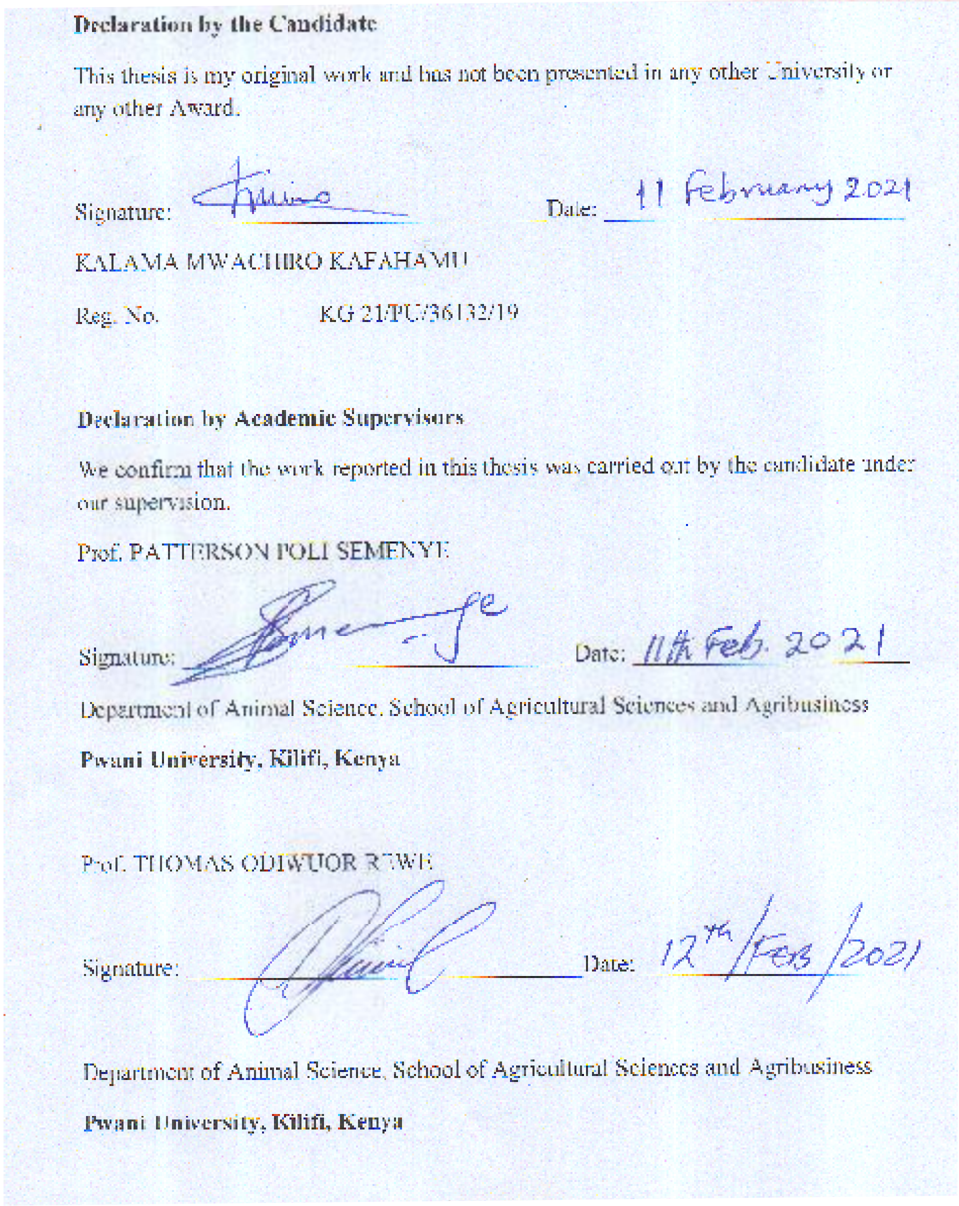
BIOLOGICAL AND ECONOMIC EFFICIENCY OF ARTIFICIAL INCUBATION AND BROODING FOR INDIGENOUS CHICKEN PRODUCTION SYSTEM IN KILIFI COUNTY, KENYA

KALAMA MWACHIRO KAFAHAMU

A thesis submitted in partial fulfillment of the requirements for the Degree of Master of Science in Livestock Sciences of Pwani University

September, 2020

DECLARATION



Declaration by the Candidate

This thesis is my original work and has not been presented in any other University or any other Award.

