur ( )
   d. Breeding purposes ( )
   e. Sales ( )
5. Period of practising rabbitry in your farm
   a. Less than 1 year ( )
   b. 2- 5 years ( )
   c. 6- 10 years ( )
   d. Over 10 years ( )
6. Are you aware of breeds of rabbits you keep?
   a. Yes ( )
   b. No ( )
7. If yes, which breed(s) do you keep in your farm and how many (please use the table below)

	Sex		
Breed	**Male**	**female**	**Total**

8. How do you identify the rabbits you keep in the table above?
    a. Ear tags ( )
    b. Tattoo ( )
    c. Cage number ( )
    d. Breeds ( )
    e. Others. ( )
    f. Colour ( )
9. In which type of structure do you house your rabbits?
    a. Hutch ( )
    b. Indoor rabbitry ( )
    c. Free range ( )
    d. Both ( )
10. a. Approximate the size of your rabbit house/ cages?
    a. 1m by 1m ( )
    b. 1.5m by 1.5 m ( )
    c. Over 1.5m by 1.5m ( )
11. Approximate number of rabbits you keep per structure/ house?
    a. 1 per structure ( )
    b. 2-4 per structure ( )
    c. 5 and above 70 ( )
13. Where did you initially acquire your first rabbits, parents' rabbits?
    a. My rabbitry practising friends ( )
    b. Accredited rabbit farmers/ breeders ( )
    c. Any other known source specify.....
14. How do you ensure you have good breeding parents?
    a. Choosing on the basis of Performance ( )
    b. Choosing on the basis breed type ( )
    c. Through rabbit keeping advice from other friendly rabbit farmers ( )
    d. Choosing on the basis of size as well as body conformity of the rabbits ( )
15. How many females / does do you ensure are served by one male /buck……....?
16. In preparation for kindling, do you ensure presence of a nesting box?
    a. Yes ( )
    b. No ( )
17. Do you frequently experience death of litters?
    a. Yes ( )
    b. No ( )
18. How many kits per adult doe in average does your does give rise to..?
19. In estimate, how may kits per litter fortunately get to reach the market age...

20. In case of death of your rabbits, do you replace them?
    a. Yes ( )
    b. No ( )
21. If yes, where do you normally buy...?
22. In your farm, at what level is your rabbit farming?
    a. For meat provision for family ( )
    b. Commercial purposes ( )
    c. For multiple reasons ( )
23. If you sell your rabbits, to where specifically?
    a. Nearby local markets ( )
    b. To individual rabbit keepers or meat consumers ( )
    c. To local hotels ( )
    d. Others.....
24. Please indicated the approximated average weight of your mature.....kg's
25. Please indicated the approximated age of your rabbits prior to selling them…...?
26. Please indicated the approximated sale price of adult rabbit in Kshs……

Section D. Rabbit farming practices and management

27. How many times do you clean your rabbit houses/ cages?
    a. Daily ( )
    b. Once a week ( )
    c. Twice weekly ( )
    d. Thrice weekly ( )
    e. Never ( )
28. How do you clean?
    a. Sweeping alone ( )
    b. Adding more straw ( )
    c. Manure removal only ( )
    d. Disinfectant/ bleach jivu ( )
    e. All of the above ( )
29. Where do you source water for use in your farm/ home?
    a. Tap water ( )
    b. River ( )
    c. Well ( )
    d. Rain water ( )
    e. Other……..…….
30. If your rabbits are zero grazed, which food types do you offer them?
    a. Commercially produced rabbit Pellets ( )
    b. Green vegetables sourced from the farm ( )
    c. Kitchen left overs ( )
31. If green vegetables from the farm, do you offer them to rabbit while wet?
    a. Yes ( )
    b. No ( )
32. If your rabbits are fed with Commercially produced rabbit Pellets, where do you buy them?

a. Agro-Vet suppliers ( )
b. Farm produce ( )

33. Do you change the rabbit feed suppliers? If yes, how often
    a. ……. b…… c…….
34. How many times do you give your rabbits food per day?
    a. Has food available throughout
    b. At intervals from morning to evening ( )
35. Who manages your rabbits?
    a. I myself ( )
    b. *Shamba boy* / farm hand ( )
    c. Siblings/ children ( )
    d. Anyone in the family ( )
36. Do you source any advice on rabbit farming and management?
    a. Yes ( )
    b. No ( )
37. If yes, specify from who?
    a. Government accredited animal health officers ( )
    b. From other successful rabbit farmers ( )
    c. Any other ( )

Section E. Rabbit farming problems and diseases

38. Please indicate rabbit farming problems you have ever faced in your farm?
    a. Disease skin disease envamped ( )
    b. Predators /thieves ( )
    c. Mortality of the rabbits ( )
    d. Unavailability of rabbit commercially produced pellets/feed ( )
    e. Others (please specify) .....
39. Aware of the disease symptoms that affect your farmed rabbits?
    a. Yes ( )
    b. No ( )
40. If yes, list some of the symptoms…….
41. Do you issue commercial medicine to your sick rabbits?
    a. Yes ( )
    b. No ( )
42. If yes, do you administer the drugs by yourself of you seek help?
    a. Seek help from fellow rabbit farmers ( )
    b. Form livestock Vet ( )
    c. Both ( )
47. Are you a registered member to any rabbit group organization?
    a. Yes ( )
    b. No ( )
48. If yes, which one...?

Appendix II: Sampled counties in Kenya

S/N	COUNTY	SUB-COUNTY	SEX	NUMBER	BREED
1	Bungoma	Bumula Kimilili Kapchai kandui	Male Female Female Female	1 1 1 1	Newzealand Dutch Silverfox Califonian white
2	Busia	Nambale Bunyala Butula	Female Female Male	1 2 1	Dutch Newzealand Flemish giant
3	Kakamega	Likuyani Lugari Butere Mumias	Female Male Female Female	1 1 1 1	Dutch Newzealand Rex silverfox
4	Vihiga	Emuhaya Sabatia Vihiga Luanda	Male Female Female Female	1 1 1 1	Rex Dutch Newzealand Dutch
5	TransNzoia	Kimilili Sabatia Kwanza	Female Male Female Female	1 1 1 1	Dutch Newzealandwhite Flemish Giant Rex
6	Elgeyo-Marakwet	Keiyo north Keiyo south Marakwet Keiyo east	Female Male Female Female	1 1 1 1	Dutch Rex Newzealand Dutch
7	Baringo	Mogotio Eldama ravine Baringo north	Female Male Female Female	1 1 1 1	Palomino Newzealand Newzealand Flemish giant
8	Nandi	Aldai Nandihills Tindiret	Male Female Female	1 2 1	Dutch Dutch Silverfox
9	KALRO,NJORO	KALRO,NJORO	Male Female	1 3	New Zealand white-pure breed

