

**PERFORMANCE OF IMPROVED INDIGENOUS CHICKEN REARED ON  
SORGHUM-BASED RATIONS UNDER THREE PRODUCTION SYSTEMS IN  
WESTERN AND NORTH-RIFT REGIONS, KENYA**

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**A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN ANIMAL  
PRODUCTION, DEPARTMENT OF ANIMAL SCIENCE, SCHOOL OF  
AGRICULTURE AND BIOTECHNOLOGY,  
UNIVERSITY OF ELDORET, KENYA**

**2025**

## DECLARATION

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**DEDICATION**

I dedicate this work to my loving parents, Mrs. Christine Sote Chesang and my late father, Eng. George Kiptui Chesang. Special dedication goes to my siblings, Mr. Albert Kipyegon, Ms. Betty Jerotich, Ms. Gladys Jelagat, Ms. Beverly Jeruto and Ms. Jackline Jepchumba, for their spiritual, moral, and financial support. Extra special dedication is also extended to my loving friend, Mable Kipkoech.

## ACKNOWLEDGEMENTS

I am deeply grateful to the Almighty God for the blessing of life and the guidance provided during this study. I want to profusely acknowledge McKnight Foundation for the financial assistance provided through the Collaborative Crop Research Program (CCRP) Grant Number 20 – 085 that enabled me to carry out this study. I am indebted to the PI of the Project on “Transforming Sorghum-based Farming Systems in Eastern & Western Kenya through Agro-ecological Intensification,” Professor Samuel Gudu of Rongo University for permitting my studentship on the project. Additionally, I want to acknowledge moral, logistical/technical support and general encouragements from Dr. Benson Ouma Nyongesa of School of Science, University of Eldoret. I also appreciate the Agricultural Extension Officers and farmers under the CCRP Program from Siaya, Busia, and Uasin Gishu Counties for allowing me to use their farms and providing vital information for the field study. I also thank University of Eldoret, specifically the Department of Animal Science in the School of Agriculture and Biotechnology for allowing me to pursue my studies. I recognize the staff as well as students from SAGR fraternity; more so, from Animal Science Department, who offered vital moral/social support and valuable encouragements which is neither taken lightly nor for granted. I acknowledge Spectralab Analytical Services, Nairobi for allowing me to use their facilities to analyse the experimental diets. In a very special way, I want to appreciate my supervisors – Drs. Eunice Akello Mewa and Rachuonyo, Harold Anindo as well as Professor Beatrice Ang’iyo Were – for their guidance, encouragements and unmerited support not only in my research work but also on the overall outcome of my academic advancement. They worked with me closely throughout as I focused on aspects to do with sorghum-poultry feeding interventions on

nutrition and farm productivity. I also acknowledge the crucial support, encouragement, and prayers of my family throughout this endeavour.

## ABSTRACT

Improved indigenous chicken (IIC) contribute to nutritional requirements, socio-cultural benefits, and welfare of smallholder farmers. Maize as an energy source in chicken feed is becoming unrealistic due to high costs and competition with humans; therefore, alternatives like low-tannin sorghum should be considered. Semi-arid conditions in Western Kenya make sorghum a viable option. Objectives of this study were to determine performance of IIC on sorghum-based rations under three production systems and investigate socio-economic drivers of IIC rearing in Busia, Siaya and Uasin Gishu Counties. A randomized complete block experimental design with split-plot arrangement of treatments determined nutrient composition of sorghum-based diets and growth of 390, 4-week-old IIC for 12 weeks. Diets consisted T<sub>1</sub> (50%), T<sub>2</sub> (75%), RUC26 sorghum variety inclusion levels, T<sub>3</sub> – a commercial feed designated as Control and T<sub>4</sub> was Free-range feeding. Farmers were purposively selected; those practicing Semi-intensive and Intensive production systems received one of the diets, while Free-range farmers received none. Field survey investigated socio-economic dynamics from forty-five purposively selected sorghum-growing and chicken-rearing farmers supplied eight Rainbow Rooster growers. Nutrient composition showed significant differences ( $p < 0.05$ ) among diets for crude ash, crude fat, crude fibre and metabolizable energy. Crude protein was highest (15.15%) in T<sub>1</sub>. Metabolizable energy (3616 Kcal/Kg) and lysine (0.86%) were highest in T<sub>2</sub>. Growth of IIC was significantly different ( $p < 0.05$ ) among diets and production systems. Diet T<sub>1</sub> had higher (694.56g) weight gain than T<sub>3</sub> (668.02g), which significantly differed ( $p < 0.05$ ) from T<sub>2</sub> (618.83g). Weight gain in Intensive system was significantly ( $p < 0.05$ ) higher (880.26g) than Free-range (424.94g) and Semi-intensive (416.25g) systems. Survey showed that most (36%) farmers' age ranged from 30 to 39 years, with majority (58%) being female. Management practices adopted most were veterinarian services (76%) and poultry housing (67%). The IIC breed was highly (69%) preferred, with 58% having 1 to 15 birds flock size. Most (69%) farmers purchased feeds, majorly (24%) being chick mash. Home-grown rations were formulated by majority (71%), with maize (71%) intensely used than sorghum (51%). Feed cost per kilogram of T<sub>1</sub> (63 KSh) and T<sub>2</sub> (59 KSh) were significantly lower ( $p < 0.05$ ) than T<sub>3</sub> (70 KSh). Most (64%) farmers did not incur marketing costs. Egg and chicken sales were high at 78%, and domestic consumption of chicken products was 98%. Diet T<sub>1</sub> met minimum nutrient requirements, promoted high growth, and was cost-effective. Growth was best in intensive system, and IIC breed was highly preferred. Farmers should grow RUC26 sorghum for chicken feed.

**Keywords:** Chicken performance, Improved indigenous chicken, Low tannin sorghum, Production systems, Socio-economic dynamics, Sorghum-based rations

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**LIST OF ABBREVIATIONS**

<b>AEZ</b>	-	Agro-ecological Zone
<b>AM</b>	-	Ante Meridiem
<b>ANOVA</b>	-	Analysis of Variance
<b>AOAC</b>	-	Association of Official Analytical Chemists
<b>ASAL</b>	-	Arid and Semi-Arid Land
<b>CF</b>	-	Crude Fibre
<b>CP</b>	-	Crude Protein
<b>FCR</b>	-	Feed Conversion Ratio
<b>FI</b>	-	Feed Intake
<b>FAO</b>	-	Food and Agriculture Organization of the United Nations
<b>GDP</b>	-	Gross Domestic Product
<b>HSD</b>	-	Honest Significant Difference
<b>IIC</b>	-	Improved Indigenous Chicken
<b>IC</b>	-	Indigenous Chicken
<b>KALRO</b>	-	Kenya Agricultural and Livestock Research Organization
<b>KARI</b>	-	Kenya Agriculture Research Institute
<b>KEBS</b>	-	Kenya Bureau of Standards
<b>KENAS</b>	-	Kenya Accreditation Service
<b>KNBS</b>	-	Kenya National Bureau of Statistics
<b>KSh</b>	-	Kenya Shilling
<b>LTS</b>	-	Low Tannin Sorghum
<b>LM</b>	-	Lower Medium
<b>ME</b>	-	Metabolizable Energy
<b>MoALF</b>	-	Ministry of Agriculture Livestock and Fisheries
<b>NFE</b>	-	Nitrogen Free-Extracts
<b>PM</b>	-	Post Meridiem
<b>RCBD</b>	-	Randomized Complete Block Design
<b>REP</b>	-	Replicate
<b>SSA</b>	-	Sub-Saharan Africa
<b>T<sub>1</sub></b>	-	Treatment 1
<b>T<sub>2</sub></b>	-	Treatment 2
<b>T<sub>3</sub></b>	-	Treatment 3
<b>T<sub>4</sub></b>	-	Treatment 4
<b>UM</b>	-	Upper Midland

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background information

Poultry is the world's primary source of animal protein (FAO, 2022), with meat and eggs being widely consumed products, always having a growing demand due to their high-quality protein and low-fat level (FAO, 2020). Poultry accounts for more than 30% of all animal protein consumption worldwide. It is estimated that by 2030, poultry will account for 41% of all animal protein consumed by people due to low income and population growth (Kolobe *et al.*, 2022). Sub-Saharan African rural communities obtain food security, household income, breeding stock, and socio-cultural and religious uses from indigenous chicken (Kanyama *et al.*, 2023). Poultry farming is a major livestock subsector in the country with an estimated 31.8 million birds, 81% of which are indigenous chickens (Anyona *et al.*, 2023).

Poultry farming, including indigenous breeds is vital in Kenya's economic and social life of resource-poor households, contributing to a cheap source of animal proteins and cash income (Wambua *et al.*, 2021). In many rural communities, indigenous chicken play key roles in improving food security, socio-cultural development, economic growth, insurance against emergencies and has the potential to reduce poverty (Cheruiyot *et al.*, 2025). The robust nature of chicken enables them to flourish in tough environmental conditions, requiring little inputs or care (Muremera *et al.*, 2022). Chicken products offer nutritious protein, essential vitamins, and minerals (Susan *et al.*, 2023).

Chicken production systems are mainly categorized into three, namely: Free-range, Semi-intensive, and Intensive. They categorized by their housing and feeding systems. Free-

range is scavenging outdoors, semi-intensive system is partly indoors and fed with home-made feed, while in the intensive system the chickens are permanently indoors and fed with commercial or home-made feed or both (Wilson *et al.*, 2022). The backyard production system has recently gained popularity in East Africa, featuring more productive and resilient dual-purpose chicken breeds (Wilson, 2015; Vernooij *et al.*, 2018). These improved breeds have enabled the economically disadvantaged smallholders to transition from backyard to market-oriented production (Ahuja *et al.*, 2008; Pius & Mbagi, 2018). The study considered the Rainbow Rooster IIC breed whose parent stock was imported from Indbro Research and Breeding Farms Private Limited, India. Rainbow Rooster was developed through interbreeding of fast-growing broilers and high-laying brown birds which are resistant to diseases. They have desirable characteristics ideal for rearing in rural areas and most areas in Kenya (Njuguna *et al.*, 2017).

The poultry industry in sub-Saharan Africa (SSA) is faced with inadequate feed, associated with high cost of feeds (Ochieng *et al.*, 2021). Seasonal changes, including climate change and drought conditions, affect quantity and quality of feed resources, resulting in shortages and increased feed costs (Mthethwa, 2018). Poultry feed accounts for about 70% or more of total cost of production (Etuah *et al.*, 2021). Feed quality and quantity are important aspects determining production and productivity of chickens (Wilson *et al.*, 2023). High feed costs and scarcity are major problems faced by livestock, specifically poultry farmers residing in rural communities (Kolobe *et al.*, 2022). Increased feed costs result from competition among human, animal and industrial users (Moritz *et al.*, 2023).

Cereal grains are an indispensable source of energy and essential nutrients in everyday human and livestock diet through direct consumption (Mnisi *et al.*, 2023). Cereals are

commonly used as energy sources in poultry diets due to their high carbohydrate content (Mutinda, 2023). Maize is the major cereal grain used globally in the poultry feed sector. Price volatility and changing availability of maize has stimulated interest in using other less popular but upcoming crops such as sorghum grain as feed ingredients (Ciurescu *et al.*, 2023). In advanced countries, about 90 percent of maize is utilized for making animal feeds and other industrial products whereas in developing countries nearly the same percentage (80 – 90 percent) is consumed as food (Rajoo, 2021). The ever-growing demand for this major cereal grain for human consumption, livestock feeds and some industrial uses has pushed its market price to an alarming height (Maidala *et al.*, 2020). There is therefore need to use alternative sources of energy whose performance is similar to that of maize and this can be actualized by using Low Tannin Sorghum (LTS) grains (Kleih *et al.*, 2000).

Sorghum (*Sorghum bicolor* L. Moench) is the fifth most vital cereal crop in the world and the second most cultivated crop in Africa after maize. It is a native and well-adapted cereal crop to the tropical areas of Africa (Omoyo, 2020). In Sub-Saharan Africa, drought-resistant crops like sorghum boost food security amidst climate change. Kenya is boosting sorghum production since its landmass is 80% ASAL (Okeyo *et al.*, 2020). Sorghum has enormous potential and is particularly suited to production for processing for both human consumption and livestock feed (Ochieng *et al.*, 2020).

Sorghum is considered a climate-resilient crop owing to its ability to adapt to varied agro-ecological conditions, including drought-proneness, limited resources and erratic rainfall patterns (Hao *et al.*, 2021). Sorghum is known for drought resistance (Batista *et al.*, 2019; Reddy, 2019; Isticioaia *et al.*, 2020; Abreha *et al.*, 2022) and ability to yield high under

stressed conditions (Clarke *et al.*, 2019; Thomas *et al.*, 2019). Sorghum grain is made up of carbohydrates followed by proteins, lipids, fibre and ash (Althwab *et al.*, 2015; Cabrera-Ramírez *et al.*, 2020). Sorghum fodder is a source of energy for poultry (Utama *et al.*, 2023). Sorghum possess a nutrient composition similar to maize and can substitute it in poultry feeds considering its nutritional quality, affordability and availability (Maunder, 2002; Rumler *et al.*, 2021).

Sorghum contains anti-nutritional substances like tannin, kafirin and phytate that restrict its use in poultry diets, by binding nutrients to form complex compounds that are hard to be broken down in the digestive tract of poultry (Selle *et al.*, 2018, Hassan *et al.*, 2020; Selle *et al.*, 2021). New low-tannin sorghum varieties are maize alternatives due to their low levels of anti-nutritional substances enabling increased inclusion in diets without negative effects in chicken performance (Saleh *et al.*, 2019; Puntigam *et al.*, 2020; Osman *et al.*, 2022). Sorghum variety used in this study was RUC26.

## **1.2 Statement of the problem**

Poultry feeds have become expensive due to competition from human beings for maize consumption, which is the primary source of energy for poultry and a staple crop for many families (Wongnaa *et al.*, 2023). Moreover, sale of commercial feeds in small quantities that are affordable for smallholder chicken farmers is an uncommon practice. The availability of feed resources has been compromised due to unpredictable climatic conditions resulting in a low harvest inadequate to meet human beings and livestock needs (Fushai *et al.*, 2025). The scarce feed resources have increased the demand hence escalating costs.

The use of sorghum in poultry diets is limited because its anti-nutritional compounds bind nutrients, forming complex substances that are difficult to break down during digestion (Abu Hafsa *et al.*, 2022; Hidayat *et al.*, 2022). High-tannin sorghum varieties reduce feed intake, depress growth rate, and decrease nutrient digestibility when used as chicken feed (Yanza *et al.*, 2021). This results in low adoption and utilisation of sorghum grain as a feed ingredient by smallholder chicken farmers.

### **1.3 Justification**

The number of farmers rearing improved indigenous chicken for commercial purposes is on the upward trajectory, not only locally but regionally as well as across the nation and beyond. Village poultry systems play critical roles in food security of rural people in fragile and resource-poor ecosystems (Chaiban *et al.*, 2020). Poultry farming has been acknowledged as a strategic approach in mitigating food scarcity in rural areas (Milkias *et al.*, 2019). Poultry production contributes to sustainable food systems as it supports nutrient cycling through feed, manure and soils (Weiler *et al.*, 2023). Indigenous chicken provides vital protein and income source and contributes abundantly to the socio-economic status and cultural practices communities (Liswaniso *et al.*, 2020). The economic contributions include income generation used to cater for education, medical expenses, and agricultural inputs such as fertilizer and hybrid cultivars (Birhanu *et al.*, 2021). There is high chicken rearing in Western Kenya since communities there are associated with it. Chicken production is resilient venture and can be practiced in all agro-ecological zones without limitation. Space requirement for production is minimal and return on investment is quick. Chicken producers use local small grains as major components for inclusion in poultry diets in order to decrease cost of production and increase the profits (Sibanda *et al.*, 2023).

Sorghum, ‘the camel of cereals’, is a climate-resilient food crop that is less susceptible to the impacts of climate changes, and is therefore considered a crucial grain in many regions across the globe (Chadalavada *et al.*, 2021). Western Kenya is classified as an ASAL area where sorghum can establish well. Sorghum presents adequate nutritional characteristics and is often used to replace maize, especially in semi-arid regions (Sriagtula *et al.*, 2019). Sorghum holds a crucial position in global food security due to its versatile usage as a staple food, bioenergy source, feed for livestock and industrial products (Habyarimana *et al.*, 2020). Sorghum is considered the main source of energy for poultry feeds regarding its high energy content (Gworgwor *et al.*, 2023). Price of sorghum in many areas is 10 – 15% lower than that of maize (Visarada, 2019). Low tannins inclusion in poultry diets has a positive impact on their health and performance (Sugiharto *et al.*, 2019). Therefore, this research aimed to determine performance of improved indigenous chicken provided sorghum-based rations under three systems of production as well as investigate socio-economic drivers to keeping IIC.

## **1.4 Objectives**

### **1.4.1 Broad objective**

To contribute in enhancing food and nutrition security and poverty alleviation through promotion of rearing improved indigenous chicken (IIC) among smallholder farmers in Western Kenya and North-Rift region using sorghum-based rations and a commercial feed.

### **1.4.2 Specific objectives**

- i. To determine nutrient composition of formulated sorghum-based rations and a commercial feed used in production of improved indigenous chicken
- ii. To determine performance of improved indigenous chicken fed with formulated sorghum-based rations and a commercial feed under three production systems among smallholder farmers
- iii. To investigate the diversity of socio-economic drivers among smallholder farmers rearing improved indigenous chicken

### **1.4.3 Hypotheses**

- i.  $H_{a1}$ : Nutrient composition in formulated sorghum-based rations is similar to that of maize-based diets as well as commercial feed
- ii.  $H_{a2}$ : Sorghum-based rations give similar performance results as those of maize or commercial feed used in rearing improved indigenous chicken under three production systems
- iii.  $H_{a3}$ : There is diversity of socio-economic drivers among smallholder farmers rearing improved indigenous chicken

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Poultry production in developing countries

Poultry rearing provides income and employment to large number of people (Ajmal *et al.*, 2023). Smallholder chicken production boost rural livelihoods through income generation, family nutrition and women empowerment in developing countries (Alemayehu *et al.*, 2023). It holds significance as a vital source of sustenance and income for many small-scale farmers in Kenya (Kariithi *et al.*, 2020; Macharia *et al.*, 2020). Poultry production plays an important economic role with rural populations majorly (80%) practising it (Moussa *et al.*, 2019). Village chicken products contain macro- and micro-nutrients (Rowland *et al.*, 2018).

##### 2.1.1 Indigenous and improved indigenous chicken production

Indigenous chicken (IC) provides food and income (Mujyambere *et al.*, 2022). The IC contribute significantly to nutrition and socio-economic wellbeing of rural households (Anyona *et al.*, 2023). Producers also prefer indigenous breeds because of their resilience nature to diseases and to harsh environmental conditions which result in less need for veterinary drugs (Muhikambele, 2019; Kapella *et al.*, 2022). Despite their adaptability, IC are predominantly raised under challenging environments, which limit their optimal production. The production of IC is highly variable (Chesoo *et al.*, 2021). Countries, mainly low- and middle-income ones, are making sincere efforts to develop improved backyard poultry to overcome the slow growth, delayed maturity and poor production of indigenous breeds (Rajkumar *et al.*, 2021). Rearing IIC breeds and advancing smallholder farmer's attitude through training and creating awareness can improve chicken meat and

egg productivity (Gonta & Getaneh, 2023). The IIC is high performing and produces 180-250 eggs compared to 80-100 by the IC. It attains market weight at 4 to 5 months (Wambua *et al.*, 2022). Improved dual-purpose chickens (*Sasso* and *Kuroiler* breeds) have huge production potential due to their high genetic potential and adaptability in semi-scavenging systems (Sanka *et al.*, 2020; Guni *et al.*, 2021). The IIC breeds namely *Kuroiler*, Rainbow Rooster, *Kenbro* and Kenya Agricultural and Livestock Research Organization (KALRO) Naivasha were developed from various IC ecotypes to enhance indigenous poultry production (Kariuki *et al.*, 2022). The IIC breeds are largely dual-purpose, producing more eggs and meat compared to pure-line indigenous chicken (KARI, 2011). The combination of improved growth rate, egg productivity, adaptability, disease resistance, meat quality and dual-purpose utility make the Rainbow Rooster a highly desirable chicken breed for small-scale farmers (Anno *et al.*, 2024).