Signature: Date: 11 February 2021

KALAMA MWACHIRO KAFAHAMU

Reg. No. KG 21/PU/36132/19

Declaration by Academic Supervisors

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

Prof. PATTERSON POLI SEMENYE

Signature: Date: 11th Feb. 2021

Department of Animal Science, School of Agricultural Sciences and Agribusiness

Pwani University, Kilifi, Kenya

Prof. THOMAS ODIWUOR REWE

Signature: Date: 12th/Feb/2021

Department of Animal Science, School of Agricultural Sciences and Agribusiness

Pwani University, Kilifi, Kenya

DEDICATION

I devote effort of all the work to my kinfolk’s inspiration: Parents, Mwachiro Mwembe and Dzidza Tunje; spouse, Rose; children Joy, Ivy, Wisdom, Washe.

ACKNOWLEDGEMENT

I would wish to direct my genuine gratitude to Prof. Thomas O. Rewe who through his guidance, mentorship, constructive critic, and companionship that contributed fundamentally to professional and personal development, which has extended beyond the graduate program. Appreciation is expressed to Prof. Patterson P. Semenye. for providing leadership and insight during the progress of the whole program. Again Prof. Patterson P Semenye is esteemed for facilitating access of the grant funds from treasury of the Pwani University Research fund as the I did not hold imprest portfolio. Admiration is placed upon Mr. Hussein Katama for assisting in data enumeration in my absence. Express gratefulness is expressed to my spouse Rose Wali for encouragement, financial understanding and moral support. Finaly, I acknowledge the Directorate of Livestock Production, Department of Agriculture Livestock Development and Fisheries, of Kilifi County Government, having granted me time to attend to the studies.

ABSTRACT

Consistent supply of indigenous chicken (IC) products has been lacking in the industry with farmers unable to keep up with the normal consumer/market demands in Kilifi and the country at large. Optimization of indigenous chicken output for sustainable and profitable commercialization of the production system through management of egg incubation and chick brooding time is necessary. Discharging hens from the productive roles could make them to be only lay eggs. Whereas brooding artificially also exempts experience to killer external environmental effects, increasing chick survival. The study employed a 2X3 factorial in a randomized complete block design (RCBD) with chicken phenotypic lines as first factor and the blocking factor: (naked neck (NN), frizzled feathers (FF) and normal feathers (NF)). The second factor was the management system adopted; a combination of incubation mode (natural incubation (NI) or artificial incubation (AI) and brooding method (natural brooding (NB) or artificial brooding AB)): (NI*NB, NI*AB, AI*AB). The design also embedded two sub-studies using factorial treatments in a RCBD, involving the first factor (NN, FF, and NF) with the second factors as NI or AI and NB or AB. Investigations were created in relation to size of clutches, interval between clutches and yearly number of clutches. Gross margin analysis was applied to determined economic efficiency. The NN had higher ($P<0.05$) clutch sizes than FF and NF at 17.44 against a mean of 15.71 for the latter. The NN and FF had similar and better clutch intervals ($P<0.05$) at 58.79 days than NF at 62.66 days. The NF exhibited lower ($P<0.05$) number of yearly clutching at 5.82 compared to NN and FF which had no significant difference at 6.25 and 6.17 respectively. Incubation mode did not show significant variation on the size of clutches. The incubation mode showed clutch intervals varied significantly, that AI had a mean at 41.25 days against 83.33 days for NI. The yearly clutches were higher for AI ($P<0.05$) reaching 8.85 relative to 4.13 attained during NI. The brooding method had no influence on clutch size; whereas intervals of clutching were longer ($P<0.05$) for NB reaching 114.28 days relative to 53.41 for AB. The effect of brooding on yearly clutching was significant with AB realizing 6.83 while NB gave 3.19 clutches. The combinations AI*AB, NI*AB and NI*NB did not affect size of clutching. All the clutch intervals were varied ($P<0.05$); the combinations recorded intervals of clutching as 40.88, 68.30 and 114.05 days for AI*AB, NI*AB and NI*NB respectively. The three combinations demonstrated significantly varied yearly clutches; AI*AB scored the highest at 8.85, NI*AB at 5.33 and NI*NB had 3.19. Adoption of AI*AB or NI*AB is suitable in the improvement of indigenous chicken productivity; respectively increasing output by 171.30% and 63.40%. Gross margins showed AI*AB had the highest profitability while NI*NB the lowest (Kenya Shillings 958,076, 720,332 and 240,745 for AI*AB, NI*AB and NI*NB correspondingly). This represented 298% and 199% more profits for AI*AB and NI*AB respectively compared to NI*NB. Minimally, IC producers should adopt AB for improvement of productivity.