Appendix III: Lab equipment

Equipment	Function
1. Tissue lyser	Lysis of tissues during DNA extraction
2. Centrifuge	Separation of mixtures in solutions. Used for DNA isolation from cell components
3. -40^{o}C freezer	Storage of DNA and temperature sensitive reagents
4. Nanodrop spectrophotometer	Measurement of quantity and Purity of DNA, RNA, Proteins and cell cultures.
5. Microwave	Making agarose gels
6. Gel electrophoresis tanks	Running gel electrophoresis for quantification of DNA and RNA
7. UV transiluminator	Visualizing gel electrophoresis gels
8. PCR Machines (Thermocyclers)	Running PCR reactions for amplification of DNA and RNA segments
9. Minispin centrifuge	For centrifuging contents in PCR strips
Important chemicals used in DNA Extraction	
10. CTAB (Cetyl Trimethyl Ammonium Bromide)	Buffer used for cell lysis during DNA Extraction. Also simply called lysis buffer.
11. CIA (Chloroform: Isoamyl alcohol ratio 24:1)	Mixture of chloroform and isoamyl alcohol used to remove proteins and fats during DNA extraction.
12. Isopropanol	Used to precipitate (remove from solution) DNA/RNA during extraction. Absolute ethanol can also be used
13. 70% Ethanol	Used for removing carry over chemicals from DNA/RNA in steps called washing
14. Gel stain	Used to give colour to the gels so they can be seen under UV in the transilluminator. Eg. EthidiumBromide and CyberSafe
15. Loading Dye	Used during loading of agarose gels to give the DNA weight to settle in wells and enables the worker to know already loaded gels. Eg. Bromocresol blue
Important chemicals used in PCR	
16. PCR Mastermix/premix	Solution containing dNTPs (building blocks), polymerase enzyme, MgCl and buffer solution. Provides ingredients for PCR reaction.
17. Primers	Short DNA/RNA sequences that attach/anneal to the region of interest and serve as starting points for amplification

Appendix IV: Research Permit (NACOSTI)

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **655450**

Date of Issue: **21/June/2021**

RESEARCH LICENSE

This is to Certify that Ms.. Philomena Cheptanui Sergon of University of Eldoret, has been licensed to conduct research in Baringo, Bungoma, Busia, Elgeyo-Marakwet, Kakamega, Nandi, Transnzoia, Vihiga on the topic: Population structure and genetic diversity of domesticated rabbits in western Kenya for the period ending : 21/June/2022.

License No: **NACOSTI/P/21/7936**

655450

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Director General
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Appendix V: Morphometric characteristics of the sampled rabbits.

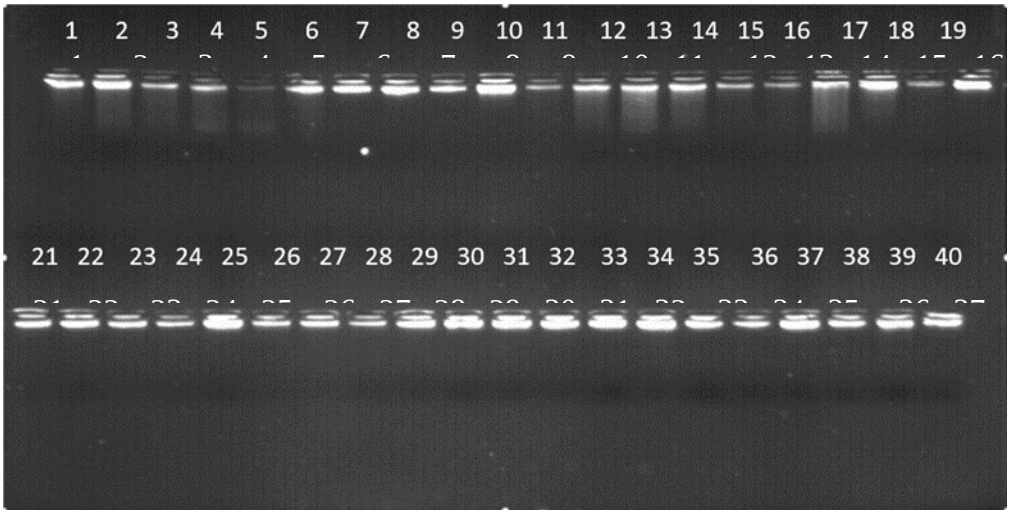
SN	**Region**	**County**	**Body length**	**Girth**	**Belly**	**Leg**	**Ear width**	**Ear length**	**Sex**	**Weight**	**Colour**	**Breed**
7	1	1	48	26	23	7	5	10	1	1.98	7	1
22	1	2	50	28	28	7	5	10	2	2.51	6	1
23	1	2	46	22	24	7	6	11	2	2.66	7	1
24	1	2	48	28	23	8	5	9	1	2.45	6	1
49	1	4	44	29	29	7	6	8	1	2.67	6	1
50	1	4	39	24	28	8	5	10	2	1.42	6	1
52	1	4	50	26	28	9	5	9	1	2.09	7	1
53	1	4	48	27	28	8	6	10	2	1.91	7	1
54	1	4	47	37	32	11	7	11	2	2.01	7	1
59	2	5	41	30	32	8	6	11	1	1.76	7	1
60	2	5	41	29	33	8	6	11	2	2	6	1
68	2	5	44	28	31	6	5	6	1	1.56	7	1
109	2	8	49	29	30	12	8	10	2	1.02	6	1
5	1	1	45	25	26	8	7	10	1	2.47	3	2
57	2	5	46	28	30	9	5	8	1	2.16	3	2
65	2	5	51	31	42	8	6	11	2	3.31	1	2
2	1	1	48	25	24	8	6	9	2	1.96	3	3
14	1	1	43	24	23	9	6	9	1	2.66	3	3
33	1	3	50	36	26	8	6	11	2	2.21	3	3
35	1	3	48	28	23	8	5	11	2	2.63	3	3
63	2	5	47	26	28	8	6	13	1	2	3	3
75	2	6	47	25	31	10	6	10	1	1.42	3	3
91	2	7	45	28	29	8	5	10	1	1.52	11	3
103	2	8	44	30	24	7	6	8	2	1.92	3	3
107	2	8	48	30	32	11	6	11	2	1.25	3	3
112	2	8	42	25	25	7	6	9	2	1.58	3	3
9	1	1	45	23	20	7	6	9	1	2.65	8	4
12	1	1	48	23	17	7	6	10	1	2.66	10	4
13	1	1	47	26	27	8	7	10	1	2.51	10	4
16	1	2	46	25	24	10	5	10	1	1.93	10	4
19	1	2	43	27	24	7	6	9	2	2.69	9	4
25	1	2	40	20	20	6	6	6	2	2.07	10	4
27	1	2	48	37	18	8	6	9	2	2.47	10	4
28	1	2	45	37	17	7	6	9	2	2.14	10	4
30	1	3	46	35	28	8	6	11	2	2.73	8	4
40	1	3	47	30	31	9	8	10	2	2.14	10	4
41	1	3	41	28	30	7	7	10	2	2.43	6	4
42	1	3	43	27	27	7	9	7	2	1.71	10	4
43	1	4	45	30	27	6	6	10	2	2.13	10	4
44	1	4	43	28	33	9	8	10	1	1.76	10	4
56	1	4	45	30	39	7	7	9	2	2.12	9	4