### **2.1.2 Constraints in chicken production**

Poultry farming encounters many problems such as diseases and parasites, high feed costs, drugs, water and electricity, inadequate housing facilities, predation, inadequate information on both input and output markets, scanty extension services and limited knowledge on chicken rearing (Abadi *et al.*, 2018; Mutua, 2018; Wambua *et al.*, 2021). Poultry diseases result to poor performance and flock mortalities hence affecting profitability of small-scale producers in Sub-Saharan Africa. Inadequate disease control measures have exacerbated prevalence of poultry diseases (Kanyama *et al.*, 2023b). Low quality feed supplementation that do not meet the minimum nutrient requirements contribute to poor performance of IC. These nutritional problems are mainly due to costly feeds, poor feeding regimes and feed scarcities (Melesse, 2014). Low feed supplementation

in free-range system results to poor quality of chicken products (Queenan *et al.*, 2016). The quality of feed resources foraged by IC varies seasonally and in rain-fed farming systems hence impairing their production (De Bruyn *et al.*, 2018; Miyumo *et al.*, 2018). Poor linkages to reliable marketing channels affects IC sales and consumption dynamics therefore limiting development of this value chain (Kanyama *et al.*, 2023b). Inappropriate housing systems cause stress to IC, negatively impacting their growth (Melesse, 2014; Mujyambere *et al.*, 2022).

### **2.1.3 Strategies to improve production in chicken rearing**

Appropriate strategies that could address nutrition security problems include; applying proper management practices, providing high quality feed and clean water, proper housing systems and good health care to IC (Kpomasse *et al.*, 2023). Feeding the required nutrients to poultry is important for growth, production, and health. Improving genetics plays a role in boosting production (Manyelo *et al.*, 2020).

### **2.1.4 Chicken production systems**

Chicken production systems are grouped into three main types, that is, Free-range, Semi-intensive and Intensive.

#### **2.1.4.1 Free-range production system**

Free-range (extensive) production system is regarded as low input–low output (Manyelo *et al.*, 2020). Free-range systems require more land and often require more labour than conventional methods (Rocchi *et al.*, 2019). This system is extensive or scavenging in nature. It is characterized by; keeping of few birds, specific poultry houses are rare, scavenging and occasional feeding with home grains and refuse, no regular health program

with no biosecurity and no formal marketing channel. Birds reared in free-range system are usually native, dual-purpose breeds that are adapted to the scavenging production environment (Plate 1

). Birds are produced through natural incubation. This system has high chicken mortality (often >70%) due to lack of proper health care and veterinary services (Urgesa, 2023). Night shelters include; human habitats, kitchens, rudimentary coops, or stores. Supplementation include household feeds sources (Khobondo *et al.*, 2015). All scavenging chicken producers practice supplementary feeding (100%) from all type of feed, supplemented maize account (63%) (Guteta & Ameha, 2020).

Advantages of Free-range system include; chicken are healthy because they exercise freely outdoors, minimal parasite infestation if there is enough space, little or no labour input, amount of litter is reduced in a productive manner and direct costs are low. Disadvantages include; difficulty of controlling and managing chicken, especially that young chicks are easily exposed to predators and unfavourable weather conditions, chicken eat planted seeds when foraging, losing of eggs laid in the fields, chicken are less productive, high disease transmission and high mortality (Mogesse, 2007).



**Plate 1. Free-range system IIC rearing (Source, Kiptui, 2023)**

#### 2.1.4.2 Semi-intensive production system

Semi-intensive production system flock sizes range from 50 to 200 birds; using commercial, crossbred, or indigenous breeds reared under scavenging management conditions with regular feed supplementation. Mortality rates range from 20 to >50% due to improved health care and housing (Urgesa, 2023). Levels of inputs vary in different flocks. Chicken scavenge for feed in the homestead (Kingori *et al.*, 2010). This system is common in high human population density rural and peri-urban areas (Plate 2 **Plate 2**).

Advantages of Semi-intensive system include; complete operation control, useful for recording purposes, year-round operation and economical use of land. Disadvantages include; high cost of the fencing, the risk of overstocking and exposure to various diseases if the site is not clean and dry (Majeed & Al-Gburi, 2023).



**Plate 2. Modern portable housing for semi-intensive production system**

**(Source, Kiptui, 2023)**

### 2.1.4.3 Intensive production system

Intensive system includes total confinement of birds, total dependence on their owner for all their requirements and invested capital. Production is greater than extensive system. It is mostly used by medium to large-scale commercial enterprises (Plate 3). It can be three types: Deep litter system, Slatted floor system and Battery cage system (Kpomasse *et al.*, 2023). Deep litter system was used for this experiment. Its advantages include; low cost of running the enterprise, minimum land requirement, low labour and increased value of manure. Intensive system involves rearing of commercial day-old chicks or pullets (200–1,000 broilers, 100–500 layers), provision of commercial balanced rations and presence of modern poultry houses. Producers have full access to veterinary services and mortality rates are less than 20% (Urgesa, 2023). Chicken production is highly for sale and household consumption. Intensive system is the most widely adopted worldwide as a result of its practicality and efficient handling (Pinto da Rosa *et al.*, 2021). Intensive poultry farming has a significant environmental footprint which impact diverse environmental elements, including air, water and soil (Gržinić *et al.*, 2023).



**Plate 3. Improved indigenous chicken reared in a deep litter under intensive production system (Source, Kiptui, 2023)**

## **2.2 Sorghum as a crop**

Sorghum can be utilized as food, feed and biofuel production (Stamenković *et al.*, 2020). In Africa, sorghum production plays a major role in socio-economic development through food security and in serving the increased industrial demands resulting from population growth and changing climatic patterns (Ahmad Yahaya *et al.*, 2022).

### **2.2.1 Sorghum grain production**

Sorghum is the fifth most produced cereal crop in the world, behind wheat, rice, maize and barley (Espitia-Hernández *et al.*, 2022). In Africa, it is the second most important grain after maize, producing about 20 million tons per annum and contributing one-third of the worldwide crop production (Mwenda *et al.*, 2019). Sorghum is a carbohydrate from the Gramineae family that originated in Africa. The net profits from sorghum farming are high despite low production costs of land lease and inputs such as fertilizers, seeds and pesticides (Hossain *et al.*, 2022). The nutrient content of sorghum matches that of rice, maize and wheat (Widowati & Luna, 2022). Sorghum production improves socio-economic development in Kenya and Africa (Omoyo, 2020).

Sorghum is gaining prominence as a major alternative crop in SSA and water-deficient areas, attributed to its drought resilience, modest water requirements, wide germplasm availability, and enhanced nutritional qualities (Hadebe *et al.*, 2017), pest and disease resistance and well-adapted to arid and semi-arid environments (Chibarabada *et al.*, 2017) as well addressing micro-nutrient deficiencies prevalent among farming households (Muui *et al.*, 2013; Govender *et al.*, 2017). Sorghum is well-suited to marginal areas as it

withstands harsh environments and mycotoxin contamination (Njinju *et al.*, 2022; Zarei *et al.*, 2022; Kazungu *et al.*, 2023).

### **2.2.2 Sorghum-based rations as chicken feed**

Poultry diets mainly consist of maize due to its high starch content, metabolizable energy, and carotenoid levels (Kufel *et al.*, 2019; Garcia & Shultz, 2021). Insufficient maize production and competition among humans, industry, and livestock have led to high costs of poultry feed (Maidala *et al.*, 2016; Tamburawa *et al.*, 2018; Ashiru *et al.*, 2020).

Sorghum is a suitable replacement for maize in poultry feed due to its comparable nutritional composition, adaptability to different soil types, and strong performance in poultry-rearing areas (Mbulwe *et al.*, 2020; Moritz *et al.*, 2022). Its high-energy and drought-resilient features make it an optimal crop choice amidst climate change (Lee *et al.*, 2021).

### **2.2.3 Sorghum nutritional value**

Sorghum grain is used as an energy source for poultry, pigs and ruminants. Energy is responsible for metabolism, physiological, maintenance, growth, tissue turnover, and heat production in animals (Wu *et al.*, 2020). Protein facilitate growth and muscle development. Amino acids including methionine, lysine, cysteine and threonine, are the limiting essential amino acids that poultry cannot synthesize; therefore, they must be supplied in diet to stimulate muscle development, tissue repair, facilitate metabolism and feather growth (Moritz *et al.*, 2022). Poultry diets should contain adequate levels of essential amino acids to stimulate growth and reproduction (Sibanda *et al.*, 2023).

Sorghum contains a higher protein content but digestibility of essential amino acids such as lysine, methionine and threonine are lower compared to maize (Ebadi *et al.*, 2011; Puntigam *et al.*, 2020). Amino acids and digestible lysine contents are similar to that of yellow maize (Saleh *et al.*, 2019). Crude ash and crude fibre content is higher in sorghum than maize (Manyelo *et al.*, 2019). Lipid and starch content of sorghum match that of maize (Johnston & Moreau, 2017). The comparable nutrient composition of these grains are shown in Table 1 below.

**Table 1. Nutritional composition (%) of sorghum and maize grains**

<b>Components</b>	<b>Sorghum</b>	<b>Maize</b>
Crude protein	5.9 – 16.8	12.90
Dry Matter	31.6 – 90.9	89
Ether extract	3.3 – 4.1	4.31
Ash	1.9 – 5.5	2.16
Crude fibre	3.6	2.81
Metabolizable energy, (Kcal/kg)	2539.7	2883

(Saeed *et al.*, 2013; Mnisi *et al.*, 2023)

#### **2.2.4 Anti-nutritional factors in sorghum**

Anti-nutritional factors are primarily associated with compounds or substances of natural or synthetic origin that interfere with absorption of nutrients thereby reducing nutrient intake, digestion, and utilization as well as producing adverse effect. Presence of anti-nutrients in feed limits digestibility of proteins and carbohydrates through inhibition of their respective proteolytic and amylolytic enzymes (Zubair *et al.*, 2023).

In broiler chicken, the combination of anti-nutritional factors, including tannin, phytate and kafirin compounds in grain sorghum, resulted in decreased nutritive value and palatability, affecting feed intake (FI) and, thus, reduced growth (Moritz *et al.*, 2022). Some sorghum

cultivars are known to harbour condensed tannins, a substance that exhibits potent anti-nutritional properties (Gidado *et al.*, 2020). Phytate can bind protein and minerals so that it cannot be digested in the intestinal tract of poultry (Humer *et al.*, 2015; Dersjant-Li *et al.*, 2021). Kafirin is one form of protein in sorghum, with studies showing that the composition of kafirin in sorghum protein is in the range 49–54% (Gómez Soto *et al.*, 2018).

The two categories of tannins are hydrolysable and condensed (Sugiharto *et al.*, 2019). Tannins bind nutrients including proteins and starch hence reducing the energy digestibility in non-ruminants (Houshmand *et al.*, 2015; Tapiwa, 2019). Tannins limit activities of fibrolytic and proteolytic enzymes reducing nutrient digestibility and bioavailability (Yanza *et al.*, 2021; Nipuna *et al.*, 2022). High tannin sorghum reduces absorption of minerals including calcium, phosphorous, magnesium, sodium, potassium, iron and cobalt (Hassan *et al.*, 2003). Tannin level in poultry rations ranging from 0.5% to 2.0% can cause depression in growth and egg production while 3% to 7% can cause mortality (Giner-Chavez, 1996). Tannin level ranges from 1.3 to 3.6% in high tannin sorghum and from 0.1 to 0.7% in low tannin sorghum (Myer *et al.*, 1986).

Different processing methods to reduce tannin content in feed ingredients include; cooking, dehulling, autoclaving, toasting, soaking, using wood ash, adding tallow and using tannin-binding agents and enzymes (Hassan *et al.*, 2020).

### **2.2.5 Low tannin sorghum variety**

Low tannin sorghum grains are perfect for animal feeds (Palacios *et al.*, 2021). Low tannin sorghum (Plate 4) inclusion in poultry feeds has improved due to progresses in breeding

(Arroyo *et al.*, 2016; Xu *et al.*, 2017). High dietary condensed tannin inclusion has negative impacts on chicken performance (Hidayat *et al.*, 2021). Low tannin sorghum has tannin levels of about 5% and higher nutrient bioavailability than high tannin sorghum (Batal & Dale, 2010). Low tannin sorghum is used as an alternative to maize in animal feed in countries such as Australia and the Americas (Srinivasa Rao *et al.*, 2018), although its potential is underexploited in Kenya.

Improved sorghum varieties for drought tolerance include RUE95, Nyadundo, and RUC26. Acid tolerant sorghum varieties include RUT53, RUE95, Nyadundo-2, N57, N68, T30B, RUC26, among others. Sorghum producers adopt improved varieties to enhance yields (Chavula & Turyasingura, 2023).

RUC26 sorghum variety is an improved cultivar that is drought tolerant, high yielding and adapted for acidic soils of Western Kenya. It was developed to improve sorghum production, disease resistance and adaptability to varying environmental conditions, thereby ensuring better yields and food security. In a previous study, RUC26 variety proximate composition (per 100g) results were as follows; moisture (13.24%), protein (7.99%), fibre (3.30%), fat (2.80%), carbohydrates (72.63%) and ash (1.41%) (Mugalavai & Onkware, 2018). These results defined its utilization in the animal feeds industry.



**Plate 4. Low tannin sorghum (RUC26 variety) (Source, Kiptui, 2023)**

### **2.3 Performance indicators for chicken rearing**

Performance indicators for chicken include; average daily gain, feed intake, feed conversion ratio (FCR), survival rate, among others. Growth promotion in chickens, including improved body weight gain and FCR, can be obtained by improving feed intake and feed utilisation (Rafeeq *et al.*, 2023). Feed intake (FI) refers to amount of feed consumed over a definite period of time (Prakash *et al.*, 2020). The FCR represents the ratio between feed intake and chicken body weight gain for a specific period of growth (Zampiga *et al.*, 2021). Among the key factors influencing broiler growth performance, stocking density and sex are very important (Abudabos *et al.*, 2013; Qaid *et al.*, 2016). Stocking density is defined as body mass (kg) or number of birds per unit of housing space (m<sup>2</sup>) (Abdelazeem, 2019). Stocking density has effects on animal production parameters, including performance, health, welfare and producer profitability. It can have adverse effects on performance such as body weight, feed efficiency and mortality (Jhetam *et al.*, 2022).

### **2.4 Socio-economic drivers of poultry production by smallholders in developing countries**

Livestock sector is a source of food security, employment and daily cash income which is attractive and meaningful for the lives of small, landless and poor rural families (Faraz *et al.*, 2023). Developing countries gain economic, social, and cultural benefits from poultry production, which plays an important role in family nutrition (Urgesa, 2023). Poultry rearing is an essential part of subsistence farming in developing regions, providing a

significant contribution to the livelihoods of both rural and urban households (Birhanu *et al.*, 2023). Poultry farming constitutes an important economic activity across Africa, providing livelihoods for millions of people and offering benefits across a wide range of societal, cultural, and environmental spheres (Akinola & Essien, 2011; Birhanu *et al.*, 2022; Gheyas *et al.*, 2022). Economic benefits enable families to meet their essential needs (Birhanu *et al.*, 2021). Revenue from poultry farming is generated by selling live birds, products, and waste. Poultry farming by smallholders in SSA enhances food availability and dietary well-being, as poultry products are a valuable source of animal protein and essential micronutrients (Grace *et al.*, 2024). Poultry are also raised to serve diverse societal and cultural ends, such as religious rites, festival celebrations, gift exchanges and competitive sports (Birhanu *et al.*, 2022). Poultry can likewise provide a means of quickly generating cash to cope with crises or unforeseen domestic expenses. It decreases the ups and downs in income particularly at the time of crop failure thus playing an imperative role in elevating the socio-economic status of poor and rural communities (Faraz *et al.*, 2019).

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Study sites

The study was conducted in Busia and Siaya Counties of Western Kenya and Uasin Gishu County in North-Rift Region. Analysis of nutrient composition of experimental feeds was done at a commercial laboratory (Spectra Lab, Nairobi) that was accredited as a testing laboratory upon satisfying the requirements of ISO/IEC 17025:2017 by the Kenya Accreditation Service (KENAS). Specific sites for experiments on performance of IIC fed on sorghum-based rations were done in Nambale sub-County of Busia County, Ugunja sub-County of Siaya County and Moiben and Soy sub-Counties of Uasin Gishu County. The field study that investigated socio-economic drivers of rearing IIC under three production systems was conducted in the same sites between February 2022 to September 2023. However, performance of IIC under Intensive production system was only conducted in Uasin Gishu County, allowing for a controlled assessment of dietary impacts on growth (Ogolla, 2016).

Busia County lies between longitude 34° 25 East and latitudes 0° and 0° 45 North. The county has four agro-ecological zones (AEZ): lower medium (LM) 1–4, with wetter LM1 in the centre of the county. The range of mean temperature is 21–27 °C, with annual rainfall of about 750–2000 mm (Wanjala, 2018). The county receives bimodal rainfall patterns with prolonged rainy seasons spanning from March to May (first season), while short rain season is between August and October (second season). The county altitude of 1,140–1,500 metres above sea level makes it appropriate for crop farming. Most commonly grown crops include; maize, beans, sorghum, groundnuts, millet, cotton, sugarcane, and cassava, along

with many other minor crops. Every household owns chicken, mainly in small-scale farming ranging from 15 to 20 birds (MoALF, 2016a).

Siaya County is situated within longitudes 33 ° 58' East and 34 ° 33' West and latitudes 0 ° 26' to 0 ° 18' North. This county records a mean annual rainfall between 900–1500 mm, with an average temperature of 22.3 °C. The county has an altitude of 1,300–1,500 metres above sea level. Largest AEZ is lower midland zones (LM), starting from LM 1 up to LM 5, with traces of upper midland zones (UM) in areas with high agricultural potential. Key crops grown include maize, beans, sorghum, and sweet potatoes, among others. Poultry keeping is practised semi-intensively among all households (MoALF, 2016b).

Uasin Gishu County lies on longitudes of 34°50'E, 35°37'E, and latitudes of 0°03'N, 0°55'N. A cool climate with mean annual temperatures of predominantly below 21 °C is a factor attributed to its location on a plateau that rises gently from 1,500 –2,700 metres above sea level. Rainfall is relatively high, with the northern and central parts receiving between 1000 and 1250mm of rainfall annually, the southern parts receiving 1250–1500 mm annually, and the western tip receiving above 1500mm. Rainfall is reliable throughout the year, and even the driest months between November and February receive some rainfall. The county has three main distinct agro-ecological zones (AEZs), namely the lower highlands (LH), upper midlands (UM), and upper highlands (UH). The lower highlands constitute LH2, LH3, and LH4. The primary crops cultivated are maize, wheat, beans, potatoes, and horticultural crops. Both large- and small-scale farmers are engaged in local chicken production, with major production systems being Extensive, Semi-intensive, or Intensive (MoALF, 2017).