ACRONYMS

AB	Artificial Brooding
AI	Artificial Incubation
ANOVA	Analysis of Variance
ASDS	Agricultural Sector Development Strategy
ASDSP	Agricultural Sector Development Support Program
CCSP	Climate Change Science Program
CCVS	Climate Change Variability Scenario
CGK	county Government of Kilifi
CL	Coastal Lowland
DOC	Day Old Chick
ERA	Economic Review of Agriculture
FAO	Food Agricultural Organization
FF	Frizzled Feathers
GDP	Gross Domestic Product
GMA	Gross margin analysis
GLM	General linear Model
GOK	Government of Kenya
IC	Indigenous Chicken

IPCC	Intergovernmental Panel on Climate Change
KAPAP	Kenya Agricultural Productivity and Agribusiness Project
LS-means	Least Square Means
MOLD	Ministry of Livestock Development
NB	Natural Brooding
NI	Natural Incubation
NF	Normal Feathers
NN	Naked Neck
NPDP	National Poultry Development Program
PIC	Total Population of Indigenous Chicken
TFP	Total Factor Productivity
RH	Relative Humidity
SAS	Statistical Analysis for Scientists
TFP	Total Factor Productivity
USDA	United States Department of Agriculture

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Background

Indigenous chickens (IC) (*Gallus domesticus*) are among the domesticated avian species (Mwacharo *et al.,* 2013). They belong to the order Galliformes, family Phasianidae and genus Gallus. The closest feral taxonomic relatives of the IC are the Red Jungle Fowl (*Gallus gallus*), Grey Jungle Fowl (*Gallus sonnerati*), Ceylon Jungle Fowl (*Gallus lafayettei*) and *Gallus varius*. According to Moiseyeva et al., (2003) the species which has been seen reasonably close to the IC and imagined to be their progenitor is, *Gallus gallus*. The IC has co-existed with mankind among the various domesticated livestock species, for a long history (Parabakaran *et al.,* 2003). They are kept for food (meat and eggs), fiber (feathers used in garments, shuttle cock and feather meal) as well as sport recreation (cock fight), cultural function, batter, ritual activities, and commerce (employment and sale) besides manure (used as soil fertility nourishment and or animal feed). They are widely distributed and kept more abundantly than any other livestock species (Mtileni *et al.,* 2009; Moreki *et al.,* 2010; Economic Review of Agriculture [ERA], 2015). The production systems provide an easy, cheap and convenient means of converting low-quality feed into high-quality protein in form of eggs (Lwelamira *et al.*, 2010) and meat besides manure and feathers. The IC perform important role in the rural communities' livelihoods: they heftily provide for food and nutrition security, employment creation and building wealth of the rural households as the products from chicken are acceptable to most cultural and religious affiliations (Dessie *et al.*, 2003; Mtileni *et al.*, 2009).

In 2005, the projection to the world population of poultry and in third world countries was about 16.200 billion and 11.599 billion respectively, and their meat and egg production about 67.72 million metric tons and 57.86 million metric tons correspondingly (Gueye, 2005). As at 2006, the Food and Agricultural Organization (FAO) reported that the IC accounted for 80% of the 2.10 million tons of poultry meat produced by an estimated 1.30 billion birds (FAO, 2008). In the continental set up, IC in Africa contributed more than 70% of poultry products and 20% of meat and eggs gross domestic product (GDP) (Daghir, 2008; Fowler, 2004). In the Eastern Africa countries, over 80% of the communities live and derive their livelihoods in the countryside where more than 75% of the household's rear IC (Ochieng *et al.*, 2013). In Kenya IC contribute more than 80% of the total country's tally of all poultry; and accounts for a range of 40% to 60% of the domestically consumed poultry produce (Olwande *et al.*, 2010).