58	2	5	42	29	30	6	6	10	2	2.49	2	4
61	2	5	47	27	28	9	6	11	1	2.65	10	4
66	2	5	44	29	32	8	5	10	2	2.37	10	4
67	2	5	46	23	32	9	5	9	1	1.86	10	4
69	2	5	46	26	23	7	5	9	1	1.56	10	4
99	2	8	32	18	16	6	4	10	1	1.15	2	4
104	2	8	35	23	24	7	4	9	2	1.84	10	4
105	2	8	44	26	25	7	5	10	2	2.29	2	4
1	1	1	47	29	28	8	7	9	1	2	11	5
3	1	1	44	25	25	8	6	10	1	2.34	11	5
4	1	1	45	25	26	8	7	9	2	2.23	11	5
6	1	1	47	25	26	6	5	9	2	2.68	11	5
8	1	1	44	28	21	8	6	10	1	1.98	11	5
21	1	2	50	26	25	8	6	10	2	2.6	13	5
26	1	2	42	30	15	8	6	9	2	2.05	11	5
29	1	3	45	30	25	8	6	11	2	2.52	11	5
32	1	3	47	34	27	8	6	10	2	2.03	11	5
34	1	3	50	36	28	7	6	10	2	2.05	11	5
36	1	3	50	30	30	9	6	10	2	2.39	11	5
37	1	3	50	35	35	7	6	11	2	2.6	11	5
38	1	3	50	30	34	8	5	10	2	2.73	11	5
39	1	3	49	29	30	8	6	10	2	2.13	11	5
45	1	4	41	25	22	8	7	9	1	1.43	11	5
46	1	4	44	20	26	9	11	7	1	1.89	11	5
47	1	4	41	25	30	6	6	10	1	1.71	11	5
48	1	4	45	25	29	7	5	10	1	1.66	11	5
62	2	5	44	24	32	7	5	10	2	1.67	11	5
70	2	5	48	26	27	8	5	9	2	1.8	11	5
71	2	6	45	25	30	8	5	11	1	1.89	10	5
72	2	6	44	25	30	8	5	12	2	2.2	11	5
73	2	6	48	26	31	9	5	10	1	2.03	11	5
74	2	6	45	29	29	7	6	10	1	1.56	1	5
76	2	6	45	25	32	7	6	9	1	1.9	11	5
77	2	6	43	27	30	8	5	11	1	1.63	11	5
78	2	6	45	26	30	8	6	10	1	1.63	11	5
79	2	6	43	27	31	7	7	10	1	2.26	11	5
80	2	6	39	23	20	10	5	8	1	1.03	11	5
81	2	6	42	22	21	9	5	8	1	1.03	11	5
82	2	6	40	25	30	8	6	11	1	1.59	10	5
83	2	6	40	24	29	8	6	9	1	1.2	11	5
84	2	6	44	28	29	8	6	9	1	1.92	11	5
85	2	7	43	20	24	8	5	9	1	1.26	11	5
86	2	7	47	25	26	8	7	9	1	1.41	11	5
87	2	7	46	22	21	9	6	10	1	1.54	11	5
88	2	7	37	20	20	8	5	9	1	1.76	11	5
89	2	7	45	23	23	9	6	9	1	1.62	11	5

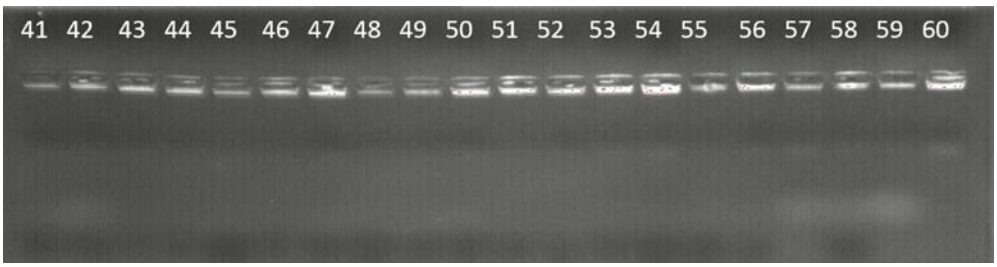
90	2	7	47	26	26	7	6	10	1	2.09	10	5
96	2	7	45	29	26	6	7	9	2	1.87	11	5
97	2	7	46	27	25	7	6	8	1	1.98	8	5
98	2	7	44	24	27	7	6	9	1	2.66	10	5
100	2	8	38	25	22	7	5	8	1	1.42	11	5
101	2	8	31	24	21	7	5	8	1	1.71	11	5
102	2	8	43	25	24	7	4	7	2	1.59	3	5
108	2	8	47	30	29	12	6	12	2	1.19	11	5
110	2	8	45	20	20	10	7	10	2	1.25	11	5
111	2	8	47	30	30	10	7	10	2	1.11	11	5
11	1	1	48	23	25	7	6	10	1	2.55	7	6
20	1	2	50	27	25	8	6	11	1	2.89	1	7
31	1	3	47	33	26	8	5	11	2	2.07	1	7
51	1	4	40	24	29	9	6	11	1	1.79	1	7
92	2	7	48	27	25	7	5	10	1	1.66	7	7
93	2	7	36	19	19	6	4	8	2	1.1	1	7
106	2	8	48	28	28	10	6	10	2	1.21	1	7
113	2	8	38	19	23	8	7	9	2	1.58	1	7
10	1	1	46	25	21	6	6	10	1	2.8	12	8
15	1	2	43	23	21	10	6	9	1	2.44	12	8
17	1	2	50	29	26	8	6	11	2	2.57	12	8
18	1	2	34	29	24	7	4	9	2	2.09	12	8
55	1	4	45	34	38	7	6	9	1	3.01	12	8
64	2	5	45	31	32	6	5	11	2	2.45	12	8
94	2	7	40	23	22	6	4	9	2	1.41	12	8
95	2	7	41	24	24	7	5	9	1	1.72	12	8