## **3.2 Determination of nutrient composition of formulated sorghum-based rations and a commercial feed used in production of improved indigenous chicken**

### **3.2.1 Sample collection and preparation**

The experimental diet ingredients were purchased in Busia County and Uasin Gishu County (Table 2). Sorghum (RUC26 variety) was purchased from sorghum growing farmers in Busia County. Diets comprised two compounded sorghum-based (RUC26) rations, maize, soybean (as a source of protein), vegetable oil (as an energy source), ‘*omena*’ (*Rastrineobola argentea*) (as a high-quality protein feed ingredient, rich in essential amino acids, Vitamin B12 and choline), limestone (as a calcium source & crucial for bone health) and premix (contained balanced vitamins, minerals, and trace elements for overall nutritional adequacy). Soybeans were roasted for 10 minutes to enhance intake and digestibility before being ground. The preparation process involved grinding maize, sorghum, ‘*omena*’ and soybean were ground using a Power Pak mill (HM-200, Ludhiana, Punjab, India) before mixing with precise quantities of limestone, premix and vegetable oil. Ground ingredients were mixed in right quantities to form two out of the three dietary treatments (Plate 5). This careful selection and preparation of ingredients aimed to provide a balanced diet that promotes optimal growth and health in IIC.



**Plate 5. Mixing ingredients to formulate feed rations (Source, Kiptui, 2023)**

### 3.2.2 Formulation of experimental diets

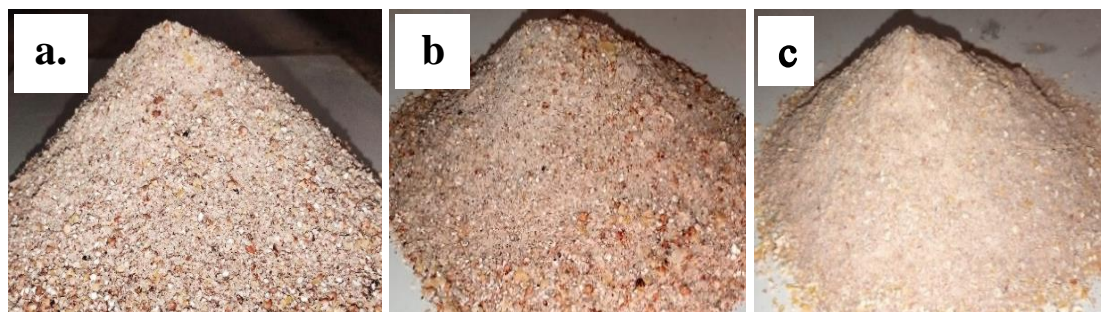
The two formulated treatments were T<sub>1</sub> and T<sub>2</sub>, with 50% and 75% sorghum-variety RUC26 inclusion levels and Treatment three (T<sub>3</sub>), was a purchased commercial feed acting as a control (Plate 6). The selected sorghum inclusion levels (50% & 75%) were derived from recommendations established in a study by Eric *et al.* (2020). Being a commercial feed, T<sub>3</sub> ingredients were kept private and confidential by the manufacturer.

**Table 2. Sorghum-based feed ingredients used to formulate rations for improved indigenous chicken**

Ingredient	Dietary treatment, %	
	T <sub>1</sub>	T <sub>2</sub>
Sorghum, kg	50	75
Maize, kg	23	2.5
Soybean, kg	22	17.5
'Omena', kg	2	2
Vegetable oil, lt	1	1
Limestone, kg	1.5	1.5
Premix	0.5	0.5

<b>Total</b>	<b>100</b>	<b>100</b>
<b>Calculated nutrient content</b>		
Crude protein	13.6	13.2
Crude fibre	3.2	3.1
Metabolizable energy, Kcal/kg	2861.1	2799

Diet T<sub>1</sub> with 50% sorghum inclusion constituted a higher maize inclusion of 23 kg which provided additional energy and balanced the carbohydrate content. Conversely, diet T<sub>2</sub>, had a higher sorghum inclusion of 75%, therefore maize content was significantly reduced to only 2.5 kg, as sorghum itself offered a substantial source of carbohydrates.



**Plate 6. Formulated experimental diets and control (a – T<sub>1</sub>, b – T<sub>2</sub>, c – T<sub>3</sub>) for feeding improved indigenous chicken (Source, Kiptui, 2023)**

### **3.2.3 Sampling and laboratory analysis of dietary treatments**

Six samples weighing 250g, two from each treatment (T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>), plus sorghum (RUC26), were analysed at Spectra commercial laboratory based in Nairobi, for proximate and amino acids, including cysteine, tryptophan, methionine and lysine. Sorghum variety of RUC26 that formed the base component of formulated feeds was also analysed for

tannin content. Nutrient composition analysis was essential to determine whether the diets met minimum nutrient requirements for chicken feeds.

### **3.2.3.1 Determination for moisture content of feeds**

Moisture was determined by oven drying method in a ventilated oven at 135 °C for 2 hours following procedures of AOAC (2005). A ventilated oven, is a high temperature oven which comprises part of the equipment found in most research laboratories. Petri dishes were weighed ( $W_1$ ) to the nearest 0.1 mg. About 1g ground samples was added to each petri dish. Weight of the dish and ground sample was recorded ( $W_2$ ) to the nearest 0.1 mg. The finely ground samples were incorporated into a pre-heated oven at  $135\pm 2$  °C and dried for at 2 hours. Samples were allowed to cool in desiccators to room temperature. Dried samples were weighed ( $W_3$ ) to the nearest 0.1 mg. Determination of percent moisture content of the feed is shown in Equation 1 below:

#### **Equation 1. Calculation of percent moisture content (g)**

$$\% \text{ Moisture content} = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100\%$$

Where:

$W_1$  = weight of empty dish

$W_2$  = weight of dish and sample before drying

$W_3$  = weight of dish and sample after drying

### **3.2.3.2 Determination of feed dry matter (DM) content by calculation**

Dry matter refers to material remaining after removal of water, and the moisture content reflects the amount of water present in the feed ingredient. The nutrients in feeds required by animal for maintenance, growth, pregnancy, lactation among others, are part of the DM

portion of feed. Ascertaining the moisture content of a feed ingredient is important, for the moisture content alters the weight of the feed, though does not furnish nutrient value to the animal. Calculation of DM content was done as shown in Equation 2 below:

**Equation 2. Calculation of feed dry matter content (%)**

$$\% \text{ Dry Matter} = 100 - \% \text{ moisture content}$$

**3.2.3.3 Determination for crude protein content of the feeds**

Protein content was determined using the micro-Kjeldahl method which involved wet digestion, distillation and titration (AOAC, 2005). Nitrogen content was multiplied by the factor of 6.25 to estimate the crude protein content.

Homogenized sample of 0.3g was weighed and noted to the nearest 0.1mg (W) then moved to digestion tube. Then, 3.5g potassium sulphate ( $K_2SO_4$ ), 0.3g copper sulphate and 10ml sulphuric acid were added. Tubes in a digestion unit were placed and connected to the fume removal manifold. Sample was digested at  $390 \pm 10$  °C and continued until the solution became clear, and then further digested between 10 minutes to 1 hour. Digestion system was turned off, tubes removed and allowed to cool for 10 – 20 minutes. Distilled water was added to each tube to a total volume of approximately 80ml. A 100ml beaker containing 25ml of the 4% boric acid and 3 to 4 drops of the indicator was placed under outlet of the condenser of distillation unit in such a way that delivery tube was below surface of boric acid solution. A 50ml sodium hydroxide (NaOH) was added in to distillation flask and the ammonia distilled into the trapping solution until 80 to 100ml distil was collected and bumping started to occur in the distillate indicating complete ammonia trapping. The content of the conical flask with 0.05M sulphuric acid standard solution was titrated after adding a few droplets of indicator solution to the end point. Similar titration for the blank

and reference samples were performed and recorded accordingly. Amount of acid used was recorded to the nearest 0.05ml for the blank test ( $V_b$ ) and for each sample ( $V_s$ ). Calculations of percent nitrogen and percent crude protein were done according to Equation 3 and Equation 4, respectively:

**Equation 3. Determination of percent nitrogen**

$$\%N = \frac{V_s - V_b \times M(H_2SO_4) \times 2 \times 14.007}{W \times 10 \times \%Recovery} \times 100$$

Where:

$V_s$  = mL  $H_2SO_4$  needed to titrate sample

$V_b$  = mL  $H_2SO_4$  needed for the blank test

$M$  = molarity of  $H_2SO_4$

2 = the acid factor

14.007 = molecular weight of N

10 = conversion from mg/g to %

$W$  = weight of the sample (g)

**Equation 4. Calculation for percent crude protein**

$$\%CP = \%N \times F$$

Where:

CP = Crude Protein

N = % nitrogen obtained in the determination

F = Nitrogen to Protein Conversion Factor (6.25)

#### 3.2.3.4 Determination for ash content of the feeds

Ash was determined gravimetrically as the residue after incineration of known weights of samples in a muffle furnace set at 670 °C for 1 hour (AOAC, 2005).

Incineration crucible was dried at 550 °C for at least 5 minutes, removed from oven and cooled in a desiccator. Empty dish was weighed to the nearest 0.1mg ( $W_1$ ). A sample of 2.5g was placed to the dish then measured to the nearest 0.1mg ( $W_2$ ). Crucible was then transferred to a preheated muffle furnace at  $670 \pm 10$  °C for 1 hour. The crucible and its contents were transferred into a desiccator and allowed to cool to room temperature; then weighed to the nearest 0.1mg ( $W_3$ ). Calculation of percent ash content was based on Equation 5 below:

##### Equation 5. Calculation for percent ash content of the feeds (g)

$$\%Ash = (W_3 - W_1) \times 100 / (W_2 - W_1)$$

Where:

$W_1$  = weight of empty dish

$W_2$  = weight of the dish and sample

$W_3$  = weight of dish and residue after incineration

#### 3.2.3.5 Determination for crude fat content of the feeds

Crude fat was determined by exhaustively extracting a known weight of sample in petroleum ether in a Soxhlet extractor (AOAC, 2005). A 5g of the sample was weighed to the nearest 0.1mg ( $W_1$ ) into the extraction thimble and covered with a fat-free wad of cotton wool. Silicon carbide chips were transferred to a dry flask and weighed to the nearest 0.1mg ( $W_2$ ), 150ml petroleum ether was added. The thimble was then placed in the extractor and

connected to the Dry flask and Reflux Unit. Extraction lasted for 4 hours with petroleum ether and heating apparatus regulated to obtain at least 10 siphoning per hour. Solvent was distilled until the flask was nearly free from the solvent then left overnight in a fume-hood to ensure all solvent evaporated. Flask was then dried with residue for 1.5 hour in a vacuum oven (4g) at  $80 \pm 2$  °C. It was cooled in a desiccator (4.8) and weighed to the nearest 0.1mg ( $W_3$ ). Calculation of percent crude fat was as shown in Equation 6 below:

**Equation 6. Calculation for percent crude fat of the feeds (g)**

$$\%Crude\ fat = (W_3 - W_2) \times 100/W_1$$

Where:

$W_1$  = initial sample weight

$W_2$  = tare weight of flask

$W_3$  = weight of flask and fat residue

**3.2.3.6 Determination for total carbohydrate content of feeds by calculation**

The total carbohydrate is part of diet that affects blood glucose levels. The Daily Value (DV) for total carbohydrate is approximately 300g or 100% DV, based on a 2,000-calorie diet. This number combines several types of carbohydrates such as dietary fibre, sugars and complex carbohydrates. Calculation of total carbohydrate was as shown in Equation 7 below:

**Equation 7. Calculation for total carbohydrate content of feeds**

$$Total\ Carbohydrate\ (dry\ matter\ basis) = \frac{NFE + Crude\ fibre}{Moisture\ factor\ (100/Dry\ matter)}$$

### 3.2.3.7 Determination for Nitrogen-free extract (NFE) content of feeds by calculation

Nitrogen-free extract is crucial in poultry diets as it provides a significant energy source from digestible carbohydrates, which supports growth, feed efficiency, and overall health (McDonald *et al.*, 2002). The NFE represented the soluble carbohydrates of feed, such as starch and sugar, and equates to the original sample weight minus the sum of the weights of moisture (water), ether extract, crude protein, crude fibre, and ash. Calculation of nitrogen-free extracts was done according to Equation 8 below:

#### Equation 8. Calculation for nitrogen-free extract content of feeds

$$NFE = 100 - (Ash\ content + Fiber\ content + Fat\ content + Crude\ protein)$$

### 3.2.3.8 Determination for metabolizable energy of feeds by calculation

Calculation of metabolizable energy is shown in Equation 9 below.

#### Equation 9. Calculation for metabolizable energy of feeds (Kcal /kg)

$$Metabolizable\ energy = \{(35.5 \times NFE) + (81 \times Fat) + (36 \times Protein)\}$$

### 3.2.3.9 Determination for amino acids composition by Ninhydrin procedure

Composition for amino acids was measured calorimetrically following post-column reaction with Ninhydrin (AOAC Official Method 999.13, 2004). A 0.5ml portion of citrate buffer, pH 5 (0.2M) was mixed with 1ml of amino acid solution containing 0.05 to 5.6µg of amino acid nitrogen. This was added to 0.2ml of methyl cello solve Ninhydrin solution and 1ml of the Potassium Cyanide-Methyl cello solve solution. The well combined mixture was subjected to heating for 15 minutes at 100 °C and cooled for 5 minutes in running tap water. Solution was prepared to a convenient volume with ethanol, shaken well, and optical

density determined using a 1cm glass cell on a Spectrophotometer at 570nm for all amino acids. Amino acids were determined at a wavelength of 570nm.

### 3.2.3.10 Determination for tannin content of sorghum variety RUC26

Tannin, an anti-nutrient factor in RUC26 sorghum variety was determined through a titration procedure involving a standard potassium permanganate solution (Kavanagh, 1981).

A 3g of the homogenized sorghum grain sample was weighed and added 250ml distilled water and extract. An extract of 25ml was measured into 1 litre conical flask followed by 25ml of indigo carmine solution. Distilled water volume of 750ml was added. Titration against 0.1N potassium permanganate solution until blue colour changes to green was done. Few drops of potassium permanganate were added until the colour turned to golden yellow. Calculation of percent tannin was as shown below in Equation 10:

#### Equation 10. Determination for percent tannin content of sorghum (RUC26 variety)

$$\% \text{ Tannin} = \frac{(V - V_0) \times 0.004157 \times 250 \times 100\%}{g \times 25ml}$$

Where:

$V$  = volume of 0.1N aqueous solution of potassium permanganate used for titration of the sample

$V_0$  = volume of 0.1N aqueous solution of potassium permanganate used for titration of the blank

0.004157 = tannins equivalent in millilitres of 0.1 N aqueous solution of potassium permanganate

$g$  = mass of the sample

### **3.3 Determination of performance of improved indigenous chicken fed formulated sorghum-based rations and a commercial feed under three production systems among smallholder farmers**

#### **3.3.1 Experimental design and set-up**

Three hundred and ninety (390), 4-week-old improved indigenous chicks, of the Rainbow Rooster breed, with initial average body weights of 301.66 grams were obtained from Kukuchic Limited, Eldoret. Chicks were randomly selected and distributed without sex discrimination to 45 purposefully selected farmers, that is, 15 each from Siaya, Busia, and Uasin Gishu Counties. Purposive sampling technique was used to obtain the 45 farmers. Farmer selection followed criteria such as being a beneficiary from groups that were initially recruited to grow improved sorghum cultivars by University of Eldoret, ability to keep good records, willingness to participate in the Project and have experience in rearing chicken. Farmers were trained on management practices and the importance of rearing improved indigenous chicken for high production. Production systems in practice were Semi-intensive, whereby 3 dietary treatments (T<sub>1</sub>: 50%, T<sub>2</sub>: 75% and T<sub>3</sub>: Commercial Control) had 3 replicates in each of the three counties and a Free-range (T<sub>4</sub>), where no feeds were provided. Free-range had six replicates in each county, for a total of 45 experimental units. The replicates in Free-range system were more to account for the increased environmental complexity and variability, and more so, the potential losses. The intensive system was conducted as an on-station experiment with the three treatment diets mentioned above. To analyse resulting data from this aspect, production systems were considered the main plot and dietary treatments were designated as sub-plots in a split-plot arrangement of treatments. Three counties were categorized as blocks in randomized complete block

design (RCBD). The feeding experiment lasted for 12 weeks. The split-plot linear model and experimental layout in RCBD are shown in Equation 11 and Table 3, respectively, below:

**Equation 11. Equation for split-plot linear model for RCBD**

$$Y_{ijk} = \mu + \alpha_i + \gamma_k + (\alpha\gamma)_{ik} + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

$Y_{ijk}$  = response variable

$\mu$  = overall population mean

$\alpha_i$  = effect of the  $i^{\text{th}}$  main plot factor

$\gamma_k$  = effect of the  $k^{\text{th}}$  block

$(\alpha\gamma)_{ik}$  = interaction effect between the  $i^{\text{th}}$  main plot factor and the  $k^{\text{th}}$  block effect

$\beta_j$  = effect of the  $j^{\text{th}}$  subplot factor

$(\alpha\beta)_{ij}$  = interaction effect between the  $i^{\text{th}}$  main plot factor and the  $j^{\text{th}}$  subplot factor

$\varepsilon_{ijk}$  = error term

**Table 3. Experimental layout for the split-plot arrangement of treatments in RCBD**

<b>Layout for Semi-intensive production system in the three counties</b>		
<b>T<sub>1</sub> (50%)</b>	<b>T<sub>2</sub> (75%)</b>	<b>T<sub>3</sub> (COM)</b>
REP 1 (8b)	REP 1 (8b)	REP 1 (8b)
REP 2 (8b)	REP 2 (8b)	REP 2 (8b)
REP 3 (8b)	REP 3 (8b)	REP 3 (8b)
<b>Layout for Free-range production system for the three counties</b>		
REP 1 (8b)	REP 3 (8b)	REP 5 (8b)
REP 2 (8b)	REP 4 (8b)	REP 6 (8b)

<b>Intensive system (Uasin Gishu County)</b>		
<b>T<sub>1</sub> (50%)</b>	<b>T<sub>2</sub> (75%)</b>	<b>T<sub>3</sub> (COM)</b>
REP 1 (10b)	REP 2 (10b)	REP 3 (10b)

*Semi-intensive production system (3 treatments x 3 replicates)3 counties =27 experimental units, Intensive production system (3 treatments x 1 replicates)1 counties= 3 experimental units, Free-range production system (6 replicates)3 counties= 18 experimental units each with 8 birds (b) where T=treatment; REP=replicate, COM=commercial, 10b=10 birds*

### **3.3.2 Feeding and management of IIC under the three production systems**

The IIC in all production systems were provided with water *ad libitum*. Feeds in Intensive and Semi-intensive production systems were provided twice a day at 0700hrs and 1700hrs. This followed a feeding strategy known as Ante Meridiem/Post Meridiem (AM/PM) feeding, also identified as split feeding. The AM/PM feeding is a structured feeding regime that involves dividing the daily feed allocation into two distinct dietary formulae, typically offered in the morning and evening separately (Molnár *et al.*, 2018). Vaccinations against fowl pox and fowl typhoid were administered at weeks 6 and 8, respectively, in all production systems for uniformity.

#### **3.3.2.1 Intensive production system**

The IIC were completely indoors in a deep litter system. Three pens (4 square feet) made of plywood, timber and nails were constructed. Sawdust was used as litter to give birds a suitable surface for feeding, watering and other management procedures. It also absorbed moisture from bird droppings, kept the floor dry and offered some degree of foot insulation (Dunlop *et al.*, 2015). The pens were disinfected with Ultraxide, and each were randomly stocked with 10 four-week-old chicks after being weighed (Plate 7). Two formulated treatment diets (T<sub>1</sub>-50% and T<sub>2</sub>-75% used sorghum as per the two inclusion rates) and T<sub>3</sub>-

Control diet were weighed and fed to the IIC for 12 weeks. Feeds were provided at *ad libitum* to IIC twice a day. Measures on rate of growth, feed consumption, FCR and survival rate were collected and analysed for each treatment.