In Kenya, various initiatives have been undertaken by the government to improve IC productivity but the main one was with the National Poultry Development Program (NPDP) which spanned 18 years between 1976 and 1994. However, the program experienced a number of challenges, which included; incompatible donor interests, low off-spring fertility, conflict with traditional practices which impeded adoption rates of the improved breed and associated extension messages. Learning points the NPDP offered include; the need for institutional participatory approach and a focus on the entire poultry value chain (GoK, 2008)

In Kilifi County, the human population was at 1,453,787 people in 2019 according to KNBS, (2019). This population together with emerging trading centers' growth and towns, and the proximity to the city of Mombasa, provide ready market to livestock and livestock products. In the County, livestock rearing is a major economic sector which includes poultry as one of the main enterprises County Director of Livestock Production

(CGK), (2014). Like in the global, continental and regional level, in the country level; the IC are the most common followed by layers and broilers respectively as shown in figure 1.1. The county has benefited from national government projects that supported farmer capacity building. Such projects include agricultural sector development project (ASDSP), Kenya agricultural productivity, Kilifi youth economic empowerment project (KYEEP), Kenya agricultural productivity and agribusiness project (KAPAP) and the national agriculture and rural inclusiveness growth (NARIG). Some non-governmental organizations such as Islamic relief and Anglican development service (ADS) also have activities supporting indigenous poultry development. The main challenge in building farmers' capacity on the institutional front has been low staffing in the mandate directorate and limited financing to mobilize the service delivery CGK, (2017). At the farmers'

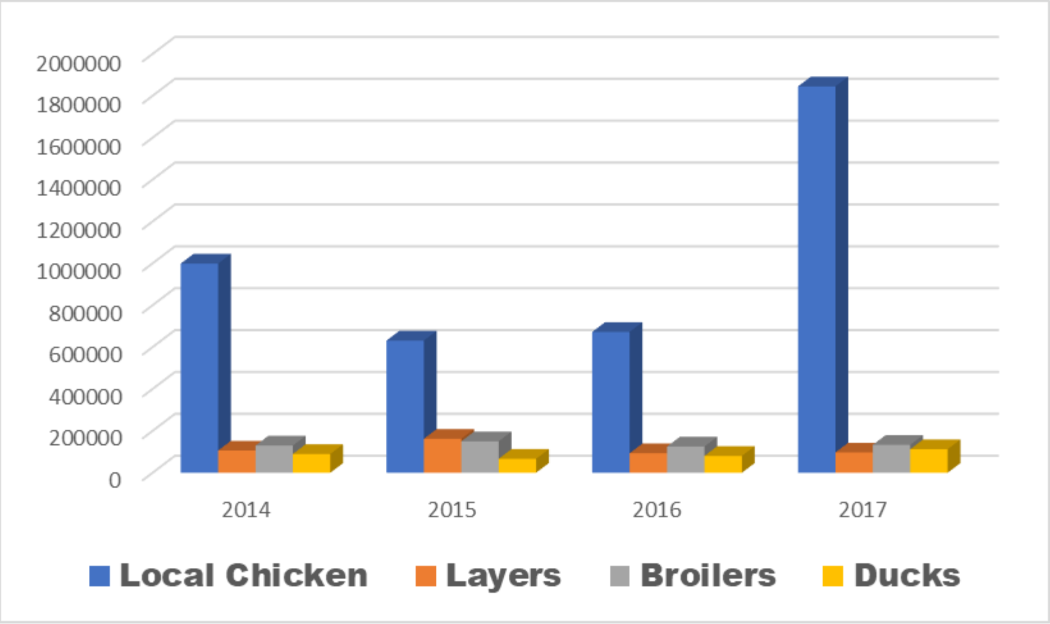


Figure 1.1: Poultry Population Trend in Kilifi County

Source: CGK, (2013, 2015, 2016, 2017)

level, illiteracy, poverty and lack of market orientation (CGK, 2014; Akinola & Essien, 2011) have been cited as major hinderance according to IC productivity improvement.