Appendix VI: Agarose Gel electrophoresis

Samples 1 - 40



1. Samples 41 – 60



Figures 1 and 2. DNA quantification agarose gels showing presence of DNA

Appendix VII: Nano Drop DNA quantification showing DNA concentration and purity

Sample ID	Nucleic Acid	Unit	260/280	Sample Type	Factor
1	148.8	ng/µl	1.71	DNA	50
2	156.3	ng/µl	1.82	DNA	50
3	142.1	ng/µl	1.77	DNA	50
4	111	ng/µl	1.86	DNA	50
5	80.6	ng/µl	1.48	DNA	50
6	151.2	ng/µl	1.87	DNA	50
7	138.7	ng/µl	1.49	DNA	50
8	148.8	ng/µl	1.79	DNA	50
9	123.9	ng/µl	1.78	DNA	50
10	119.7	ng/µl	1.91	DNA	50
11	44.4	ng/µl	1.62	DNA	50
12	94.7	ng/µl	1.49	DNA	50
13	488.4	ng/µl	1.56	DNA	50
14	88.9	ng/µl	1.55	DNA	50
15	124.7	ng/µl	1.79	DNA	50
16	134.4	ng/µl	1.76	DNA	50
17	75.8	ng/µl	1.59	DNA	50
18	216.7	ng/µl	1.82	DNA	50
19	159	ng/µl	1.78	DNA	50
20	87.9	ng/µl	1.52	DNA	50
21	198.6	ng/µl	1.83	DNA	50
22	199.8	ng/µl	1.75	DNA	50
23	43.4	ng/µl	1.49	DNA	50
24	176.4	ng/µl	1.74	DNA	50
25	180	ng/µl	1.86	DNA	50
26	334.7	ng/µl	1.89	DNA	50
27	104.8	ng/µl	1.5	DNA	50
28	58.9	ng/µl	1.45	DNA	50
29	194.3	ng/µl	1.46	DNA	50
30	77.2	ng/µl	1.53	DNA	50
31	120.4	ng/µl	1.82	DNA	50
32	251.6	ng/µl	1.86	DNA	50
33	92	ng/µl	1.48	DNA	50
34	61	ng/µl	1.46	DNA	50
35	94.4	ng/µl	1.5	DNA	50
36	243.1	ng/µl	1.85	DNA	50
37	202.4	ng/µl	1.82	DNA	50
38	372.2	ng/µl	1.65	DNA	50
39	94	ng/µl	1.49	DNA	50
40	90.2	ng/µl	1.51	DNA	50
41	71.1	ng/µl	1.45	DNA	50
42	62.3	ng/µl	1.52	DNA	50
43	169.7	ng/µl	1.91	DNA	50
44	84.4	ng/µl	1.53	DNA	50
45	165.1	ng/µl	1.58	DNA	50
46	87.6	ng/µl	1.6	DNA	50
47	102.4	ng/µl	1.56	DNA	50
48	83.9	ng/µl	2	DNA	50

49	47.8	ng/µl	1.3	DNA	50
50	51.8	ng/µl	1.64	DNA	50
51	121.7	ng/µl	2.16	DNA	50
52	759	ng/µl	1.65	DNA	50
53	396	ng/µl	1.67	DNA	50
54	264.6	ng/µl	1.83	DNA	50
55	956.2	ng/µl	2.16	DNA	50
56	238	ng/µl	1.93	DNA	50
57	271.1	ng/µl	1.76	DNA	50
58	576.3	ng/µl	1.64	DNA	50
59	330.8	ng/µl	2	DNA	50
60	468.4	ng/µl	2.14	DNA	50

Appendix VIII: Growth characteristics of domesticated rabbit breeds in North Rift and Western Kenya from week 0 to week 5.

NZW*SF					
NZW*SF	BWT	WK1	WK2	WK3	WK4
1	0.03	0.06	0.093	0.128	0.17
2	0.03	0.06	0.093	0.128	0.17
3	0.03	0.06	0.095	0.13	0.175
4	0.03	0.05	0.095	0.13	0.175
5	0.04	0.07	1.105	0.135	0.18
6	0.04	0.07	0.105	0.135	0.18
B. NZW*KALRO					
1	0.04	0.07	0.103	0.138	0.18
2	0.04	0.07	0.103	0.138	0.18
3	0.04	0.07	0.103	0.138	0.185
4	0.04	0.07	0.103	0.138	0.185
5	0.04	0.07	0.103	0.135	0.18
6	0.04	0.07	0.103	0.135	0.18
C. NZW*P					
1	0.05	0.08	0.113	0.148	0.195
2	0.05	0.08	0.113	0.148	0.195
3	0.05	0.08	0.113	0.148	0.195
4	0.05	0.08	0.113	0.148	0.195
5	0.05	0.08	0.113	0.148	0.195
6	0.05	0.08	0.113	0.148	0.195
7	0.05	0.07	0.095	0.13	0.18
D. KALRO X KALRO					
1	0.06	0.09	0.123	0.158	0.208
2	0.06	0.09	0.125	1.158	0.208
3	0.06	0.09	0.125	0.15	0.208
4	0.06	0.09	0.123	0.146	0.2
5	0.05	0.08	0.113	0.146	0.195
6	0.05	0.08	0.113	0.146	0.195
7	0.05	0.08	0.113	0.146	0.195
8	0.06	0.08	0.115	0.151	0.201
9	0.05	0.08	0.115	0.151	0.202
E. KALRO X KALRO					
1	0.06	0.095	0.133	0.17	0.225
2	0.06	0.095	0.133	0.17	0.225
3	0.05	0.095	0.123	0.161	0.225
4	0.05	0.095	0.123	0.161	0.225
5	0.06	0.095	0.128	0.168	0.225
6	0.06	0.095	0.128	0.168	0.225
7	0.06	0.095	0.128	0.168	0.225
8	0.05	0.085	0.128	0.168	0.225
F. NZW*R					
1	0.05	0.08	0.113	0.148	0.228
2	0.05	0.08	0.113	0.148	0.228