**Plate 7. Weighing of improved indigenous chicken to determine weight**

(Source, Kiptui, 2023)

### 3.3.2.2 Semi-intensive production system

Each improved indigenous chicken (IIC) was supplemented with 80g of feed per day (Plate 8). Feed supplemented were T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>. They were released at 1400hrs from housing units to exercise and get extra nourishment.



**Plate 8. Weighing of feeds into feeders (Source, Kiptui, 2023)**

### 3.3.2.3 Free-range production system

This was treatment 4 (T<sub>4</sub>). No supplementary feed was given to the IIC; instead, they were released during the morning hours to source their own feeds.

### 3.3.3 Performance of improved indigenous chicken

#### 3.3.3.1 Survival rate

This was calculated by subtracting the number of birds that died during the experimental period from birds initially stocked divided by the number stocked multiplied by 100 to convert the figure into a percentage as shown in Equation 12 below (Charo-Karisa *et al.*, 2006).

**Equation 12. Calculation of survival rate (%)**

$$\text{Survival rate} = \frac{\text{Birds initially stocked} - \text{Dead birds}}{\text{Birds initially stocked}} \times 100\%$$

#### 3.3.3.2 Determination of growth rate for the improved indigenous chicken (IIC)

Improved indigenous chicken were weighed at an interval of 2 weeks to determine weight gain and to minimize stress that could hinder rate of growth if practiced often.

- i. **Total weight gain** per bird was calculated by getting the difference between the mean final weight and the mean initial body weight (g) of each treatment when the experiment ended as shown in Equation 13 below (Güroy *et al.*, 2006):

**Equation 13. Calculation for the total weight gain in chicken (g)**

$$\text{Total weight gain} = \frac{\text{Mean final body weight} - \text{Mean initial body weight}}{1}$$

- ii. **Average daily weight gain** was calculated by subtracting the mean initial body weight (g) from the mean final body weight over the days of experiment as shown in Equation 14 below:

**Equation 14. Calculation for the average daily weight gain in chicken (g)**

*Average daily weight gain*

$$= \frac{\text{Mean final body weight} - \text{Mean initial body weight}}{\text{Days of experiment}}$$

- iii. **Average weekly weight gain** in grams per week was calculated as shown by Equation 15.

**Equation 15. Calculation for the average weekly weight gain (g)**

*Average weekly weight gain*

$$= \frac{\text{Mean final body weight} - \text{Mean initial body weight}}{\text{Number of Weeks}}$$

- iv. **Feed intake (FI)** was determined after 24 hours using the difference between the amount of feed supplied and the amount left over as shown in Equation 16 (Muremera *et al.*, 2022).

**Equation 16. Calculation for average feed intake (g)**

$$\text{Feed intake (FI)} = \frac{\text{Feed given} - \text{Feed leftover}}{\text{Number of chicken}}$$

- v. **Feed conversion ratio** was calculated to determine the amount of feed converted to body weight as shown in Equation 17 (Susan *et al.*, 2023):

**Equation 17. Calculation of feed conversion ratio (g)**

$$\text{Feed conversion ratio} = \frac{\text{Feed intake}}{\text{Weight gain}}$$

**3.3.4 Statistical analysis**

Nutrient composition of dietary treatments and growth performance of improved indigenous chicken data were analysed using RStudio (R Version 4.3.2). Following one-way analysis of variance (ANOVA), Tukey's Honest Significant Difference (HSD) test was used for comparisons of means in nutrient composition data to determine significant differences at  $p < 0.05$  (Appendix I). Growth performance data for IIC under different production systems were analysed using one-way ANOVA. Additionally, the growth of IIC across various dietary treatments was evaluated using repeated measures ANOVA. Means were separated using the least significant difference (LSD), with the significance level set at  $p < 0.05$  (Appendix II & III). All data were presented as means, percentages and standard deviations in tables and figures.

**3.4 Diversity of socio-economic drivers among smallholder farmers rearing improved indigenous chicken****3.4.1 Survey design**

Purposive selection was done to engage 45 representative farmers from among those who grew sorghum, reared chicken, able to keep accurate records and utilize sorghum as chicken feed. Purposive sample aims to produce a sample which is logically assumed to represent the population (Chakraborty & Biswal, 2023). Farmer selection was also based on proximity to each other, appropriate production system (Semi-intensive or Free-range), knowledge of chicken production, and willingness to keep and avail production records.

Farmers were given eight 4-week-old, dual-purpose, disease-resistant, fast-growing, IIC of the Rainbow Rooster breed. A structured questionnaire was used to gather relevant information as shown in Table 4 below:

**Table 4. Socio-economic drivers surveyed in improved indigenous chicken rearing**

Parameter	Measures recorded
1. Demographic aspects	Age, gender, education, land size and household size
2. Improved technologies and management practices	None, deworming, vaccinations, supplements, improved feeds, housing & record keeping
3. Production dynamics	Flock size, breed and veterinarian costs
4. Feeding dynamics	Purchased feeds and types, homemade rations and cost of feeds
5. Production costs	Marketing costs and labour costs
6. Egg and chicken sale records	Egg/chicken sales and marketing channels
7. Dietary diversification	Dietary diversity and consumption rate

#### 3.4.1.1 Costing of feed rations used in rearing of IIC

The cost of feed rations ( $T_1$ ,  $T_2$  and  $T_3$ ) was carried out since it is a critical factor in terms of production as shown in Equation 18 (Abubakar *et al.*, 2020).

**Equation 18. Calculation for total cost of feed in Kenya Shilling (KSh)**

- i.  $Total\ cost\ of\ feed = Total\ feed\ intake \times Cost\ of\ feed\ per\ kilogram$
- ii.  $Total\ feed\ intake = Average\ daily\ feed\ intake \times Days\ of\ experiment$

#### 3.4.2 Data collection and analysis

Structured questionnaires collected data that was subjected to statistical analysis. Descriptive statistics including means and percentages were generated and entered into tables and figures to present results.

## CHAPTER FOUR

### RESULTS

#### 4.1 Nutrient composition of dietary treatments

There was significant difference ( $p < 0.05$ ) in crude ash content between diets T<sub>1</sub> and T<sub>3</sub> (Table 5). Crude ash content value for T<sub>3</sub> was much higher (12.31%) than T<sub>2</sub> (5.12%) and T<sub>1</sub> (4.33%). There was significant difference ( $p < 0.05$ ) in crude fat content between diets T<sub>2</sub> and T<sub>3</sub>. The crude fat content of T<sub>2</sub> was, however, relatively higher (9.01%) than T<sub>1</sub> (7.94%) and T<sub>3</sub> (6.04%). Crude fibre content in T<sub>3</sub> was significantly different ( $p < 0.05$ ) from T<sub>1</sub> and T<sub>2</sub>. Crude fibre content in T<sub>3</sub> was significantly higher (12.69%) than T<sub>1</sub> (4.73%) and T<sub>2</sub> (4.68%), respectively. Metabolizable energy (ME) in T<sub>3</sub> significantly differed ( $p < 0.05$ ) from T<sub>2</sub> and T<sub>1</sub>. The T<sub>3</sub> had significantly lower (2941.67 Kcal kg<sup>-1</sup>) ME content than T<sub>2</sub> (3616 Kcal kg<sup>-1</sup>) and T<sub>1</sub> (3594 Kcal kg<sup>-1</sup>). Sorghum-based rations had higher ME content than the Control. However, there were no significant differences ( $p > 0.05$ ) across dietary treatments in the following parameters: crude protein, dry matter, nitrogen-free extracts, total carbohydrates, and amino acids (cysteine, lysine, methionine, and tryptophan). Tannin content in the RUC26 sorghum variety was 1.24%.

**Table 5. Results, p-values and KEBS standards of nutritional parameters for rations used in feeding improved indigenous chicken**

Parameter	Dietary Treatments, %			SD	p-values	KEBS, 2021
	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>			
Crude ash	4.33 <sup>b</sup>	5.12 <sup>ab</sup>	12.31 <sup>a</sup>	4.57	0.029	12 (Max)
Crude fat	7.94 <sup>ab</sup>	9.01 <sup>a</sup>	6.04 <sup>b</sup>	1.49	0.014	8 (Max)
Crude fibre	4.73 <sup>b</sup>	4.68 <sup>b</sup>	12.69 <sup>a</sup>	4.21	0.001	3 - 8
Crude protein	15.15 <sup>a</sup>	14.55 <sup>a</sup>	12.73 <sup>a</sup>	1.5	0.104	13 (Min)
Dry matter	89.70 <sup>a</sup>	90.30 <sup>a</sup>	91.20 <sup>a</sup>	1.41	0.485	88 (Min)
Nitrogen free extracts	67.90 <sup>a</sup>	66.70 <sup>a</sup>	56.30 <sup>a</sup>	7.02	0.055	50 - 70
Total carbohydrates	72.60 <sup>a</sup>	71.30 <sup>a</sup>	69.00 <sup>a</sup>	3.82	0.569	30 - 60
Cysteine	0.65 <sup>a</sup>	0.61 <sup>a</sup>	0.47 <sup>a</sup>	0.26	0.736	0.50 (Min)
Lysine	0.50 <sup>a</sup>	0.86 <sup>a</sup>	0.67 <sup>a</sup>	0.27	0.292	0.50 - 1.2
Methionine	0.82 <sup>a</sup>	1.28 <sup>a</sup>	1.05 <sup>a</sup>	0.53	0.633	0.25 (Min)
Tryptophan	0.29 <sup>a</sup>	1.00 <sup>a</sup>	0.82 <sup>a</sup>	0.43	0.088	0.14 (Min)
Metabolizable energy, Kcal kg <sup>-1</sup>	3594.0 <sup>a</sup>	3616.0 <sup>a</sup>	2941.67 <sup>b</sup>	351.20	0.001	2400 (Min)

(KEBS, 2021)

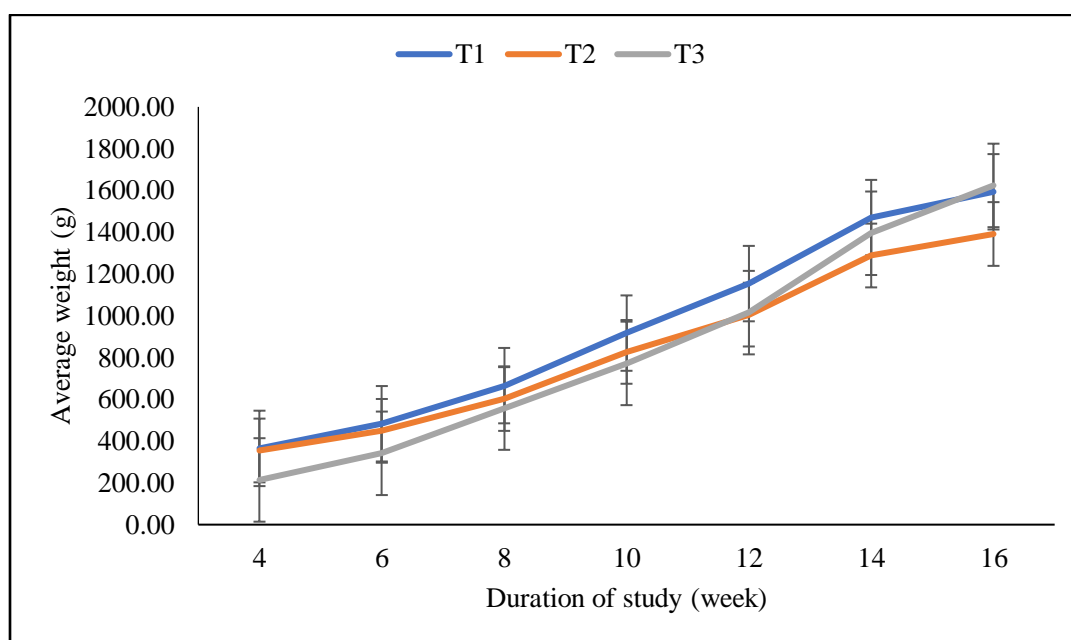
*a, b, c Values with different superscripts in the same row are significantly different ( $p < 0.05$ ), Min= Minimum & Max= Maximum, SD= Standard deviation, KEBS= Kenya Bureau of Standards, T<sub>1</sub>= 50%, T<sub>2</sub>= 75% & T<sub>3</sub>= Control*

#### **4.2 General performance of improved indigenous chicken on sorghum-based feed rations and a commercial feed in farmers' production systems**

This section presents the findings for growth performance of improved indigenous chicken in three production systems, growth trends in formulated sorghum-based feed rations, and growth performance characteristics, including weight gains (total, average daily and average weekly), average daily feed intake, FCR and survival rate.

#### 4.2.1 Average IIC growth rate in T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> under intensive production system in Uasin Gishu County

Average weight at bi-weekly intervals was used to assess growth rate of IIC. Average weight for the IIC was significantly different ( $p < 0.05$ ) across treatments during the study period (Figure 1). At week 4, results for average weight in T<sub>1</sub> (365.00g) and T<sub>2</sub> (355.00g) were significantly ( $p < 0.05$ ) higher than T<sub>3</sub> (214.00g). At week 8, average weight was significantly different ( $p < 0.05$ ) in all treatments, with T<sub>1</sub> (665.50g) average weight being highest, followed by T<sub>2</sub> (601.50 g) and lowest in T<sub>3</sub> (558.00g). Data for week 12 showed that average weight were significantly ( $p < 0.05$ ) higher in T<sub>1</sub> (1154.00g) than T<sub>3</sub> (1015.00 g) and T<sub>2</sub> (1005.50g). On reaching week 16, average weight was significantly ( $p < 0.05$ ) higher in T<sub>3</sub> (1624.00g) and T<sub>1</sub> (1593.50 g) than T<sub>2</sub> (1391.50g).

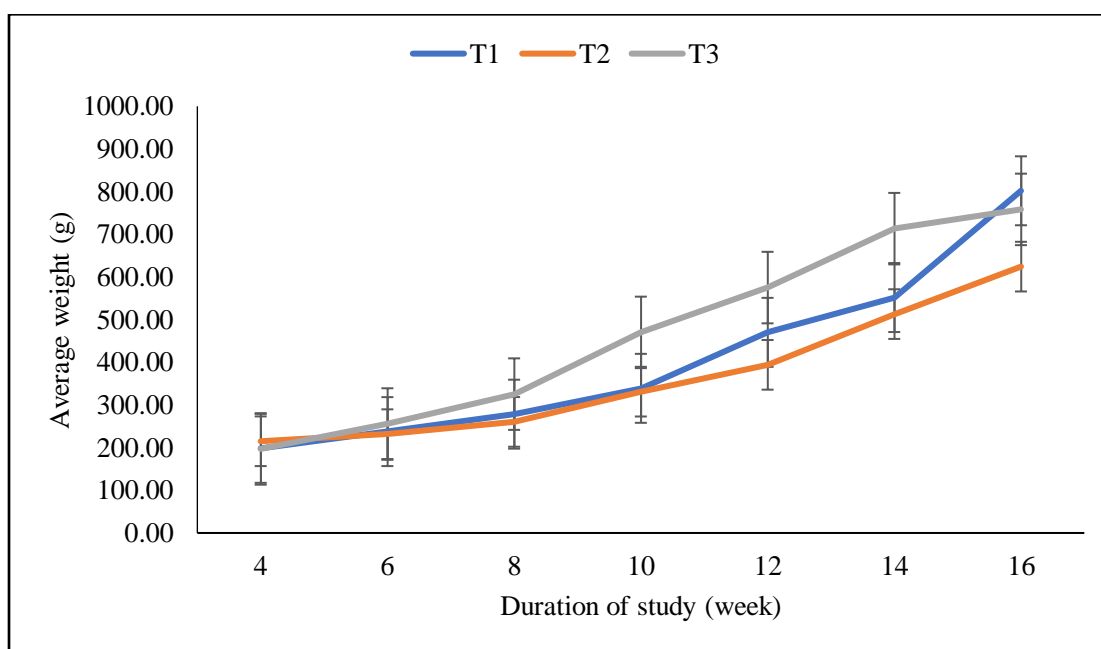


*T<sub>1</sub> = 50%, T<sub>2</sub> = 75% & T<sub>3</sub> = Control*

**Figure 1. Bi-weekly average growth rate of improved indigenous chicken reared on sorghum-based rations and a commercial diet in an intensive production system**

#### 4.2.2 Average growth rate of IIC in T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> under semi-intensive production systems in Busia, Siaya and Uasin Gishu Counties

Data for growth rate of IIC in terms of average weight showed significant differences ( $p < 0.05$ ) across treatments during the study period (Figure 2). At week 4, average weight in T<sub>1</sub> (198.33g) and T<sub>3</sub> (197.00g) were significantly lower ( $p < 0.05$ ) than T<sub>2</sub> (215.00g). At week 8, average weight in T<sub>3</sub> (325.44g) was significantly ( $p < 0.05$ ) higher than T<sub>1</sub> (278.44g) and T<sub>2</sub> (260.33g). At week 12, average weight was significantly ( $p < 0.05$ ) different across treatments, with T<sub>3</sub> (575.11g) being highest, followed by T<sub>1</sub> (470.22 g), and T<sub>2</sub> (394.11g). At week 16, the average weight in T<sub>1</sub> (802.00g) was significantly ( $p < 0.05$ ) higher than T<sub>3</sub> (758.33g) and T<sub>2</sub> (624.22g).

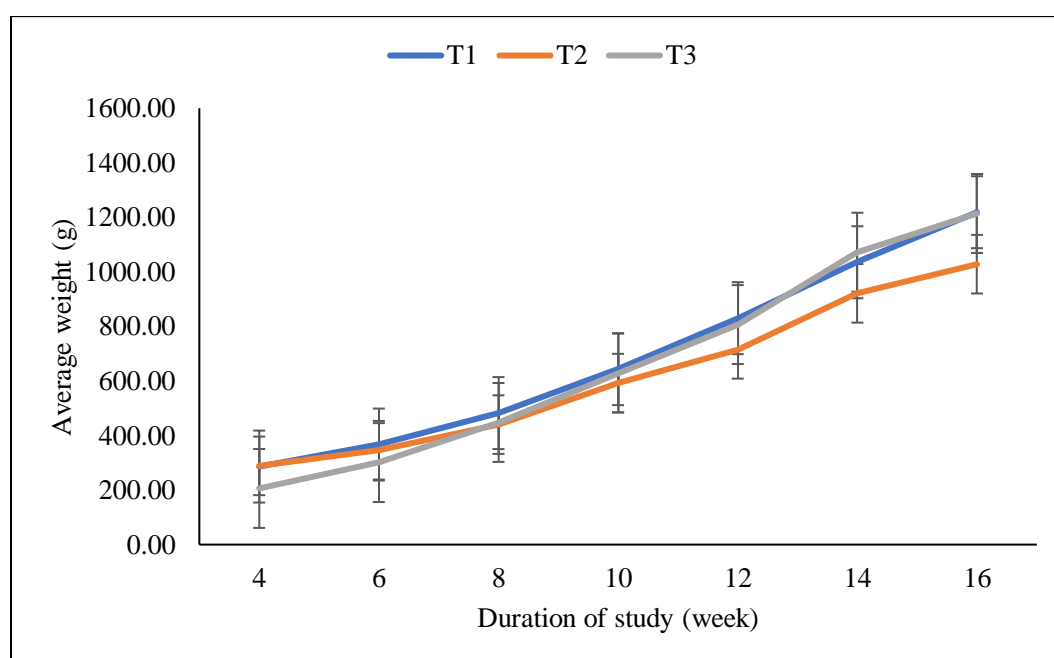


*T<sub>1</sub> = 50%, T<sub>2</sub> = 75% & T<sub>3</sub> = Control*

**Figure 2. Bi-weekly average growth rate of IIC in semi-intensive production system**

#### 4.2.3 A comparison of average growth rate of IIC from the three treatments

Average weight of IIC from all the treatments ( $T_1$ ,  $T_2$  and  $T_3$ ) were significantly different ( $p < 0.05$ ) during the study period. At week 4, average weight for  $T_2$  (288.68g) and  $T_1$  (286.05g) were significantly higher ( $p < 0.05$ ) than  $T_3$  (205.95g) as reflected in Figure 3 below. At week 8, average weight was highest in  $T_1$  (482.16g) followed by  $T_3$  (477.84 g) and lowest in  $T_2$  (439.89g). At week 12, average weight was highest in  $T_1$  (830.11g) followed by  $T_3$  (806.63 g) and lowest in  $T_2$  (715.89g). At week 16, average weight in  $T_1$  (1218.58g) and  $T_3$  (1213.95g) were significantly higher ( $p < 0.05$ ) than  $T_2$  (1028.05g).