The IC are kept under varied production system ranging from intensively, semi-intensive and or free range (extensive or back yard) FAO, (2008). According to Thieme *et al.,* (2014) the production system is in four categories of family poultry by flock size: small extensive scavenging (1–5 adult birds), extensive scavenging (5–50 birds), semi-intensive (50–200 birds), and small-scale intensive production (> 200 broilers or > 100 layers). The management practices employed vary along the production system of choice in relation to genomic lines reared, size of flocks kept, production objectives and quality of technology adopted, giving varied merges of the production systems that suit the farmers condition (Rota *et al.,* 2014).

Most past studies have centered on characterization of the production systems (Danda *et al.,* 2010; Okeno *et al.,* 2012; Daikwo *et al.,* 2011) breeding systems (Ahlers, 2009; Olwande *et al.,* 2015); input-output relationship (King'ori *et al.,* 2007; Ochieng *et al.,* 2013); comparison with improved commercial breeds (Nyaga, 2007) and on challenges and opportunities facing the industry (Abdelqader *et al.,* 2007; Abdelqader *et al.,* 2008; Gondwe and Wollny, 2007).

Adequate exploitation of local resources and available technologies with the IC keeping communities could assist in developing appropriate capacities and capabilities for sustainable livelihood skills and abilities that contribute to their food and nutrition security. This would also support wealth creation in rural communities where a greater proportion of the poor population are to be found (Gonsalves *et al.,* 2005; Ndegwa, 2013) The integrated service delivery and mutual stakeholder capacity building had been identified as key to IC production improvement; besides the inadequacy of data on impacts, which was noted as confined to indigenous technical knowledge (Wachira *et al.*, 2010) and the need to improve the situation cannot be overemphasized. The information inadequacy was significant because the farmers have not seen the rationale to take up technologies and innovations disseminated by extension agents in order to improve productivity and exploit available and emerging market gaps.

The FAO, (2009) reported that per capita consumption of meat rose from 14.9 Kg in 1991 to 16 Kg in 2007 and is projected to reach 22 Kg in 2050. The increased demand of IC has been reported as due to taste preference (Choprakarn & Wongpichet, 2007; Umaya, 2014), increasing population growth, proliferation of trading centers and growing urban areas and towns, health consciousness and raised per capita disposable income thus boosting consumers' expenditure on food, according to USAID, (2010); Okello *et al*., (2010) WSPA, (2012). Despite the revelation that the IC are most abundant (Moreki *et al.*, 2010; ERA, 2015), preferred, highly demanded and adopted to the poor production environment (FAO, 2014; Raphulu *et al.*, 2015; Ncobela & Chimoyo, 2016) compared to hybrid broilers, their productivity is lowly (Sørensen, 2010; Pym & Alders, 2012) such that their products supply cannot meet market demand (Kenya Agricultural Research Institute (KARI), 2011, King'ori *et al.*, 2010).

Indigenous chickens are of various phenotypic lines and exhibit different environmental adaptation hence geographical habitation and varied phenotypic expression, a manifestation of adaptive genetic makeup (Magothe *et al.*, 2010; Sørensen, 2010; Okeno *et al.*, 2012). The IC thus differentially stop egg laying when they become broody and start natural egg incubation and latter natural chick brooding; only to come back to lay when the chicks are of age and behaviorally break broodiness (Chen & Li, 2007).

Denial of natural egg incubation and or natural chick brooding could then allow the mother hens to break broodiness and come back to lay early (Hossen, 2010; Lwesya *et al.,* 2004). The production performance of IC; size of clutches, interval of clutches and number of yearly clutches, that dictate output of IC replacement day old chicks, are comparatively lower than projected requirements (Mapiye *et al.,* 2008; Fotsa *et al.,* 2014). The weaned proportion of IC chicks is similarly relatively lower due to poor survival rate. This calls for implementation of suitable contemporary technological packages for yield and output improvement (ASDS, 2010; Wachira *et al.,* 2010).

1.2 Problem Statement

Despite the IC being most abundant, highly preferred, exceedingly demanded and adopted to the poor production environment compared to hybrid broilers, their supply has been low causing market uncertainty. Market supply gaps are due to low IC productivity. There are many causes for low IC productivity and products in the market; however, the choice of the IC phenotypic lines reared besides the implementation of incubation and brooding are paramount factors. Basically, the main concern is the inconsistent supply of IC products in the industry. Farmers are unable to keep up with the normal consumer/market demands; due to rearing of inappropriate IC phenotypic lines coupled with poor management of incubation modes and brooding methods in Kilifi County and the country at large.