3	0.05	0.08	0.113	0.148	0.228
4	0.05	0.08	0.113	0.148	0.228
5	0.05	0.08	0.113	0.148	0.228
6	0.05	0.08	0.113	0.148	0.228
G. NZW*FG					
1	0.03	0.05	0.093	0.128	0.18
2	0.03	0.05	0.093	0.128	0.208
3	0.03	0.05	0.083	0.118	0.198
4	0.03	0.05	0.083	0.118	0.198
5	0.04	0.06	0.094	0.129	0.209
6	0.04	0.06	0.095	0.208	0.208
H. NZW*D					
1	0.04	0.06	0.09	0.13	0.21
2	0.04	0.06	0.085	0.128	0.208
3	0.04	0.06	0.085	0.128	0.208
4	0.04	0.06	0.093	0.128	0.208
5	0.04	0.06	0.093	0.128	0.208
6	0.04	0.06	0.085	0.128	0.208
I. NZW*P					
1	0.05	0.08	0.113	0.148	0.23
2	0.05	0.08	0.113	0.148	0.228
3	0.05	0.08	0.115	0.148	0.228
4	0.05	0.08	0.115	0.15	0.23
5	0.05	0.08	0.115	0.15	0.23
6	0.05	0.08	0.115	0.15	0.23
7	0.05	0.08	0.115	0.15	0.23
J. KALRO X KALRO					
1	0.06	0.094	0.127	0.16	0.26
2	0.05	0.08	0.113	0.162	0.262
3	0.05	0.08	0.113	0.162	0.262
4	0.05	0.08	0.113	0.162	0.262
5	0.05	0.08			
6	0.05	0.08	0.11	0.16	0.26
7	0.06	0.085	0.11	0.147	0.237
8	0.06	0.08	0.112	0.15	0.25
9	0.05	0.08	0.113	0.15	0.25
10	0.05	0.08	0.113	0.16	0.26

Appendix IX: Growth characteristics of domesticated rabbit breeds in North Rift and Western Kenya from week 5 to 16

NZW*FG												
	WK5	WK6	WK7	WK8	WK9	WK 10	WK 11	WK 12	WK 13	WK 14	WK 15	WK 16
	0.25	0.33	0.14	0.56	0.70	0.85	1.00	1.15	1.30	1.50	1.70	1.90
	0.25	0.33	0.14	0.56	0.70	0.85	1.00	1.15	1.30	1.50	1.70	1.90
	0.26	0.34	0.42	0.56	0.70	0.84	1.00	1.15	1.30	2.00	1.70	1.90
	0.26	0.23	0.42	0.57	0.70	0.86	1.00	1.15	1.31	2.00	1.71	1.91
	0.26	0.34	0.42	0.57	0.71	0.86	1.01	1.55	1.31	1.51	1.71	1.91
	0.26	0.34	0.42	0.57	0.71	0.86	1.01	1.16	1.31	1.51	1.71	
	0.26	0.32	0.33	0.56	0.70	0.85	1.00	1.21	1.30	1.67	1.70	1.90
KALRO X KALRO												
	0.26	0.34	0.42	0.57	0.71	0.86	1.01	1.16	1.31	1.51	1.71	1.91
	0.26	0.34	0.42	0.57	0.72	0.86	1.01	1.16	1.31	1.51	1.71	1.91
	0.26	0.35	0.43	0.57	0.72	0.86	1.01	1.16	1.31	1.51	1.71	1.91
	0.26	0.35	0.43	0.57	0.72	0.86	1.01	1.16	1.31	1.51	1.71	1.91
	0.26	0.35	0.43	0.58	0.72	0.87	1.02	1.17	1.32	1.52	1.72	1.92
	0.26	0.34	0.40	0.58	0.69	0.87	0.99	1.14	1.29	1.49	1.69	1.89
	0.26	0.34	0.42	0.57	0.71	0.86	1.01	1.16	1.31	1.51	1.71	1.91
NZW*SF												
	0.28	0.36	0.44	0.58	0.73	0.87	1.02	1.17	1.32	1.52	1.77	1.94
	0.28	0.36	0.44	0.58	0.73	0.87	1.02	1.17	1.31	1.57	1.72	1.97
	0.28	0.36	0.43	0.58	0.72	0.87	1.02	1.17	1.32	1.52	1.78	1.92
	0.28	0.36	0.44	0.59	0.73	0.88	1.03	1.18	1.38	1.58	1.78	1.98
	0.28	0.36	0.44	0.59	0.73	0.88	1.03	1.75	1.37	1.57	1.77	1.97
	0.28	0.36	0.33	0.50	0.64	0.79	0.93	1.09	1.24	1.44	1.64	1.84
	0.27	0.35	0.34	0.48	0.63	0.77	0.92	1.09	1.22	1.42	1.62	1.82
	0.27	0.35	0.41	0.55	0.70	0.84	0.99	1.23	1.31	1.52	1.72	1.92
NZW*D												
	0.31	0.36	0.51	0.65	0.81	0.96	1.10	1.31	1.51	1.76	2.01	2.21
	0.29	0.36	0.51	0.65	0.81	0.96	1.10	1.31	1.51	1.76	2.01	2.21
	0.29	0.36	0.51	0.51	0.81	0.96	1.10	1.31	1.51	1.76	2.01	2.21
	0.28	0.36	0.44	0.59	0.73	0.88	1.03	1.18	1.33	1.53	1.73	1.93
	0.28	0.36	0.44	0.58	0.73	0.87	1.02	1.17	1.32	1.52	1.72	
	0.28	0.36	0.44	0.58	0.73	0.87	1.02	1.17	1.32	1.52	1.72	
	0.27	0.36	0.44	0.58	0.73	0.88	1.02	1.17	1.32	1.47	1.62	
	0.28	0.36	0.44	0.52	0.67	0.81	0.96	1.11	1.26	1.46	1.66	1.86
	0.28	0.36	0.44	0.59	0.88	0.88	1.04	1.12	1.34	1.54	1.74	1.94
	0.28	0.36	0.46	0.58	0.76	0.90	1.04	1.20	1.38	1.59	1.80	2.06
KALRO X KALRO												
	0.33	0.43	0.53	0.98	0.83	0.98	1.18	1.38	1.53	1.83	2.08	2.35
	0.33	0.43	0.53	0.68	0.83	0.97	1.12	1.27	1.42	1.62	1.82	2.20
	0.40	0.38	0.46	0.60	0.75	0.89	1.04	1.19	1.34	1.54	1.74	1.96