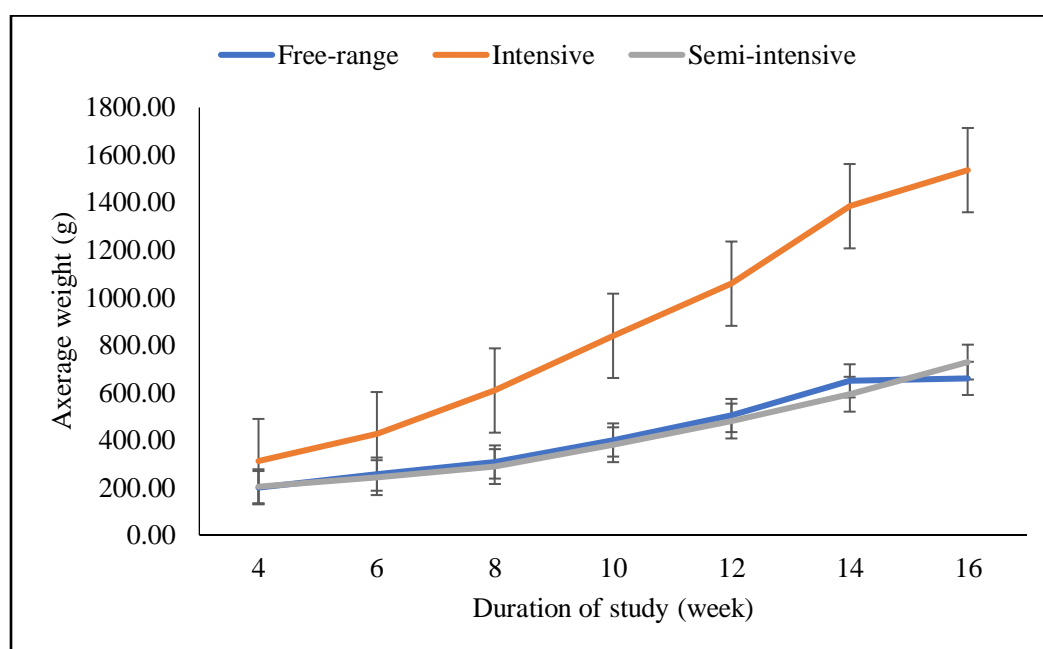
$T_1 = 50\%$ ,  $T_2 = 75\%$  &  $T_3 = \text{Control}$

**Figure 3. Bi-weekly average growth rate trends of IIC from the three treatments**

#### 4.2.4 Comparison for growth performance of IIC from three production systems

The IIC growth rate in terms of average weight was significantly different ( $p < 0.05$ ) in Intensive, Semi-intensive, and Free-range production systems (Figure 4). At week 4, average weight in the Intensive (311.33g) was significantly higher ( $p < 0.05$ ) than in Semi-intensive (203.44g) and Free-range (199.39g) systems. Data for week 8 showed average

weight in Intensive (608.33g) as being significantly higher ( $p < 0.05$ ) than Free-range (307.39g) and Semi-intensive (288.07g) systems. For week 12, the average weight in Intensive (1058.17g) was significantly higher ( $p < 0.05$ ) than in Free-range (503.11g) and Semi-intensive (479.81g) systems. At week 16, average weight in Intensive (1536.33g) was significantly higher ( $p < 0.05$ ) than Semi-intensive (728.19g) and Free-range (659.39g) systems. The average weight of IIC for Semi-intensive and Free-range production systems were not significantly different throughout the study duration.



*Production systems = Free-range, Intensive & Semi-intensive*

**Figure 4. Bi-weekly average growth rate of IIC from three production systems**

#### **4.2.5 Overall performance of IIC reared on sorghum-based rations and a commercial feed under three production systems**

##### **4.2.5.1 Average total weight gain of the improved indigenous chicken**

There were significant differences ( $p < 0.05$ ) in average total weight gain of IIC across treatments (Table 6). The average total weight gain was highest ( $p < 0.05$ ) in T<sub>3</sub> (1008g) and lowest in T<sub>4</sub> (460g). The T<sub>3</sub> (1008g) and T<sub>1</sub> (932.53g) were not significantly different in average total chicken weight gain; however, T<sub>2</sub> (739.37g) and T<sub>4</sub> (460g) differed significantly ( $p < 0.05$ ).

##### **4.2.5.2 Average daily weight gain of improved indigenous chicken**

There were significant differences ( $p < 0.05$ ) in average daily weight gain of IIC between T<sub>2</sub> (8.80g) and T<sub>4</sub> (5.48g). Results showed that T<sub>3</sub> had highest (12g) gain while T<sub>4</sub> had the lowest (5.48g) gain as shown in Table 6. There were no significant differences between T<sub>3</sub> (12g) and T<sub>1</sub> (11.1g).

##### **4.2.5.3 Average weekly weight gain of the improved indigenous chicken**

There were significant differences ( $p < 0.05$ ) in average weekly weight gain of IIC across treatments. Diet T<sub>2</sub> (61.61g) significantly differed. ( $p < 0.05$ ) from T<sub>4</sub> (54.95 g). Diet T<sub>3</sub> had the highest (84g) gain while T<sub>4</sub> had the lowest (54.95g) as shown in Table 6. There were no significant differences between T<sub>3</sub> (84g) and T<sub>1</sub> (77.71g).

##### **4.2.5.4 Average daily feed intake of the improved indigenous chicken**

There were significant differences ( $p < 0.05$ ) in treatments during the study period (Table 6). The IIC fed on T<sub>3</sub> had the highest (56.67g) average daily feed intake followed by T<sub>1</sub> (49.07g), while those fed T<sub>2</sub> had the lowest (45.5 g). Average daily feed intake in Free-

range (T<sub>4</sub>) was not determined since the improved indigenous chicken had access to a wide-range of feeds in the outdoor environment.

#### 4.2.5.5 Feed conversion ratio (FCR) of the improved indigenous chicken

There were significant differences ( $p < 0.05$ ) in FCR of IIC across treatments (Table 6). The IIC in T<sub>4</sub> (7.30) had the highest ( $p < 0.05$ ) feed conversion ratio, while T<sub>1</sub> had the lowest (4.42) (Table 6). There were significant differences ( $p < 0.05$ ) in FCR between T<sub>2</sub> (5.17) and T<sub>4</sub> (7.30) while there were no significant differences between T<sub>1</sub> (4.42) and T<sub>3</sub> (4.72).

#### 4.2.5.6 Survival rate records

There were significant differences ( $p < 0.05$ ) in survival rate of the IIC across treatments. Free-range (T<sub>4</sub>) differed significantly ( $p < 0.05$ ) in survival rate from T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> as shown in Table 6 below. Survival rate of IIC was highest in T<sub>1</sub> and T<sub>3</sub>, followed by T<sub>2</sub>, and lowest in T<sub>4</sub>.

**Table 6. Overall performance results for IIC reared on sorghum-based feed rations and a commercial feed**

Performance parameters	Experimental Treatments			
	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>	T <sub>4</sub>
Average daily feed intake (g)	49.07 <sup>b</sup>	45.5 <sup>a</sup>	56.67 <sup>c</sup>	-
Average daily weight gain (g/day)	11.1 <sup>c</sup>	8.8 <sup>b</sup>	12 <sup>c</sup>	5.48 <sup>a</sup>
Average weekly weight gain (g/week)	77.71 <sup>c</sup>	61.61 <sup>b</sup>	84 <sup>c</sup>	54.95 <sup>a</sup>
Total weight gain (g)	932.53 <sup>c</sup>	739.37 <sup>b</sup>	1008 <sup>c</sup>	460 <sup>a</sup>
Feed conversion ratio (gfeed/gwt)	4.42 <sup>a</sup>	5.17 <sup>b</sup>	4.72 <sup>a</sup>	7.3 <sup>c</sup>
Survival rate (%)	70.48 <sup>b</sup>	68.18 <sup>b</sup>	70.48 <sup>b</sup>	60.58 <sup>a</sup>

*Values within a row with different superscripts differ significantly ( $p < 0.05$ ). T<sub>1</sub> & T<sub>2</sub>, were 50% & 75% sorghum-variety RUC26 inclusion levels, T<sub>3</sub> was a Commercial feed while T<sub>4</sub> was a Free-range with no feed supplementation*

### **4.3 Diversity of socio-economic drivers among smallholder farmers rearing improved indigenous chicken**

This section addresses selected factors touching on socio-economics with potential to characterize farmers involved in production of IIC including demographic characteristics, improved technologies and management practices, production dynamics, feeding dynamics, production costs, egg and chicken sales, and farmer dietary diversification.

#### **4.3.1 Demographic characteristics of farmers rearing improved indigenous chicken**

Farmers with age ranging from 30 to 39 years were the majority (36%) overall; with similar higher numbers being found in Uasin Gishu (60%) and Busia (27%) Counties; while in Siaya County the majority (33%) ranged from 18 to 29 years (Table 7). Female gender was more (58%) involved in chicken rearing, with Uasin Gishu leading at 73% followed by Busia (60%) and Siaya (40%) Counties. In terms of education, many (42%) of the farmers had attended secondary while those who completed primary were 36%. Busia County led the other two Counties at 60% with primary education, a similar number was registered in Uasin Gishu County for those with secondary education. Busia and Siaya Counties reported 33% as having attained secondary education. Overall, range of farmland sizes owned by most (82%) farmers were between 1 – 5 acres. Farmers' overall household size was predominantly (51%) in the range of 6 – 10 persons.

**Table 7. Demographic characteristics of farmers involved in rearing improved indigenous chicken from three Counties (%)**

Parameters	The Selected Counties			Overall
	Busia	Siaya	Uasin Gishu	
<b>Age (yrs)</b>				
18 – 29	20	33	13	22
30 – 39	27	20	60	36
40 – 49	20	20	20	20
50 – 59	7	7	7	7
Greater than 60	26	20	0	15
<b>Gender</b>				
Female	60	40	73	58
Male	40	60	27	42
<b>Education level</b>				
Primary	60	20	27	36
Secondary	33	33	60	42
Tertiary	0	20	13	11
University	7	27	0	11
<b>Land size (acres)</b>				
1 – 5	100	80	67	82
6 – 10	0	20	33	18
<b>Household size, n</b>				
1 – 5	46	40	33	40
6 – 10	47	47	60	51
11 and above	7	13	7	9

#### **4.3.2 Improved technologies and management practices implemented by IIC**

##### **farmers**

A small (10%) number of farmers opted not to utilize any of the identified technologies and management practices overall; however, all farmers in Uasin Gishu County applied selected technologies and management practices (Table 8). Deworming was practiced by 56% of farmers, with Siaya and Uasin Gishu Counties leading at 73%. Vaccinations were administered by 64% of farmers, with Siaya (73%) and Busia (67%) Counties leading.

**Table 8. Percent distribution of selected technologies and management practices used in improved indigenous chicken production systems**

Technology/management practice	The Selected Counties			Overall
	Busia	Siaya	Uasin Gishu	
None	20	12	0	10
Deworming	20	73	73	56
Vaccinations	67	73	53	64
Supplements	12	46	47	35
Improved feeds	46	67	80	65
Housing	53	67	80	67
Record keeping	7	40	27	24
Veterinarian services	80	80	67	76

Supplements were administered by 35% of farmers overall, with Uasin Gishu (47%) and Siaya (46%) Counties leading. Conventional commercial feeds were provided to chicken by 65% of farmers overall, with Uasin Gishu and Siaya Counties leading (80 and 67%, respectively). Results indicated that 67% had adopted good housing provisions, with Uasin Gishu County leading at 80%. Farmers in Uasin Gishu County had varied housing systems including; traditional and modern portable houses and others had traditional chicken brooder (*Chepkube*) in the kitchen as shown in Plate 9. Record keeping was poorly (24%) implemented by farmers overall, despite Siaya County being ahead at 40%. Veterinarian services were highly (76%) consulted by farmers, with Busia and Siaya Counties leading at 80%. The percent distribution of farmers' stratification based on gender in the three counties on improved technologies and poultry management practices is shown in Table 9 below.



Plate 9. Traditional chicken brooder in the kitchen (Source, Kiptui, 2023)

Table 9. Gender percent distribution of selected technologies and management practices used in improved indigenous chicken production systems

Technology/ management practice	Percentage of respondents								
	Busia		Siaya		Uasin Gishu		Across counties		
	Male	Female	Male	Female	Male	Female	Male	Female	Total
None	2	4	0	4	0	0	2	8	10
Deworming	7	0	20	4	7	18	34	22	56
Vaccinations	11	11	20	4	2	16	33	31	64
Supplements	4	2	7	7	11	4	22	13	35
Improved feeds	9	9	16	4	7	20	32	33	65
Housing	9	9	13	9	7	20	29	38	67
Record keeping	2	0	9	4	2	7	13	11	24
Veterinarian services	9	18	20	7	4	18	33	43	76

### 4.3.3 Selected production practices influencing improved indigenous chicken

#### production

Results presented in Table 10 show that most (58%) farmers reared chicken flock sizes in the range of 1–15 overall, with Busia leading at 73% followed by Uasin Gishu having 60% and lowest (40%) in Siaya Counties. The IIC mostly (69%) preferred by farmers in the three counties were Rainbow Rooster and *Kuroiler* breeds, with Busia County leading at 87%. Exotic or pure chicken breeds were least (4%) reared, with farmers in Busia and Uasin Gishu Counties keeping none. Farmers in Siaya County predominantly reared exotic breeds (13%) due to their superior growth rates and egg production, which significantly enhanced profitability and fulfilled market demand. This study showed that accessing specialized resources and training programs further strengthened the adoption of these breeds, thereby improving overall productivity and food security. Most (42%) farmers incurred veterinarian costs in the range of Ksh 1.00 – 500.00 overall, with those in Busia and Uasin Gishu Counties (66 and 40%, respectively) being higher than Siaya County (20%). Veterinarian costs in the range of Ksh 1001.00 and above were the least (11%) incurred overall, while Siaya County incurred more (27%) than Busia (7%) and Uasin Gishu (0%) Counties.

**Table 10. Production dynamics in rearing improved indigenous chicken (%)**

Parameters of Interest	The Selected Counties			Overall
	Busia	Siaya	Uasin Gishu	
<b>Flock size, No.</b>				
1 – 15	73	40	60	58
16 – 30	7	33	20	20
31 and above	20	27	20	22
<b>Chicken breed</b>				

Improved indigenous chicken	87	60	60	69
Indigenous chicken	13	27	40	27
Exotic/Pure breed	0	13	0	4
<b>Veterinarian costs, Ksh.</b>				
None	20	20	27	22
1.00 – 500.00	66	20	40	42
501.00 – 1000.00	7	33	33	24
1001.00 and above	7	27	0	11

#### 4.3.4 Feeding practices for IIC production and feed costs

Feeds were purchased by most (69%) farmers overall, with the highest (80%) percentage of farmers being in Uasin Gishu County (Table 11). Chick mash was the most (24%) common feed type purchased by farmers, with Siaya County purchasing it highly (40%), while grower mash was highly (27%) purchased in Uasin Gishu County. Layers mash was the least (7%) purchased overall, with no purchases in Siaya County. Home-grown or made rations were formulated overall by majority (71%) of the farmers, with Uasin Gishu and Busia Counties leading at 87 and 80%, respectively. Maize, as an input in feed formulation, was intensely (71%) used compared to sorghum (51%) in the three counties (Table 11). Farmers in Busia and Siaya counties used sorghum and maize as inputs at the same ratio, while Uasin Gishu County used higher (87%) maize as input compared to sorghum.

**Table 11. Feeding dynamics for production of improved indigenous chicken (%)**

Parameters of Interest	The Selected Counties			
	Busia	Siaya	Uasin Gishu	Overall
<b>Purchased feed/supplements</b>				
Yes	53	73	80	69
No	47	27	20	31
<b>Feed type</b>				
Chick mash	20	40	20	24

Grower mash	20	7	27	18
<i>Kienyeji</i> mash	7	27	20	20
Layers mash	7	0	13	7
<b>Home-grown/made ration</b>				
Yes	80	47	87	71
No	20	53	13	29
Maize as input	80	47	87	71
Sorghum as input	80	47	27	51

There were significant differences ( $p < 0.05$ ) in cost parameters across feed rations as shown in Table 12 below. The total feed intake in 12 weeks, feed cost per kilogram and total feed cost followed the same trend in all treatments with T<sub>3</sub> being the highest, followed by T<sub>1</sub> and lowest in T<sub>2</sub>.