1.3 Objectives

1.3.1 Broad Objective

To optimize supply of IC products for sustainable and profitable commercialization of the production system through rearing of appropriate IC phenotypic lines and management of egg incubation and chick brooding time.

1.3.2 Specific Objectives

1. To examine the effect of IC phenotypic lines on size of clutches, interval of clutches and number of clutches per year in Kilifi County.
2. To assess the effect of egg incubation mode on size of clutches, interval of clutches and number of clutches per year in Kilifi County.
3. To evaluate the effect of chicks brooding method on size of clutches, interval of clutches and number of clutches per year in Kilifi County.
4. To investigate the effect of a combination of egg incubation mode and chick brooding method on clutch size, clutch interval and clutches per year in Kilifi County.
5. To analyze the effect of combinations of egg incubation mode and chick brooding method on economic profitability of IC in Kilifi County.

i. To examine the effect of IC phenotypic lines on size of clutches, interval of clutches and number of clutches per year in Kilifi County.

ii. To assess the effect of egg incubation mode on size of clutches, interval of clutches and number of clutches per year in Kilifi County.

iii. To evaluate the effect of chicks brooding method on size of clutches, interval of clutches and number of clutches per year in Kilifi County.

iv. To investigate the effect of a combination of egg incubation mode and chick brooding method on clutch size, clutch interval and clutches per year in Kilifi County.

v. To analyze the effect of combinations of egg incubation mode and chick brooding method on economic profitability of IC in Kilifi County.

1.4 Hypothesis

i. The IC phenotypic lines have no effect on size of clutches, interval between clutching and number of yearly clutching in Kilifi County.

ii. The IC eggs incubation mode have no effect on size of clutches, interval between clutching and number of yearly clutching in Kilifi County.

iii. The IC chicks brooding method have no effect on size of clutches, interval between clutching and number of yearly clutching in Kilifi County.

iv. The Combination of egg incubation mode and chick brooding method have no effect on size of clutches, interval between clutching and number of yearly clutching in Kilifi County.

v. The combination of egg incubation mode and chick brooding method have no economic profitability in Kilifi County.

1.5 Justification

This research has been prioritized as it presents a tool to combat food insecurity and poverty, auguring well with strategies for achievement of County and National strategic plans plus the sustainable development goals (SDGs) of the United Nations. This project has inherent advantages that include but not limited to:

i. The enterprise is already entrenched as one of the activities of the small holder farmers wherefore the birds are produced widely and more abundantly than other livestock types (Moreki *et al.,* 2010; ERA, 2015).

ii. The startup capital cost is lower compared to other livestock, and require less land and financing while return to investment is faster due to their short life cycle (Byarugaba, 2007, Maina *et al.,* 2015).

iii. The human population and its continual growth have increased the pressure (KNBS, 2009) on, among others, land and need for more food supply especially animal protein. The high population has caused human settlement in drier areas and land subdivision leading to a shift towards enterprises that require lesser land, fewer and inexpensive inputs; which favour the IC production.

iv. There is an increasing demand for IC in reciprocation of population growth, urbanization and a high expenditure elasticity (Steinfeld *et al.,* 2006, Bett *et al.,* 2011).

v. Future prospects of commercialization of IC are highly promising because of a “traditional” increasing demand for the birds’ products perceived as being more flavoursome compared to the quality of hybrid types (Kyarisiima *et al.,* 2009; Bett *et al.,* 2011 and Bett *et al.,* 2012a).

vi. These IC, like other poultry and non-ruminants, have low global warming potential (compared to ruminants that contribute 18% of the negative impact on climate change) as reported by Mengesha, (2011)