	0.30	0.38	0.46	0.60	0.75	0.89	1.04	1.19	1.34	1.54	1.74	1.96
	0.30	0.43	0.51	0.65	0.80	0.94	1.09	1.24	1.39	1.59	1.74	
	0.33	0.43	0.51	0.65	0.80	0.94	1.09	1.24	1.39	1.59	1.79	
	0.33	0.43	0.51	0.65	0.80	0.94	1.09	1.24	1.39	1.59	1.79	1.94
	0.33	0.43	0.51	0.65	0.80	0.94	1.09	1.24	1.39	1.59	1.79	1.96
	0.33	0.41	0.50	0.68	0.79	0.94	1.09	1.25	1.40	1.61	1.81	2.06
NZW*R												
	0.31	0.39	0.47	0.61	0.76	0.90	1.05	1.20	1.40	1.55	1.80	1.99
	0.32	0.41	0.47	0.63	0.78	0.92	1.07	1.22	1.37	1.57	1.77	1.97
	0.50	0.58	0.66	0.80	0.95	1.09	1.24	1.39	1.54	1.74	1.94	2.14
	0.50	0.58	0.66	0.80	0.95	1.09	1.24	1.39	1.54	1.74	1.94	2.14
	0.50	0.58	0.65	0.78	0.82	0.97	1.11	1.26	1.15	1.30	1.94	1.65
	0.50	0.58	0.65	0.79	0.84	0.99	1.14	1.29	1.44	1.64	1.45	2.64
	0.43	0.52	0.59	0.74	0.85	0.99	1.14	1.29	1.41	1.59	1.81	2.09
NZW*P												
	0.29	0.38	0.40	0.58	0.73	0.88	1.02	1.17	1.37	1.58	1.67	1.75
	0.29	0.37	0.45	0.59	0.74	0.88	1.03	1.18	1.33	1.53	1.72	1.93
	0.28	0.36	0.49	0.58	0.73	0.87	1.02	1.17	1.32	1.52	1.72	1.92
	0.28	0.36	0.49	0.58	0.73	0.87	1.02	1.17	1.32	1.52	1.72	1.92
	0.29	0.37	0.45	0.59	0.74	0.88	1.03	1.18	1.33	1.53	1.73	1.93
	0.29	0.37	0.45	0.59	0.74	0.88	1.03	1.18	1.33	1.53	1.73	1.93
	0.28	0.37	0.45	0.59	0.73	0.88	1.03	1.18	1.34	1.54	1.72	1.90
NZW*KALRO												
	0.37	0.45	0.53	0.68	0.80	0.97	1.12	1.27	1.42	1.62	1.82	2.02
	0.29	0.37	0.45	0.59	0.74	0.88	1.03	1.18	1.33	1.53	1.73	1.93
	0.29	0.37	0.45	0.59	0.74	0.88	1.03	1.18	1.33	1.53	1.73	1.93
	0.29	0.37	0.45	0.59	0.74	0.88	1.03	1.18	1.33	1.53	1.73	1.93
	0.29	0.37	0.45	0.59	0.74	0.88	1.03	1.18	1.33	1.53	1.73	1.93
	0.29	0.37	0.45	0.59	0.74	0.88	1.03	1.18	1.33	1.53	1.73	1.93
	0.30	0.38	0.46	0.61	0.75	0.90	1.05	1.20	1.35	1.55	1.75	1.95
NZW*P												
	0.30	0.38	0.47	0.60	0.76	0.91	1.06	1.21	1.36	1.56	1.76	1.96
	0.31	0.39	0.47	0.61	0.76	0.90	1.05	1.20	1.35	1.55	1.75	1.95
	0.31	0.38	0.47	0.61	0.76	0.90	1.05	1.20	1.35	1.55	1.75	1.95
	0.31	0.39	0.47	0.62	0.76	0.91	1.06	1.21	1.36	1.56	1.76	1.96
	0.31	0.39	0.47	0.62	0.76	0.91	1.06	1.21	1.36	1.56	1.76	1.96
	0.31	0.39	0.47	0.62	0.76	0.91	1.06	1.21	1.36	1.56	1.76	1.96
	0.31	0.39	0.47	0.62	0.76	0.91	1.06	1.21	1.36	1.56	1.76	1.96
	0.31	0.39	0.47	0.61	0.76	0.90	1.05	1.20	1.35	1.55	1.75	1.95
KALRO X KALRO												
	0.36	0.46	0.56	0.67	0.78	0.88	0.91	1.06	1.27	1.29	1.49	1.68
	0.36	0.46	0.56	0.71	0.86	0.01	1.21	1.41	1.61	1.81	2.01	2.21
	0.36	0.46	0.56	0.70	0.86	0.01	1.21	1.41	1.61	1.86	2.36	2.61
	0.36	0.46	0.56	0.70	0.84	0.99	1.13	1.28	1.42	1.62	1.86	2.11
	0.36	0.50	0.64	0.79	0.90	0.06	1.21	1.36	1.50	1.70	1.84	2.00
	0.33	0.42	0.51	0.63	0.80	0.94	1.09	1.29	1.49	1.69	1.89	2.09

	0.35	0.45	0.55	0.63	0.84	0.99	1.19	1.29	1.59	1.84	2.09	2.34
	0.35	0.45	0.55	0.63	0.84	0.99	1.19	1.39	1.59	1.84	2.09	2.34
	0.36	0.50	0.64	0.79	0.90	0.06	1.21	1.36	1.36	1.70	1.84	2.00
	0.35	0.46	0.57	0.69	0.85	0.55	1.15	1.31	1.49	1.70	1.94	2.15

Appendix X: To evaluate the carcass traits of the crosses of domesticated rabbit breeds in North Rift and Western Kenya