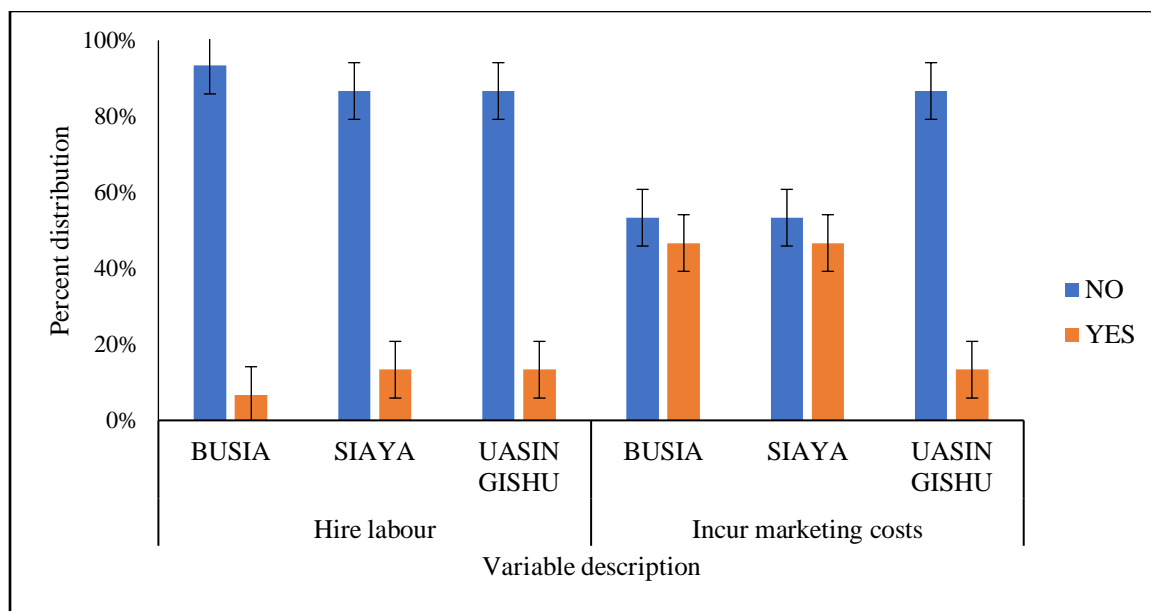
**Table 12. Cost of feed rations used in rearing of IIC**

Parameters	Experimental Treatments		
	T <sub>1</sub>	T <sub>2</sub>	T <sub>3</sub>
Total feed intake in 12 weeks per chicken (kg)	4.12 <sup>b</sup>	3.82 <sup>a</sup>	4.76 <sup>c</sup>
Total feed cost per kilogram (KSh)	63 <sup>b</sup>	59 <sup>a</sup>	70 <sup>c</sup>
Total feed cost consumed per chicken in 12 weeks (Ksh)	260 <sup>b</sup>	225 <sup>a</sup>	333 <sup>c</sup>

*Values within a row with different superscripts differ significantly ( $p < 0.05$ )*

#### **4.3.5 Production costs incurred in rearing improved indigenous chicken**

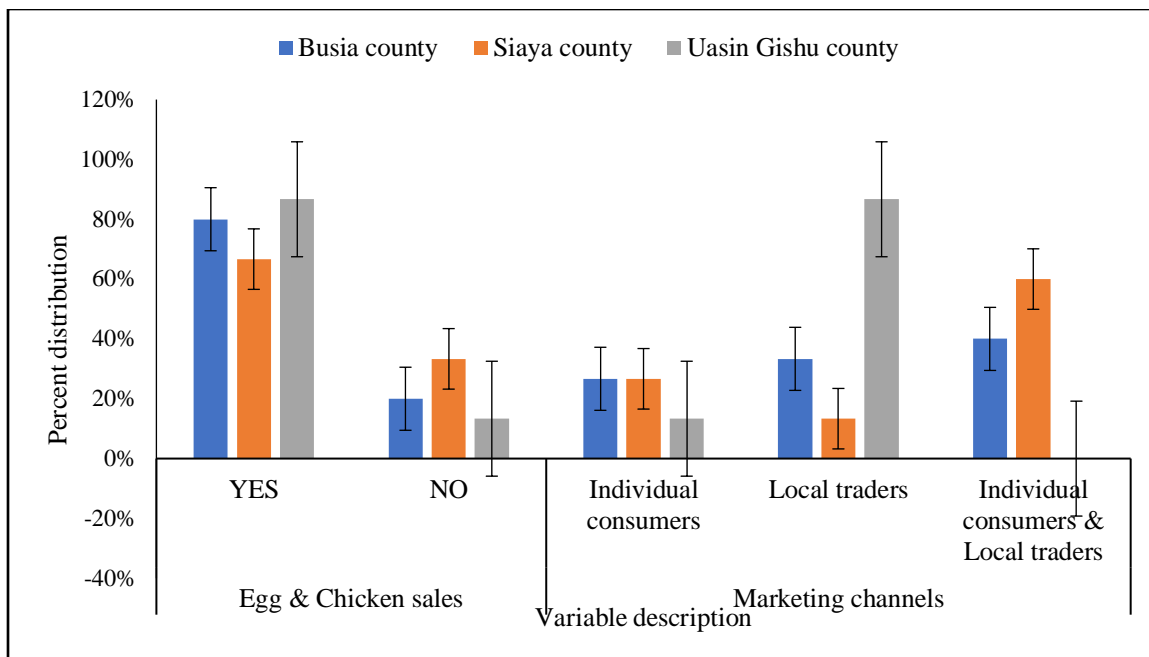
Casual labour was not hired by most (89%) farmers overall; instead, family labour was used since most (51%) household sizes ranged from 6 to 10 people (Table 7 & Figure 5) which provide labour for chicken production enterprises. Most (64%) farmers did not incur marketing costs in the three counties, especially in Uasin Gishu County at 87% (Figure 5).



**Figure 5. Selected production parameters influencing cost of rearing improved indigenous chicken from three counties**

#### **4.3.6 Improved indigenous chicken egg and bird sale records**

Most farmers carried out egg and chicken sales (Figure 6). Egg and chicken sales were high in Busia and Uasin Gishu Counties (80 and 87%, respectively). Egg and chicken products were individually consumed, sold to local traders, and both. Individual consumption was high (27%) in Busia and Siaya Counties. Sales to local traders dominated (87%) in Uasin Gishu County, and both individual consumption and sales to local traders being high in Siaya and Busia Counties (60 and 40%, respectively).

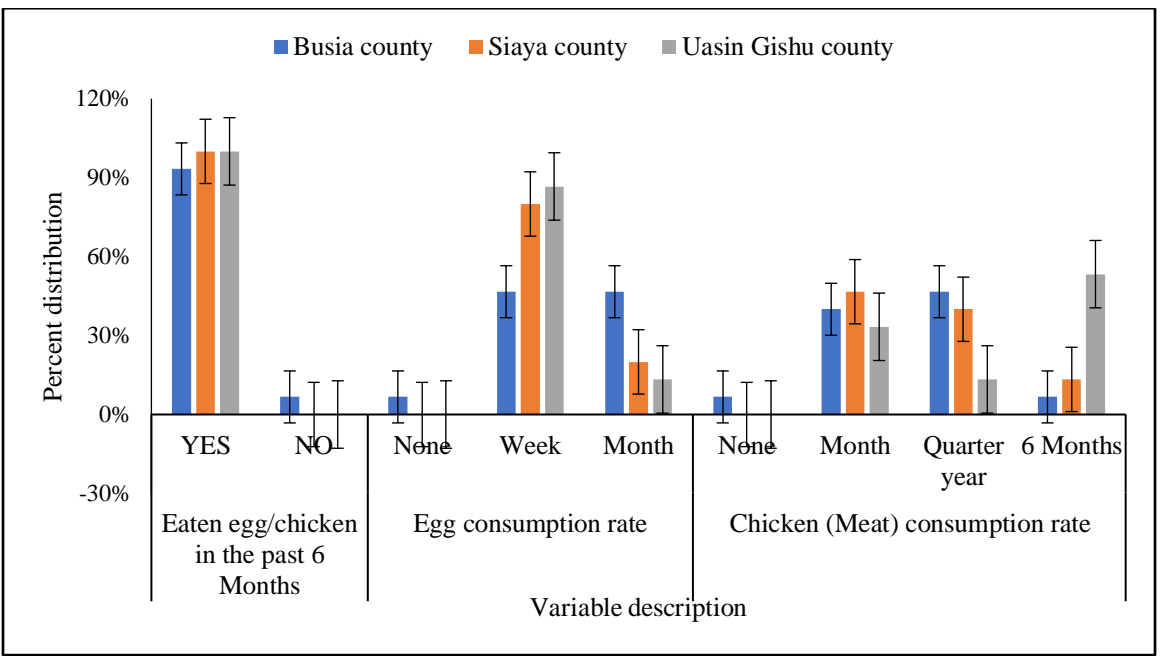


**Figure 6. Percent distribution of egg and chicken sales records from three counties**

#### **4.3.7 Dietary diversification among smallholder farmers rearing improved indigenous chicken**

The study highlighted distinct consumption patterns for eggs and chicken meat across Uasin Gishu, Siaya, and Busia Counties, influenced by cultural and economic factors. Eggs and chicken were highly consumed by all farmers in Siaya and Uasin Gishu Counties since they are common delicacy (Figure 7). The rate of egg consumption was higher per week in Uasin Gishu (87%) and Siaya (80%) Counties, reflecting strong dietary preferences and higher disposable incomes that allow for more frequent purchases. In contrast, Busia showed a monthly egg consumption rate of 47%, suggesting less frequent but significant intake, potentially due to economic constraints and alternative protein sources. For chicken (meat), Siaya had a monthly rate of 47%, while Busia reported 47% per quarter year and Uasin Gishu 53% over six months, indicating varying consumption frequencies. These

trends illustrate the complex dietary habits shaped by access to markets, nutritional awareness and demographic factors across the counties.



**Figure 7. Percent distribution of dietary diversification among improved indigenous chicken farmers**

## CHAPTER FIVE

### DISCUSSION

#### 5.1 Nutrient composition of diets

Results showed that diet T<sub>1</sub> met nutrient requirements for most tested parameters, including crude ash, crude fat, crude fibre, crude protein, dry matter, nitrogen-free extracts, cysteine, lysine, methionine, tryptophan and metabolizable energy. Diet T<sub>2</sub> exceeded nutrient requirements for crude fat and total carbohydrates, and Diet T<sub>3</sub> did not meet nutrient requirements for crude ash, crude protein, total carbohydrates and cysteine. Nutritional standards being referenced when discussing the nutrient requirements was KEBS, 2021.

The highest crude ash content ( $p < 0.05$ ) was obtained in T<sub>3</sub> (12.31%), while lower values were found in T<sub>2</sub> (5.12%) and T<sub>1</sub> (4.33%) as compared to those reported by Masenya *et al.* (2021) which ranged from 5.51 – 6.26%. This indicated that T<sub>3</sub> contained a higher concentration of inorganic minerals, likely due to the inclusion of mineral-rich additives or by-products in its formulation. Ingredients such as limestone or specialized mineral premixes could elevate ash content, contrasting with T<sub>1</sub> and T<sub>2</sub>, which were primarily composed of lower ash ingredients like sorghum and maize. This aligned with findings from the NRC (1994), which emphasized that the composition of feed ingredients significantly impacted the mineral content of animal diets, underscoring the importance of balanced mineral supplementation for optimal poultry health and performance. Low ash content in feed predisposes birds to diseases and poor eggshell formation (Ofori *et al.*, 2019). Crude ash defines the inorganic content of feed which is mainly minerals. These

critical nutrients are required in specific amounts in poultry diets for stronger bone, blood clotting, enzyme activation, and muscle contraction, and eggshell formation.

Diets T<sub>3</sub> (6.04%) and T<sub>1</sub> (7.94%) had significantly ( $p < 0.05$ ) lower crude fat contents than diet T<sub>2</sub> (9.01%). The high crude fat contents in sorghum rations was as a result of sorghum inclusion which has a slightly higher fat. All the diets had greater crude fat composition in comparison to the 5.80% as reported by Ciurescu *et al.* (2023) for birds' finisher diets of 50% sorghum level as a substitute for maize. The crude fat findings in this study were higher than those in a study by Khaleel *et al.* (2021), where the control diet contained 4.69%, and the sorghum diets with inclusion levels of 45% and 60% had 5.84% and 6.00%, respectively. Lipids (fats and oils) are a concentrated source of energy in poultry diets that improves palatability, feed consistency, provides essential fatty acids and increases the absorption of fat-soluble vitamins (Qaisrani *et al.*, 2021).

Crude fibre (CF) can escape digestion and absorption in small intestines, which makes it able to affect the way other nutrients are absorbed and metabolized in gastrointestinal tract (Tejeda & Kim, 2021). The CF content in T<sub>3</sub> (12.69%) was significantly higher ( $p < 0.05$ ) than T<sub>1</sub> (4.73%) and T<sub>2</sub> (4.68%). The crude fibre content in sorghum rations was low, as sorghum is a cereal grain with a lower crude fibre content. The CF values of all dietary rations exceeded the range between 3.12 and 3.83% reported in a study by Masenya *et al.* (2021). The crude fibre content in this study for sorghum-based rations was lower than that reported by Usman *et al.* (2020), where a broiler diet with 53% sorghum inclusion had a value of 5.10%.

Diet T<sub>3</sub> (12.73%) had low crude protein (CP) content than diets T<sub>2</sub> (14.55%) and T<sub>1</sub> (15.15%). Diet T<sub>1</sub> had the highest crude protein content due to the high levels of soybean,

which is a valuable source of plant protein (Table 2). The CP findings were lower compared to values in a study by Masenya *et al.* (2021) ranging from 16.2% – 18.7%. The findings of this study were also lower than those reported in a study by Khaleel *et al.* (2021), where a control diet contained 15.35%, and a diet with 45% sorghum inclusion had 18.63%. The bird needs proteins for growth, building body tissues and compensating for damaged ones to produce eggs and meat, and enters into the composition of blood, muscles, skin, feathers and beak (Ameen *et al.*, 2023).

Diet T<sub>1</sub> contained lower (89.70%) dry matter content compared to T<sub>2</sub> (90.30%) and T<sub>3</sub> (91.20%). The T<sub>2</sub> and T<sub>3</sub> values surpassed a range of 89.8 to 90.0%.by a small margin in a study by Ciurescu *et al.* (2023). The dry matter content in T<sub>3</sub> was higher than that of the control diet, which did not include sorghum, in a broiler diet in a study by Usman *et al.* (2020), where it was 86.17%.

Nitrogen-free extract (NFE) is the soluble carbohydrate component of feed consumed. Diet T<sub>3</sub> had lower (56.30%) NFE content than T<sub>2</sub> (66.70%) and T<sub>1</sub> (67.90%). Sorghum diets had higher NFE contents than the control, as sorghum, being a carbohydrate-rich grain, contributed significantly to the NFE content in the diets. Percent NFE in diets T<sub>1</sub> and T<sub>2</sub> were higher than 44.7 – 56.3% reported by Hayat *et al.* (2016) and Momoh *et al.* (2010) for indigenous chickens of Ethiopia and North Central Nigeria. The findings were higher than those in a study by Usman *et al.* (2020) where broilers experimental diet at 53% sorghum inclusion level had NFE at 36.85%.

Sorghum-based rations of T<sub>1</sub> and T<sub>2</sub> had higher (72.60 and 71.30%, respectively) carbohydrate contents than diet T<sub>3</sub> (69.00%). Carbohydrate contents of diets T<sub>1</sub> and T<sub>2</sub> were higher compared to a range (34.7% - 69.0%) in poultry feeds (Dewa & Tikau, 2019).

Carbohydrates and fats are mainly a source of energy that the body needs to maintain its temperature and to accomplish the vital activities and chemical reactions by which the bird builds body tissues and gets rid of waste (Ameen *et al.*, 2023).

Diet T<sub>3</sub> had the lowest (0.47%) cysteine content than diets T<sub>2</sub> and T<sub>1</sub> (0.61 and 0.65%, respectively). Diets T<sub>1</sub> and T<sub>2</sub> included significant amounts of soybean, which is a rich source of cysteine, thereby enhancing their overall amino acid profile (Table 2). Cysteine is a semi-essential amino acid belonging to the sulphur-containing amino acids. It plays essential roles in protein synthesis, structure and function (Nte & Gunn, 2021).

Lysine content in diet T<sub>2</sub> was higher (0.86%) than T<sub>3</sub> (0.67%) and T<sub>1</sub> (0.50%). Diet T<sub>1</sub> contained 22 kg of soybean, a good source of lysine, the presence of other ingredients may have diluted its lysine concentration by introducing competing amino acids or reducing its proportion relative to total protein (Table 2). In contrast, Diet T<sub>2</sub>, with 17.5 kg of soybean, was formulated to maximise lysine availability through a better balance with other protein sources (Table 2). Lysine content of diets T<sub>1</sub> and T<sub>2</sub> were lower than 1.15 and 1.08% obtained in a study by Manyelo *et al.* (2019) for 50% and 75% sorghum inclusion levels respectively. Lysine constitutes the second most limiting amino acid in chicken feeds (Attia *et al.*, 2020). Lysine was found to improve carcass quality and growth performance of broilers (Belloir *et al.*, 2019).

Diet T<sub>1</sub> had lower (0.82%) methionine content than T<sub>3</sub> (1.05%) and T<sub>2</sub> (1.28%). Diet T<sub>1</sub> had higher methionine content compared to a study by Manyelo *et al.* (2019) where a diet with a 50% sorghum inclusion level had 0.47%. Methionine is the foremost limiting amino acid in poultry rations (Adhikari *et al.*, 2023; Teng *et al.*, 2023). Methionine is a crucial component for optimum growth performance of poultry, feather synthesis and biochemical

processes (as a methyl group donator), and muscle accretion (de Castro Goulart *et al.*, 2011; Fagundes *et al.*, 2020).

Diet T<sub>2</sub> had higher (1.00%) tryptophan content than diets T<sub>1</sub> (0.29%) and T<sub>3</sub> (0.82%). All diets had higher tryptophan contents than recommended levels in a study by Wang *et al.* (2016) of 0.20% for chickens of strain Cobb 500 aged 22 to 42 days. Tryptophan is the third most limiting amino acid in poultry diets. It is recognized as an essential amino acid due to its role in protein biosynthesis (Fouad *et al.*, 2021). Tryptophan improves growth performance, reduces stress and regulates insulin, synthesizes protein in the muscles, and improves meat quality (Linh *et al.*, 2021).

Diet T<sub>3</sub> had significantly ( $p < 0.05$ ) lower (2,941.67 Kcal kg<sup>-1</sup>) metabolizable energy (ME) than diets T<sub>1</sub> (3,594.0 Kcal kg<sup>-1</sup>) and T<sub>2</sub> (3,616 Kcal kg<sup>-1</sup>). Sorghum's carbohydrate-rich composition provided sorghum rations a higher metabolizable energy. All feed samples had higher ME contents that were above the minimum requirement (2,400 Kcal kg<sup>-1</sup>) for chicken feeds (KEBS, 2021). The metabolizable energy (ME) is the convectional measure of the available energy content of feed nutrients and requirements of poultry (Ofori *et al.*, 2019). Metabolizable energy is the total useful energy that can be partitioned to any purpose dictated by the metabolic needs and priorities of the bird (Zuidhof, 2019).

Tannin content in RUC26 sorghum variety was 1.24% that was lower than findings by Shinda *et al.* (2022) who reported 1.76% for Seredo sorghum cultivar. The finding is contrary to a study by Mugalavai & Onkware (2018) where RUC26 sorghum was characterized as a no tannin cultivar. Tannins in diets for monogastric animals, such as poultry and rabbits, reduce starch and protein digestibility, lower feed intake due to decreased palatability, and ultimately result in reduced weight gain and poor feed

conversion efficiency (Muriu *et al.*, 2002; Liu *et al.*, 2015; Oke *et al.*, 2015). Low concentrations of tannins can improve gut health and digestive performance in broiler chickens (Huang *et al.*, 2018; Moritz *et al.*, 2023).

## **5.2 Growth performance of IIC on sorghum-based feed rations and a commercial feed in farmers' production systems**

### **5.2.1 Growth of IIC in three production systems in Busia, Siaya and Uasin Gishu Counties**

Growth of IIC was significantly higher in Intensive than Semi-intensive and Free-range production systems during the study period. The findings concur with results by Ghayas *et al.* (2020) where Intensive produced significantly heavier birds than Free-range system. The high growth of IIC reared in Intensive system was because of higher feed consumption and improved feed conversion efficiency, resulting from lower energy expenditure in foraging by IIC. The IIC in Free-range system were not provided feed but left to forage; unlike the Intensively managed IIC which depended solely on commercial feed that was available *ad libitum*. This finding concurred with a study by Bili *et al.* (2022) which indicated that the final body weight and weight gain in free-range chickens were adversely affected by the level of ration consumption, as well as by the nutritional content of the rations, which had to be balanced to support rapid growth. The increased physical activity in foraging, walking, and exploring environment led to higher energy expenditure and reduced muscle/fat deposition. Free-range chickens have lower feed intake compared to chickens in conventional systems, as they commit more time scavenging and consuming forage, which can be less energy-dense than commercial feed. These are the primary factors contributing to lower bodyweight performance (Fanatico *et al.*, 2007).

Growth of IIC was higher in Intensive compared to Semi-intensive which was similar to findings by Jahan *et al.* (2020) where farm reared chicken was heavier than Semi-scavenged. However, intensive system has a negative impact on poultry welfare resulting from the conditions they are reared in and high stocking densities. The solutions to better animal welfare include reduction of overcrowding in chicken holdings by adhering to the maximum stocking densities (up to 42 kgm<sup>-2</sup>) and providing specific requirements such as lighting, litter, feeding and ventilation (Directive, 2007). Decreasing the stocking density can lead to poultry spending more time engaged in active behaviours like running, scratching the litter, wing flapping, and leg stretching (Knierim, 2013).

Semi-intensive system had better growth than Free-range system in week 4 and 16, which is similar to a study where growth performance showed significant increase in Semi-intensive system compared to Free-ranging system (Ngongolo & Chota, 2021). Growth of IIC on Free-range was higher than semi-intensive in week 8 and 12. The IIC in Free-range system had diverse nutritional intake hence consuming a variety of feeds and higher activity levels during scavenging which stimulated muscle development and metabolism that led to slightly higher weight gain than Semi-intensive system birds. Food in free-range system is obtained *via* scavenging, and, occasionally, local grains are provided (Sánchez-Casanova *et al.*, 2020).

### **5.2.2 Growth of improved indigenous chicken on sorghum-based feed rations and a commercial feed in Busia, Siaya and Uasin Gishu Counties**

Growth of IIC was higher in T<sub>1</sub> than T<sub>3</sub> and lowest in T<sub>2</sub> during the study period. The T<sub>3</sub> diet had higher growth rate than T<sub>2</sub>. Findings in this study were similar to those of a study by Saleh *et al.* (2019) where broilers fed 50% yellow maize + 50% low-tannin sorghum

diet had higher significant body weight than those fed control diet. Inclusion of low tannin sorghum at 50% level had no adverse effects on broiler growth performance (Manyelo *et al.*, 2019). This is contrary to findings from studies by Torres *et al.* (2013) and Mohammed *et al.* (2019) where body weight decreased significantly in chickens fed sorghum-based diets. A study by Uduak *et al.* (2021) reported that the final live weights of finisher broilers fed the control diets (2160.00g) were significantly higher than those fed sorghum inclusion diets, where 50% had 1887.40g and 75% had 2009.70g.

Performance in intensive system was higher in T<sub>1</sub> since it was a formulated ration with fresh and high-quality ingredients than T<sub>3</sub> which formulation composition was unknown. Diet T<sub>2</sub> had lower performance compared T<sub>1</sub> and T<sub>3</sub> due to high sorghum inclusion which made the feed unpalatable resulting in low feed intake as shown in Table 12. Lower performance in substitution of maize with sorghum could be due to tannins which reduces feed intake, nutrient digestibility and growth (Batonon-Alavo *et al.*, 2015; Bedford *et al.*, 2016). Feed intake in T<sub>3</sub> was highest (Table 12) resulting to best growth in Semi-intensive system compared to that of T<sub>1</sub> and T<sub>2</sub>. This finding is supported by Leeson & Summers (2005) where chicken consume more feed to compensate for nutrient deficiencies hence resulting to higher weight gain.

### **5.2.3 Growth performance characteristics of IIC in Busia, Siaya and Uasin Gishu**

#### **Counties**

##### **5.2.3.1 Total weight gain**

The total weight gain of IIC was significantly higher when fed the control diet compared to sorghum-based rations and in the free-range system. This was due to the higher feed

intake in the control diet, whereas IIC in the free-range system spent more time and energy scavenging for food. The total weight gain in T<sub>1</sub> was slightly higher (932.53g) than a study by Saleh *et al.* (2019) where broilers fed 50% yellow maize + 50% low-tannin sorghum diet had total weight gain of 852.7g. A study by Doma and Adamu (2024) reported a significantly higher total weight gain of 1,038.40g for broilers fed a formulated diet containing 50% sorghum. The differences in total weight gains resulted from sorghum varieties or chicken breeds used in the experiments.

### **5.2.3.2 Average daily weight gain**

The average daily weight gain of IIC was high T<sub>3</sub> (12g) and T<sub>1</sub> (11.1g). Diet T<sub>1</sub> met nutrient requirements for chicken feed therefore supporting weight gain. Feed intake in T<sub>3</sub> was highest resulting to the best average daily weight gain. This implies that IIC converted nutrients effectively into body weight, thereby supporting growth. Findings in this study were lower than those of Puntigam *et al.* (2020) where average daily weight gain in broiler chickens fed with 50% partial replacement of maize with sorghum was 51.93g. Furthermore, the findings of this study were lower than those of Egbewande *et al.* (2021), where the average daily weight gain in broilers during the finisher phase (4-8 weeks), fed with 50% white sorghum inclusion, was 61.77g. The difference could be due to factors like breed differences, diet composition and management factors. Average daily weight gain in T<sub>4</sub> was lowest due to low efficiency of utilization of energy for weight gain.

### **5.2.3.3 Average daily feed intake**

The IIC on the control diet had a higher average daily feed intake compared to sorghum-based rations, as the control diet was more palatable, leading to higher consumption. Diet T<sub>1</sub> was higher (49.07g) than T<sub>2</sub> (45.50g) which is similar to a study by Mugoti *et al.* (2022)

where chicken fed sorghum-based rations of 50% had a higher (82.76g) feed intake than 75% (79.56g). This was similar to a study by Doma and Adamu (2024), where daily feed intake of sorghum diets with inclusion level of 50% (77.81 g) was higher than 75% (75.36 g). The lowest feed intake in T<sub>2</sub> was due to the high inclusion of sorghum, which decreased the feed's palatability. Implementing strategies to enhance palatability in sorghum-based diets could address this issue.

#### **5.2.3.4 Feed conversion ratio (FCR)**

The IIC in T<sub>4</sub> had the highest FCR due to high extensive foraging that required more energy. Their health and feed intake were also compromised by predators, disease, and changing weather conditions, resulting in a higher FCR. The FCR in T<sub>1</sub> and T<sub>2</sub> were higher (4.42 and 5.17, respectively) than a study by Mugoti *et al.* (2022) where sorghum rations of 50% and 75% had 2.48 and 2.60, respectively. A corresponding rise in sorghum inclusion levels in the rations resulted to increased FCR implying that it affected feed efficiency. The underlying reason for this is the presence of anti-nutritional factors like tannin and low feed intake. These findings contradict the study conducted by Ahmad *et al.* (2024), which reported significantly higher FCR in the sorghum replacements at 20% (2.10), 40% (2.09), and 100% (2.14), compared to the control (1.96).

#### **5.2.3.5 Survival rate**

Survival rate was lowest in T<sub>4</sub> primarily due to predation, illnesses, injuries, and harsh weather conditions that adversely affected their health. The free-range system is particularly vulnerable, as minimal care is provided for the birds. They depend on daily scavenging and are susceptible to diseases, parasites and unpredictable challenges posed by seasonal changes. The IIC fed diets T<sub>1</sub>, T<sub>2</sub> & T<sub>3</sub> were housed in intensive and semi-

intensive systems, where they were better housed, fed, and managed; therefore, their survival was greatly improved. The survival rate for improved indigenous chicken at 16 weeks of age in T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub> was higher (53.5%) than findings by Biratu & Haile (2016) of the chicken that survived to the laying age of the Potchefstroom Koekoek chicken breed in Areka and Jimma areas. They simply scavenge on daily basis and are prone to disease, parasites, predators and vagaries of the seasons day by day. A study by Abalaka *et al.* (2013) found that the survival rate of birds reared under a free-range system was higher (95.45%) than that observed in this study.

### **5.3 Diversity of socio-economic drivers among smallholder farmers rearing improved indigenous chicken**

#### **5.3.1 Demographic aspects of improved indigenous chicken farmers**

The age range of most (36%) farmers was 30 – 39 years since they were in self-help groups for various projects in their regions. This closely matched findings by Cheruiyot & Adhiaya, (2021) where most (34.1%) farmers' age ranged between 36 to 45 years. In this study, the proportion of farmers aged 18 – 29 years in Siaya County was highest at 33%, aligning with the KNBS (2019), which indicated that this age group constituted 28% of farmers in the county. Meanwhile, in Busia County, the predominant age range among farmers was 30 – 39 years, accounting for 27%, slightly surpassing the 20% noted in the KNBS (2019) for this region. Results showed that chicken rearing was mainly dominated by female gender; a fact that could be attributed to minimal start-up capital-base requirements and cultural perception and beliefs whereby chicken is considered a woman's livestock. This was similar to a study in Machakos, Uasin Gishu and Kiambu Counties, Kenya where 84% of chicken farmers were female (Wambua *et al.*, 2022). The findings

from Busia County matched those of KNBS (2019), where females (51%) surpassed males (49%). However, Siaya and Uasin Gishu Counties showed equal distribution, with both females and males comprising 50% each (KNBS, 2019). Female have taken over small-scale chicken production (Macharia *et al.*, 2020). Farmers with primary education level matched that of Irene *et al.* (2022) where 36.8% had attained the same. In Busia County, 60% had attained primary education, aligning perfectly with the findings from KNBS, 2019. In Siaya County, only 33% had attained secondary education, which is lower than the 55% reported by KNBS, 2019. In Uasin Gishu County, 60% had completed secondary education exceeding the 45% reported in KNBS, 2019. Education enlightened farmers to access market dynamics, keep records, adopt and implement new technologies hence enhancing their productivity in this value chain. Females empowerment through resource allocation and capacity building would play a significant role in the value chain. Chicken rearing occupies little land which was justified by the small land acreage owned. The average farm size in Uasin Gishu County was 2 to 10 acres in rural areas, 2.5 to 7.4 acres for small-scale farmers in Siaya County and 1-acre small scale in Busia County (MoALF, 2016b, 2016a, 2017). The land size owned by farmers in this study aligned with the KNBS (2019), which indicated that 1 to 5 acres were predominantly owned by farmers across all study sites: Busia County (45%), Siaya County (50%), and Uasin Gishu County (55%). However, these figures were lower than those obtained in this study as shown in Table 7. Household sizes of 1–5 persons were reported to be lower than 50% in Busia County and 45% in Siaya County, as indicated by KNBS, 2019. Conversely, the household size of 6–10 persons was the highest in both this study (60%) and in the findings from KNBS (2019), recorded at 45%. Large family sizes indicate that farm labour can be derived from

households. Households utilize family labour as a coping strategy towards meeting high labour demands (Akinola, 2014).

### **5.3.2 Improved technologies and management practices implemented by farmers rearing improved indigenous chicken**

Majority of farmers implemented selected technologies and management practices due to their positive impact on production while a few (10%) did not implement. All farmers in Uasin Gishu County utilized selected technologies and management practices, as they benefited from training provided by extension officers and agripreneurs through initiatives such as the National Agricultural Value Chain Development Project (NAVCDP), which was designed to enhance their poultry management skills. Deworming was lower due to their beliefs that it was unnecessary compared to a study by Francis *et al.* (2016) where 67% poultry farmers dewormed every month. Vaccinations were administered to keep flocks productive. Acceptance of vaccines by farmers was high due to their significance on profit. A study by Sarkar & Zalal (2023) reported that more (58.67%) farmers vaccinated their chickens as a preventive measure and control of diseases. Supplements were provided by few farmers due to their high costs. This finding was similar to a study by Joshua (2023) where other medium-scale farmers provided supplements and vitamins for treatment. Improved feeds usage trailed values by Molla (2010) and Ebsa *et al.* (2019) in Ethiopia where more than 90% of farmers provided supplementary feeding to their birds and most of them utilized commercial ration in Uganda (Natukunda & Kugonza, 2014). Commercial feeds were purchased for chicks, growers and layers. Such feeds have higher nutritive value and enhance growth (Adolwa *et al.*, 2021).

Overall, majority of the farmers had adopted good housing higher than a study by Irene *et al.* (2022) where 55% of the households had adopted housing. Farmers without chicken houses kept chicken in their living rooms or kitchens, at night. Without appropriate housing, chicken are exposed to harsh conditions and allows loss of chicken through predation, theft, extreme weather, illness and injury (Hofmann *et al.*, 2020). Therefore, improved housing is necessary to prevent such losses. Providing appropriate and adequate housing for chickens is essential for effective management and raising them to marketable age as quickly as possible. Housing should provide a conducive environment for egg-laying, brooding, feeding, and general movement, ultimately impacting their growth and productivity (Oloyo and Ojerinde, 2019).

Record keeping was done by few farmers (24%) since most of them engaged in several enterprises and mixed farming systems therefore rarely finding time to keep records. This was lower compared to a study by Yekosabeth *et al.* (2022) where majority (69.54%) of the farmers kept farm records. Record keeping is used to monitor and evaluate the flock and to make an informed decision on management practices and flock performance (Desta, 2021). Veterinarian services were highly (76%) adopted owing to the necessity of improving farm productivity through disease prevention and control. This result conflicted with a study by Gharib *et al.* (2023) where 72% of the respondent farmers had no access to veterinary services.



**Plate 10. Traditional portable chicken house (Source, Kiptui, 2023)**



**Plate 11. Modern portable house for rearing chicks (Source, Kiptui, 2023)**

### **5.3.3 Selected factors impacting rearing of improved indigenous chicken**

The flock size mostly reared by farmers was in the range of 1 – 15 chicken. This was lower compared to an average of 28 chickens reared per sampled household in Machakos and Busia counties (Irene *et al.*, 2022). This finding was supported by Desta (2021), who noted that a flock size of 15 birds met the dietary needs of an average-sized family. Rearing of improved indigenous chicken was higher (87%) than a study by Irene *et al.* (2022) where only 9% in Busia County had preference for improved indigenous crossbreeds, mainly *Kenbro* and *Kuroiler*. Rearing of improved indigenous chicken is proven to be more

profitable compared to typical indigenous chicken due to their higher growth rate as well as their adaptive capacity (Njuguna *et al.*, 2017). Indigenous chicken ecotypes were lower (27%) in overall compared to a study by Irene *et al.* (2022) where they accounted for about 90% of the birds in the interviewed households in both Busia and Machakos Counties. Veterinarian services were sought by all farmers with varying range of costs incurred implying incidences of diseases. These findings are supported in a study by Anyona *et al.* (2023) where diseases were cited by most (99.6%) respondents of the 10 chicken production constraints assessed in rural areas of Kenya. These factors were selected in order to get more information since they lower productivity of indigenous chicken (Ndegwa *et al.*, 2015).

#### **5.3.4 Feeding practices for IIC production and feed costs**

Present findings on purchase of feed surpassed figures in Eastern Kenya where 38% of households bought commercial feeds for indigenous chicken from the market (Anyona *et al.*, 2023). Feed type purchased mostly was chick mash which implied that chicks dominated the flock. Chick predominance in indigenous chicken flocks had also been reported in Machakos and Busia counties in Kenya (Irene *et al.*, 2022). Seventy-one percent (71%) farmers formulated home-grown or made rations which slightly higher than a study by Wongnaa *et al.* (2023) where 70% of the sampled poultry farmers preferred own prepared feed. According to the farmers, formulating own feed gave them control over the ingredients in their feeds since they used what was locally available to them. The high number of farmers formulating feeds aimed at lowering cost of production. Commercial feeds are expensive and mostly not available in quantities small enough to be affordable to smallholder chicken farmers (Wilson *et al.*, 2021). Given the high feed cost, farmers

knowledge in formulation of quality feed will help maximize performance and profitability in poultry production. Maize was used highly compared to sorghum as an input for home-grown/made rations. Maize is the leading cereal crop in the world and represents the most commonly used cereal grain in diets of intensively reared poultry (Sanni & Ogundipe, 2005; Leeson, 2012; Nkukwana, 2018).

The cost of feed was lower in formulated rations (T<sub>2</sub> and T<sub>1</sub>) compared to the commercial feed (T<sub>3</sub>). This concurs to a study by Gulilat *et al.* (2021) where the price for homemade diet formulated using locally available feed ingredients such as maize, wheat bran, sorghum, millet, barley, noug seed cake, and wheat was lower compared to the commercial feed. This also concurs to a study by Abubakar *et al.* (2020) where feed cost per kilogram gain was cheaper in birds fed the sorghum varieties at 50% and 100% level of inclusion than maize at 100%. The cost of feed rations was lower with the increase in RUC26 sorghum inclusion in the diet. Inclusion of sorghum in feeds results in lower feed costs and the high profits in the enterprise. Introducing sorghum in broiler chicken compound feeds aims at improving economic efficiency (Rózewicz, 2022). Therefore, this study makes important contribution towards adoption of sorghum grain as a substitute for maize in feed formulae, which is more expensive in many African countries.

### **5.3.5 Production costs for improved indigenous chicken production**

Marketing costs incurred by farmers included high cost of transporting chicken products to markets. This finding was similar to a study by Baagyere *et al.* (2023) in Northern Ghana. Casual labour was hired by few (11%) farmers which was lower than a study by Yekosabeth *et al.* (2022) where labour was hired by 43.05% farmers. Home labour was the

most applied source of labour. Family labour helps households to reduce production cost incurred on hired labour (Onyeneke, 2017).

### **5.3.6 Improved indigenous egg and chicken sale records**

Farmers egg and chicken sales in Uasin Gishu county (87%) was similar to a study by Anyona *et al.* (2023) where a higher (87.2%) proportion of households sold indigenous chicken. Egg and chicken sales to local traders were lower in Busia (33%) and Siaya (13%) Counties compared to a study by Sarkar & Zalal, 2023 where farm owners sold a large portion (62.67%) of their products at the local market. Individual consumption & local traders' sales in Busia (40%) and Siaya (60%) counties were lower compared to a study by Anyona *et al.* (2023) where most (77.8%) households kept chicken for home consumption and commercial purposes. The findings were also supported by a study conducted by Chebo *et al.* (2024), which noted that poultry is kept for home consumption in Kenya.

### **5.3.7 Dietary diversification among smallholder farmers rearing improved indigenous chicken**

Chicken meat and egg consumption by farmers was high across all counties since they provide high quality proteins and essential vitamins and minerals. Chicken is the most consumed meat across the globe (Pellattiero *et al.*, 2020). Village chicken products (meat, eggs, and offal) form an integral part in human diets as they provide essential nutrients that are barely obtained from plant-derived products (Alao *et al.*, 2017). Consumption of poultry meat, eggs, and other animal-sourced commodities has dramatically risen by almost 86 %, with the demand of indigenous chicken products almost doubling over the past few

decades (Kamau *et al.*, 2023). Poultry meat and eggs are among the animal-source foods most widely eaten at the global level (FAO, 2021).

## CHAPTER SIX

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Conclusions

Results from the study indicated that use of improved sorghum variety (RUC26) in rations, with specific focus on T<sub>1</sub> met most optimum nutrient needs for chicken as recommended by both National Research Council, 1994 and the Kenya Bureau of Standards, (2021). The RUC26 sorghum variety could serve as a viable substitute energy source for maize-based diets. Rations T<sub>2</sub> and T<sub>3</sub> did not meet some of the recommended nutrient requirements for chicken.

Intensive production had higher growth rates than Semi-intensive and Free-range systems. Ration T<sub>1</sub> produced highest growth rates of improved indigenous chicken in Intensive production system and among the three treatments (T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>). In Semi-intensive production system, growth rate of improved indigenous chicken was best in ration T<sub>3</sub>, closely followed by T<sub>1</sub>. Performance measures including; average daily & weekly weight gain, total weight gain, FCR and survival rate were best in T<sub>1</sub> and T<sub>3</sub> and had no significant differences.

Socio-economic drivers investigated were diverse among smallholder farmers. Farmers aged 30–39 years and older were involved in chicken production, with most being female. Improved technologies and management practices majorly adopted by farmers included veterinarian services, housing, improved feeds, and vaccination. Flock size most reared was 1–15 birds. Improved indigenous chicken production was practiced since it was a source of food, quick income and had better performance characteristics hence improved

productivity. Maize and sorghum grains were majorly used in formulating home-made rations due to their sufficient energy content, which resulted in reduced production costs. Feed costs were lower in sorghum-based rations than commercial feed. Chicken products were mostly sold to local traders. Eggs and chicken meat offered high-quality protein and micro-nutrients essential for normal development and good health in households.