FGR carcass traits

ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	2395	2325	2075
hot carcass weight (g)	1240	1240	1020
Skin with head and limbs weight (g)	590	430	560
Lung weight (g)	14	14	14
Liver weight (g)	79	42	67
Kidney weight (g)	18	12	15
Heart weight (g)	7	6	6
Carcass length (cm)	31	34	30
Lumbar circumference length (cm)	25	24	25
Hind legs weight (g)	185	165	135
Fore legs weight (g)	92	89	85
Breast and ribs weight (g)	240	200	240
Loin and abdominal wall weight (g)	64	64	64
Meat/bone ratio from a dissected hind leg	2530	2531	3430
Perirenal fat (g)	0	0	0
marbling score	0	0	0
ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	2395	2325	2075
hot carcass weight (g)	124	124	1020
Skin with head and limbs weight (g)	590	190	199
Lung weight (g)	14	14	14
Liver weight (g)	79	42	67
Kidney weight (g)	18	12	15
Heart weight (g)	7	6	6
Carcass length (cm)	31	34	30
Lumbar circumference length (cm)	25	24	25
Hind legs weight (g)	185	165	135
Fore legs weight (g)	92	89	85
Breast and ribs weight (g)	240	200	240
Loin and abdominal wall weight (g)	64	64	64
Meat/bone ratio from a dissected hind leg	3425	3030	2531
Perirenal fat (g)	0	0	0
marbling score	0	0	0

Appendix XI: SFR carcass traits

ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	1990	2270	1620
hot carcass weight (g)	930	1205	900
Skin with head and limbs weight (g)	460	585	400
Lung weight (g)	11	22	13
Liver weight (g)	29	22	43
Kidney weight (g)	14	18	16
Heart weight (g)	6	10	6
Carcass length (cm)	30	32	28
Lumbar circumference length (cm)	23	25	22
Hind legs weight (g)	140	110	110
Fore legs weight (g)	73	95	53
Breast and ribs weight (g)	245	280	225
Loin and abdominal wall weight (g)	76	73	73
Meat/bone ratio from a dissected hind leg	2528	2526	2522
Perirenal fat (g)	0	0	0
marbling score	0	0	0
ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	1990	2270	1620
hot carcass weight (g)	930	1205	900
Skin with head and limbs weight (g)	460	585	400
Lung weight (g)	11	22	13
Liver weight (g)	29	22	43
Kidney weight (g)	14	18	16
Heart weight (g)	6	10	6
Carcass length (cm)	30	32	28
Lumbar circumference length (cm)	23	23	22
Hind legs weight (g)	140	170	110
Fore legs weight (g)	73	95	53
Breast and ribs weight (g)	245	280	225
Loin and abdominal wall weight (g)	73	73	73
Meat/bone ratio from a dissected hind leg	2528	2526	2522
Perirenal fat (g)	0	0	0
marbling score	0	0	0

Appendix XII: DR Carcass Traits

ATRIBUTES	Rep. 1	Rep. 2	Repl. 3
Live weight (g)	1790	1935	2015
hot carcass weight (g)	930	480	995
Skin with head and limbs weight (g)	510	490	485
Lung weight (g)	17	59	14
Liver weight (g)	55	18	43
Kidney weight (g)	14	6	18
Heart weight (g)	6	31	6
Carcass length (cm)	29	25	29
Lumbar circumference length (cm)	25	155	25
Hind legs weight (g)	140	41	145
Fore legs weight (g)	56	255	79
Breast and ribs weight (g)	190	76	255
Loin and abdominal wall weight (g)	76	1836	76
Meat/bone ratio from a dissected hind leg	1831	2526	1839
Perirenal fat (g)	0	0	0
marbling score	0	0	0
ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	1790	1935	2260
hot carcass weight (g)	840	890	1930
Skin with head and limbs weight (g)	515	480	565
Lung weight (g)	17	14	14
Liver weight (g)	55	59	50
Kidney weight (g)	14	18	16
Heart weight (g)	6	6	7
Carcass length (cm)	29	31	31
Lumbar circumference length (cm)	25	25	23
Hind legs weight (g)	140	155	170
Fore legs weight (g)	56	41	87
Breast and ribs weight (g)	190	255	210
Loin and abdominal wall weight (g)	76	76	65
Meat/bone ratio from a dissected hind leg	1831	1836	1839
Perirenal fat (g)	0	0	0
marbling score	0	0	0

Appendix XIII: RR Carcass Traits

ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	2010	1925	2015
hot carcass weight (g)	900	980	995
Skin with head and limbs weight (g)	510	530	14
Lung weight (g)	9	12	43
Liver weight (g)	68	40	18
Kidney weight (g)	16	15	6
Heart weight (g)	6	6	29
Carcass length (cm)	30	31	25
Lumbar circumference length (cm)	23	24	145
Hind legs weight (g)	150	160	79
Fore legs weight (g)	77	77	255
Breast and ribs weight (g)	270	160	76
Loin and abdominal wall weight (g)	69	69	69
Meat/bone ratio from a dissected hind leg	1831	1836	1839
Perirenal fat (g)	0	0	0
marbling score	0	0	0
ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	1790	1935	2015
hot carcass weight (g)	840	890	995
Skin with head and limbs weight (g)	515	480	435
Lung weight (g)	17	14	14
Liver weight (g)	55	59	43
Kidney weight (g)	14	18	18
Heart weight (g)	6	6	6
Carcass length (cm)	29	31	29
Lumbar circumference length (cm)	25	25	25
Hind legs weight (g)	140	155	145
Fore legs weight (g)	56	41	79
Breast and ribs weight (g)	190	255	255
Loin and abdominal wall weight (g)	76	76	76
Meat/bone ratio from a dissected hind leg	1831	1836	1839
Perirenal fat (g)	0	0	0
marbling score	0	0	0