## **6.2 Recommendations**

Smallholder chicken farmers in rural areas should consider utilizing improved sorghum variety RUC26 in homemade poultry feeds. Farmers should be trained by agricultural extension officers and non-governmental organizations in feed preparation skills to adopt Ration T<sub>1</sub>. Awareness campaigns should promote sorghum adoption for chicken feeds. Additional research is recommended to determine the relationships between tannin content in sorghum-based rations and chicken performance.

Improved indigenous chicken should be reared in intensive systems for efficient and high production. This system maximizes limited space and resources to increase supply that meets the increasing demand for chicken products driven by the growing human population. Further studies should be conducted to determine the interactions between animal welfare and growth indicators in poultry production systems. Ration T<sub>1</sub> should be fed to IIC since it resulted in the best growth performance and was cheaper than commercial feed.

Smallholder chicken farmers should embrace high flock size rearing of IIC in order to achieve profits hence improving their socio-economic status. To actualize this, linkages between them and financial institutions will be necessary to facilitate easy access to credit

facilities for expanding and improving chicken production through availability of services including administration of management practices on time. Further, strategic initiatives in capacity building for chicken production including feeding dynamics, production dynamics and improved technologies should be delivered to farmers to improve profits in this enterprise. This can be actualized by forming farmer groups and cooperatives from which they can access training, information, and extension services, as well as provide links to reliable markets for their chicken products.

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## APPENDICES

## APPENDIX I: One-Way ANOVA of the nutritional parameters of dietary rations

T<sub>1</sub>, T<sub>2</sub> and T<sub>3</sub>

Response Crude ash :

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
TRT	2	116.001	58.000	6.7795	0.02887 *
Residuals	6	51.332	8.555		

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Response Crude fat :

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
TRT	2	13.5703	6.7851	9.56	0.01363 *
Residuals	6	4.2585	0.7097		

---

Response Crude fiber :

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
TRT	2	127.524	63.762	27.066	0.0009934 ***
Residuals	6	14.135	2.356		

---

Response Crude protein :

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
TRT	2	9.5006	4.7503	3.3863	0.1037
Residuals	6	8.4167	1.4028		

Response Cysteine :

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
TRT	2	0.0536	0.026800	0.3224	0.7362
Residuals	6	0.4988	0.083133		

Response Dry matter :

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
TRT	2	3.42	1.7100	0.8195	0.4846
Residuals	6	12.52	2.0867		

Response Lysine :

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
TRT	2	0.1946	0.097300	1.5243	0.2916
Residuals	6	0.3830	0.063833		

Response Methionine :

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
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TRT      2 0.31742 0.15871 0.4942 0.6329
Residuals 6 1.92687 0.32114
Response Metabolizable energy :
      Df Sum Sq Mean Sq F value Pr(>F)
TRT      2 880748 440374 24.931 0.001239 **
Residuals 6 105983 17664

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```

Response Nitrogen free extracts :
      Df Sum Sq Mean Sq F value Pr(>F)
TRT      2 244.16 122.080 4.8897 0.05498 .
Residuals 6 149.80 24.967

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Response Total carbohydrates :
      Df Sum Sq Mean Sq F value Pr(>F)
TRT      2 19.94 9.970 0.6199 0.5692
Residuals 6 96.50 16.083

```

```

Response Tryptophan :
      Df Sum Sq Mean Sq F value Pr(>F)
TRT      2 0.8174 0.4087 3.753 0.08768 .
Residuals 6 0.6534 0.1089

```

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

## APPENDIX II: ANOVA table for growth performance characteristics data

### Variate: Score

Source of variation	d.f.	Sum of squares	Mean squares	v.r	F pr.
Within groups	3	36507	12169	1.27	
Between groups	5	1865698	373140	39.01	0.001
Residual	15	143489	9566		
Total	23	2045694			

**APPENDIX III: One-way ANOVA for growth of IIC under production systems and  
Repeated measures ANOVA for dietary treatments**

**Week 4**

ANALYSIS SPLIT PLOT: Weight  
Class level information

Production : Intensive Semi-intensive Free range  
Treatment : TRT<sub>1</sub> TRT<sub>2</sub> TRT<sub>3</sub> TRT<sub>4</sub>  
Rep : 1 2 3 4 5 6 7 8 9 10

Number of observations: 75

Analysis of Variance Table

Response: Weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Rep	9	84082	9342	2.7955	0.0237152 *
Production	2	141105	70552	72.6407	2.082e-05 ***
Ea	7	6799	971		
Treatment	2	84038	42019	12.5731	0.0002284 ***
Production:Treatment	2	38223	19112	5.7187	0.0100022 *
Eb	22	73524	3342		

---  
Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

cv(a) = 12.7 %, cv(b) = 23.5 %, Mean = 245.6267

Study: Weight ~ Production

LSD t Test for Weight

Mean Square Error: 971.2516

Production, means and individual ( 95 % ) CI

	Weight	std r	se	LCL	UCL	Min	Max	Q25
Free range	199.3889	57.83662	18	7.345640	182.0192	216.7586	141	300
Intensive	311.3333	83.66532	30	5.689908	297.8788	324.7878	170	440
Semi-intensive	203.4444	58.33084	27	5.997690	189.2622	217.6267	138	323
	Q50	Q75						
Free range	176.0	253.00						
Intensive	332.5	373.75						
Semi-intensive	176.0	254.00						

Alpha: 0.05 ; DF Error: 7

Critical Value of t: 2.364624

Groups according to probability of means differences and alpha level( 0.05 )

Treatments with the same letter are not significantly different.

	Weight groups	
Intensive	311.3333	a
Semi-intensive	203.4444	b
Free range	199.3889	b

Study: Weight ~ Treatment

LSD t Test for Weight

Mean Square Error: 3341.981

Treatment, means and individual ( 95 % ) CI

	Weight	std r	se	LCL	UCL	Min	Max	Q25	Q50	Q75	
TRT1	286.0526	98.97838	19	13.26249	258.5479	313.5574	138	425	188.5	274	375
TRT2	288.6842	89.89689	19	13.26249	261.1795	316.1889	143	440	203.0	323	360
TRT3	205.9474	53.24313	19	13.26249	178.4426	233.4521	139	325	170.5	180	236
TRT4	199.3889	57.83662	18	13.62592	171.1305	227.6473	141	300	155.0	176	253

Alpha: 0.05 ; DF Error: 22

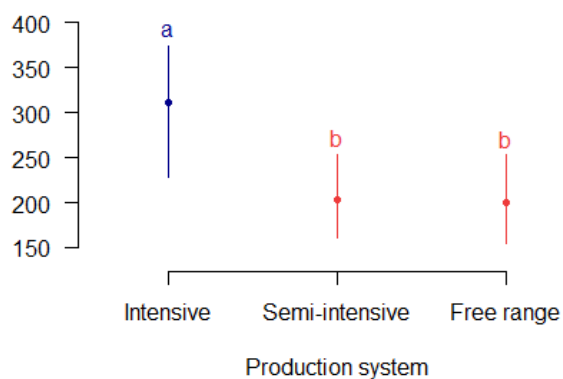
Critical Value of t: 2.073873

Groups according to probability of means differences and alpha level( 0.05 )

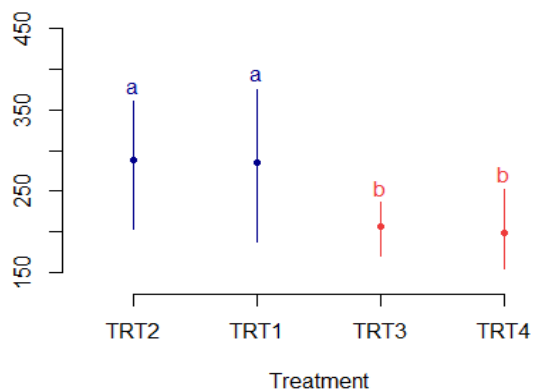
Treatments with the same letter are not significantly different.

	Weight groups	
TRT <sub>2</sub>	288.6842	a
TRT <sub>1</sub>	286.0526	a
TRT <sub>3</sub>	205.9474	b
TRT <sub>4</sub>	199.3889	b

Groups and Interquartile range



Groups and Interquartile range

**Week 8**

ANALYSIS SPLIT PLOT: Weight  
Class level information

Production : Intensive Semi-intensive Free range  
Treatment : TRT<sub>1</sub> TRT<sub>2</sub> TRT<sub>3</sub> TRT<sub>4</sub>  
Rep : 1 2 3 4 5 6 7 8 9 10

Number of observations: 75

Analysis of Variance Table

Response: Weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Rep	9	576986	64110	6.8042	0.0001205 ***
Production	2	1276511	638256	83.8263	1.289e-05 ***
Ea	7	53298	7614		

Treatment 2 19170 9585 1.0173 0.3779526  
 Production:Treatment 2 26333 13166 1.3974 0.2683367  
 Eb 22 207285 9422

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

cv(a) = 20.7 %, cv(b) = 23.1 %, Mean = 420.8133

Study: Weight ~ Production

LSD t Test for Weight

Mean Square Error: 7614.027

Production, means and individual ( 95 % ) CI

	Weight	std r	se	LCL	UCL	Min	Max	Q25
Free range	307.3889	134.69580	18	20.56700	258.7557	356.0221	145	578 211.50
Intensive	608.3333	106.37712	30	15.93113	570.6622	646.0045	430	895 531.25
Semi-intensive	288.0741	89.13254	27	16.79289	248.3652	327.7829	140	518 227.50
	Q50	Q75						
Free range	253.0	393.50						
Intensive	597.5	658.75						
Semi-intensive	277.0	304.00						

Alpha: 0.05 ; DF Error: 7

Critical Value of t: 2.364624

Groups according to probability of means differences and alpha level( 0.05 )

Treatments with the same letter are not significantly different.

	Weight	groups
Intensive	608.3333	a
Free range	307.3889	b
Semi-intensive	288.0741	b

Study: Weight ~ Treatment

LSD t Test for Weight

Mean Square Error: 9422.061

Treatment, means and individual ( 95 % ) CI

	Weight	std r	se	LCL	UCL	Min	Max	Q25	Q50	Q75
TRT <sub>1</sub>	482.1579	220.0720	19	22.26877	435.9753	528.3405	140	895	287.5	540 620.0
TRT <sub>2</sub>	439.8947	190.3377	19	22.26877	393.7121	486.0773	215	785	270.0	430 607.5
TRT <sub>3</sub>	447.8421	157.9716	19	22.26877	401.6595	494.0247	180	685	320.0	498 532.5

TRT<sub>4</sub> 307.3889 134.6958 18 22.87898 259.9408 354.8370 145 578 211.5 253 393.5

Alpha: 0.05 ; DF Error: 22

Critical Value of t: 2.073873

Groups according to probability of means differences and alpha level( 0.05 )

Treatments with the same letter are not significantly different.

Weight groups

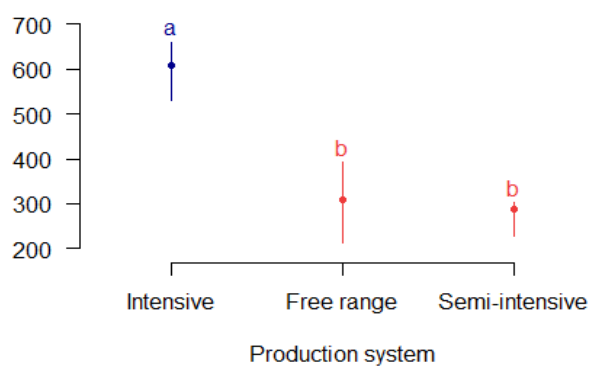
TRT<sub>1</sub> 482.1579 a

TRT<sub>3</sub> 447.8421 a

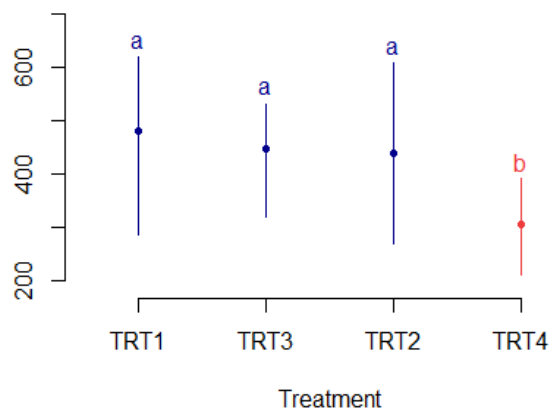
TRT<sub>2</sub> 439.8947 a

TRT<sub>4</sub> 307.3889 b

**Groups and Interquartile range**



**Groups and Interquartile range**



**Week 12**

ANALYSIS SPLIT PLOT: Weight  
Class level information

Production : Intensive Semi-intensive Free range  
Treatment : TRT<sub>1</sub> TRT<sub>2</sub> TRT<sub>3</sub> TRT<sub>4</sub>  
Rep : 1 2 3 4 5 6 7 8 9 10

Number of observations: 75

Analysis of Variance Table

Response: Weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Rep	9	1906113	211790	7.0121	9.665e-05 ***
Production	2	4141482	2070741	207.9764	5.832e-07 ***
Ea	7	69696	9957		
Treatment	2	138245	69123	2.2885	0.1250
Production:Treatment	2	70557	35278	1.1680	0.3295
Eb	22	664482	30204		

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

cv(a) = 13.9 %, cv(b) = 24.2 %, Mean = 716.7467

Study: Weight ~ Production

LSD t Test for Weight

Mean Square Error: 9956.615

Production, means and individual ( 95 % ) CI

	Weight	std r	se	LCL	UCL	Min	Max
Free range	503.1111	212.8448	18	23.51904	447.4974	558.7248	260 957
Intensive	1058.1667	171.5522	30	18.21777	1015.0885	1101.2448	825 1645
Semi-intensive	479.8148	160.4537	27	19.20322	434.4064	525.2232	285 919
	Q25	Q50	Q75				
Free range	343.00	437.0	672.5				
Intensive	938.75	1032.5	1120.0				
Semi-intensive	354.50	472.0	536.5				

Alpha: 0.05 ; DF Error: 7

Critical Value of t: 2.364624

Groups according to probability of means differences and alpha level( 0.05 )

Treatments with the same letter are not significantly different.

Weight groups		
Intensive	1058.1667	a
Free range	503.1111	b
Semi-intensive	479.8148	b

Study: Weight ~ Treatment

LSD t Test for Weight

Mean Square Error: 30203.73

Treatment, means and individual ( 95 %) CI

	Weight	std r	se	LCL	UCL	Min	Max	Q25	Q50	Q75	
TRT <sub>1</sub>	830.1053	384.5809	19	39.87066	747.4186	912.7920	285	1645	501	965	1085.0
TRT <sub>2</sub>	715.8947	331.8703	19	39.87066	633.2080	798.5814	310	1260	385	825	1002.5
TRT <sub>3</sub>	806.6316	288.0176	19	39.87066	723.9449	889.3183	345	1315	543	890	1020.0
TRT <sub>4</sub>	503.1111	212.8448	18	40.96321	418.1586	588.0636	260	957	343	437	672.5

Alpha: 0.05 ; DF Error: 22

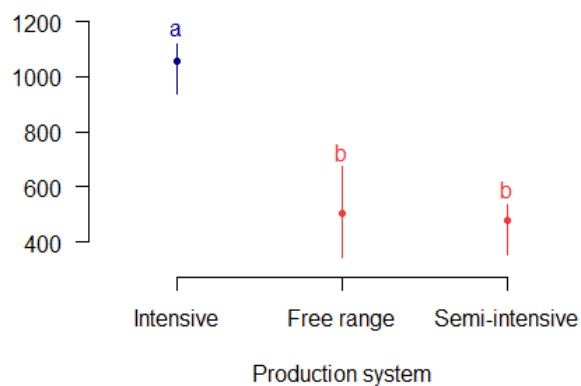
Critical Value of t: 2.073873

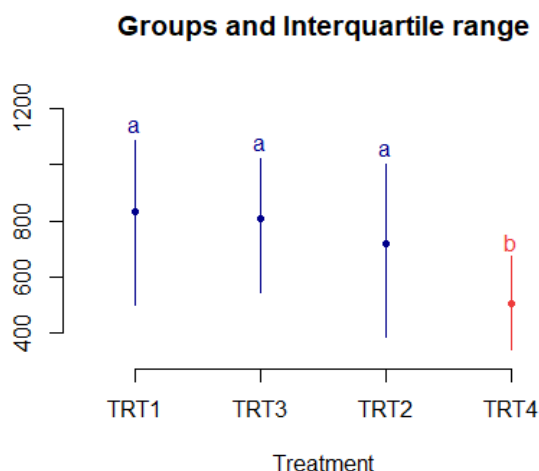
Groups according to probability of means differences and alpha level( 0.05 )

Treatments with the same letter are not significantly different.

Weight groups		
TRT <sub>1</sub>	830.1053	a
TRT <sub>3</sub>	806.6316	a
TRT <sub>2</sub>	715.8947	a
TRT <sub>4</sub>	503.1111	b

**Groups and Interquartile range**





### Week 16

ANALYSIS SPLIT PLOT: Weight  
Class level information

Production : Intensive Semi-intensive Free range  
Treatment : TRT<sub>1</sub> TRT<sub>2</sub> TRT<sub>3</sub> TRT<sub>4</sub>  
Rep : 1 2 3 4 5 6 7 8 9 10

Number of observations: 75

Analysis of Variance Table

Response: Weight

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Rep	9	5386156	598462	14.5304	2.428e-07 ***
Production	2	7680307	3840154	122.5921	3.563e-06 ***
Ea	7	219273	31325		
Treatment	2	448898	224449	5.4495	0.01196 *
Production:Treatment	2	185601	92800	2.2532	0.12877
Eb	22	906109	41187		

---

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

cv(a) = 17.1 %, cv(b) = 19.6 %, Mean = 1034.933

Study: Weight ~ Production



Alpha: 0.05 ; DF Error: 22  
 Critical Value of t: 2.073873

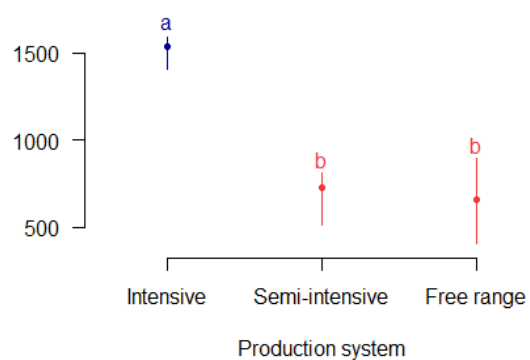
Groups according to probability of means differences and alpha level( 0.05 )

Treatments with the same letter are not significantly different.

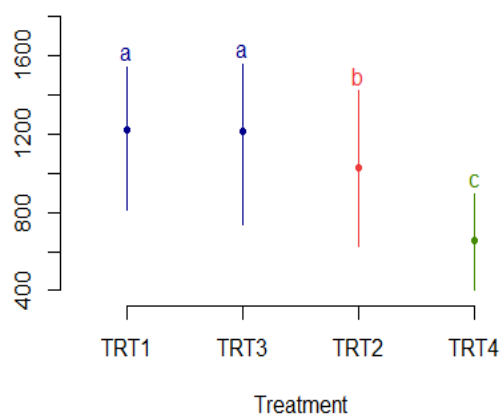
Weight groups

TRT <sub>1</sub>	1218.5789	a
TRT <sub>3</sub>	1213.9474	a
TRT <sub>2</sub>	1028.0526	b
TRT <sub>4</sub>	659.3889	c

**Groups and Interquartile range**



**Groups and Interquartile range**



## APPENDIX IV: Similarity Check



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Certificate of Plagiarism Check for Thesis



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Similarity	10%
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