Appendix XIV: PR Carcass Traits

ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	2050	2000	1790
hot carcass weight (g)	1420	1000	1200
Skin with head and limbs weight (g)	510	480	550
Lung weight (g)	9	10	12
Liver weight (g)	43	40	45
Kidney weight (g)	8	7	7
Heart weight (g)	4	10	7
Carcass length (cm)	30	29	30
Lumbar circumference length (cm)	22	25	27
Hind legs weight (g)	165	100	160
Fore legs weight (g)	45	30	44
Breast and ribs weight (g)	270	270	265
Loin and abdominal wall weight (g)	70	61	69
Meat/bone ratio from a dissected hind leg	1828	1827	2328
Perirenal fat (g)	0	0	0
marbling score	0	0	0
ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	2050	2000	1790
hot carcass weight (g)	1240	1000	1200
Skin with head and limbs weight (g)	510	480	550
Lung weight (g)	9	10	12
Liver weight (g)	43	40	45
Kidney weight (g)	14	7	7
Heart weight (g)	4	10	7
Carcass length (cm)	30	29	30
Lumbar circumference length (cm)	22	25	27
Hind legs weight (g)	165	100	160
Fore legs weight (g)	45	30	44
Breast and ribs weight (g)	270	270	265
Loin and abdominal wall weight (g)	70	61	69
Meat/bone ratio from a dissected hind leg	1828	1827	2828
Perirenal fat (g)	0	0	0
marbling score	0	0	0

Appendix XV: KALRO Carcass Traits

ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	2260	2250	2205
hot carcass weight (g)	1030	1325	1290
Skin with head and limbs weight (g)	495	590	455
Lung weight (g)	13	28	25
Liver weight (g)	51	52	45
Kidney weight (g)	18	14	18
Heart weight (g)	7	7	7
Carcass length (cm)	31	33	24
Lumbar circumference length (cm)	23	26	25
Hind legs weight (g)	111	190	100
Fore legs weight (g)	81	101	80
Breast and ribs weight (g)	265	290	155
Loin and abdominal wall weight (g)	93	93	93
Meat/bone ratio from a dissected hind leg	1828	1827	2328
Perirenal fat (g)	0	0	0
marbling score	0	0	0
ATRIBUTES	Rep. 1	Rep. 2	Rep. 3
Live weight (g)	2260	2250	2505
hot carcass weight (g)	990	1325	980
Skin with head and limbs weight (g)	495	590	455
Lung weight (g)	13	28	25
Liver weight (g)	51	52	35
Kidney weight (g)	18	14	18
Heart weight (g)	7	7	7
Carcass length (cm)	31	33	24
Lumbar circumference length (cm)	23	26	25
Hind legs weight (g)	111	190	100
Fore legs weight (g)	81	101	108
Breast and ribs weight (g)	265	290	265
Loin and abdominal wall weight (g)	93	93	93
Meat/bone ratio from a dissected hind leg	1846	1946	1951
Perirenal fat (g)	0	0	0
marbling score	0	0	0

Appendix XVI: Feed Conversion Ratio FCR) and Feed Conversion Efficiency (FCE)

	NZW*FG	NZW*SF	NZW*D	NZW*R	NZW*P	NZW*KALRO	F-Ratio
Initial mean body weight	1336.00±	1301.67±	1346.67 ±	1406.00 ±	1354.43 ±	1305.83±	4.45
	17.41ab	5.16a	33.48ab	143.84b	10.98ab	10.68a	0.0002
final body weight gain	1899.33±	1899.00±	1946.67 ±	2088.00 ±	1954.43 ±	1905.83±	2.27
	73.33a	5.47ab	33.48ab	322.27bc	0.98aab	10.68ab	0.0307
mean weight gain	600.00	610.71	642.33	600.00	682.00	563.33	0.69
	10.00	22.44	18.80	10.00	16.80	19.81	0.7111
mean daily weight gain	21.43	21.81	22.94	21.43	24.36	20.12	0.69
	0.00	0.80	2.46	0.00	9.17	3.21	0.7111
40% mean daily feed intake	81.79	84.79	86.55	87.80	74.01	82.82	105.10
	7.27	5.28	6.70	6.33	5.53	8.07	0.00
100% mean daily feed intake	114.50	118.70	121.17	122.92	103.61	115.95	105.10
	6.00	5.50	4.50	5.00	4.50	7.00	0.00
	NZW*FG	NZW*SF	NZW*D	NZW*R	NZW*P	NZW*KALRO	F-Ratio
Initial mean body weight	284.83	256.67	301.67	434.33	308.00	274.29	19.24
	5.31abc	4.08a	33.48bcd	94.04f	3.65cd	1.89ab	0.00
final body weight gain	587.67	560.00	606.67	735.17	612.29	554.29	7.65
	6.31ab	5.48a	33.48abc	87.48d	5.50abc	45.96a	0.00
Mean weight gain	302.84	303.33	305.00	300.84	304.29	280.00	>0.05
	41.31	30.08	32.48	34.04	30.65	21.89	
mean daily weight gain	10.82	10.83	10.89	10.74	10.87	10.00	p>0.05
	0.42	0.31	0.80	0.65	0.44	0.20	
100% mean daily feed intake	31.37	29.25	30.50	31.16	29.34	31.00	p>0.05
	1.00	2.12	3.16	6.70	3.21	6.70	
Feed conversion efficiency	2.90	2.70	2.80	2.90	2.70	3.10	
	0.04	0.02	0.03	0.05	0.05	0.02	
	NZW*FG	NZW*SF	NZW*D	NZW*R	NZW*P	NZW*KALRO	F-Ratio

Initial mean body weight	733.17	705.00	748.33	847.67	758.71	699.29	8.48
	5.31abc	4.08ab	33.48bcd	94.04f	3.65cd	18.9a	<0.0001
final body weight gain	1177.67	1214.17	1196.67	1291.00	1204.43	1229.29	1.54
	6.31ab	164.57abc	33.48ab	82.31bc	0.98ab	232.91abc	0.1557
Mean weight gain	444.50	509.17	448.34	443.33	445.72	530.00	
	5.62	5.51	6.00	5.85	5.64	5.40	
mean daily weight gain	15.88	18.18	16.01	15.83	15.92	18.93	
	4.97	5.12	6.16	6.70	3.21	6.70	
100% mean daily feed intake	68.26	80.01	80.06	66.50	60.49	115.46	
	13.04	12.78	13.92	13.57	13.08	12.53	
Feed conversion efficiency	4.30	4.40	5.00	4.20	3.80	6.10	
	0.04	0.08	0.06	0.05	0.09	0.02	

Appendix XVII: Rabbit Photos

Appendix XVIII: Similarity Report

Turnitin Originality Report

POPULATION STRUCTURE, GROWTH AND CARCASS CHARACTERIZATION OF DOMESTICATED RABBITS, (Oryctolagus cuniculus L) IN NORTH RIFT AND WESTERN KENYA by Philomena Sergon

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