However, despite the benefits and contribution, the IC productivity is said to be low to allow sustainable commercialization; characterized by slow growth rates, small body size, small clutch sizes, longer clutch intervals, and fewer clutches per year (Kondombo, 2005; Ssewannyana *et al.,* 2008; Yemane *et al.,* 2013; Weyuma *et al.,* 2015). At the same time, the birds have high phenotypic diversity for many traits which also offer an opportunity for current and future generations to exploit the potential (Gueye, 2009; Dana *et al.,* 2010). These birds' population exhibit significant differences (between and within) in growth rate, maturity time and weight, size of eggs, weight of eggs and clutch productivity performance (Dessie & Ogle, 2001; Ngeno, 2011). Accordingly, the productivity of IC has invariably continued to be designated being low-input low-output system of production (Danda *et al.,* 2010; Okeno *et al.,* 2010; and Daikwo *et al.,* 2011) and that commercialization opportunity is poor as compared to commercial breeds (Safalaoh, 2001; Nyaga, 2007). There is thus need to enhance productivity of the IC that reduces current differences between consumers' demands and producers' supply by exploring ways of boosting supply without genetic erosion (Gonsalves *et al.,* 2005; Ndegwa, 2013).

Artificial incubation and brooding have been used for a long time in commercial breeds that have been bred against the two traits. These technologies have been used in the IC production albeit at a small level. Essentially, these technologies are aimed at leaving the chicken with solely the duty to lay eggs. Exploiting this opportunity fully can provide avenues to improve and impact the IC industry positively. There is therefore a need to determine the effect of IC hatchery and brooding technologies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In Kenya, the free-range poultry production system is the most common type of keeping the IC. As at 2015 there were approximately 42.4 million birds, of which 34.7 million (81.7 percent) were IC, kept in small holder farms (ERA, 2015). The IC are in a wide distribution and being reared in higher abundance than the rest of other livestock types (ERA, 2015; Moreki *et al.*, 2010; Mtileni *et al*, 2009) as shown in figure 2.1.

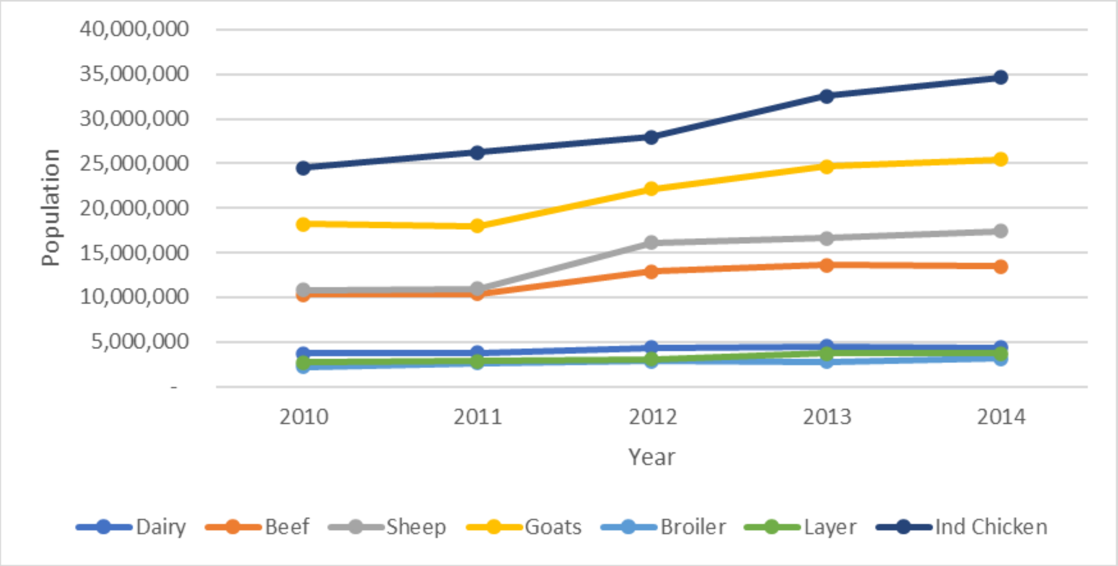


Figure 2.1: Livestock Abundance and Animal Population Trend.

Source: Economic Review of Agriculture (ERA) 2015.

The primary reasons for keeping IC in order of priority order are food consumption, (Magothe *et al.*, 2012; Turk, 2013, Yusuf *et al*, 2014) and sell for financial need (Besbes *et al.*, 2012, Bett *et al*, 2012b). The IC are also used as gifts to youth and newlywed, traditional rituals and as aesthetics, satisfying self-esteem; (Danda *et al*, 2010; Okeno *et* *al*, 2010; Daikwo *et al*, 2011). The main challenges in IC production are diseases, pests, predators, theft, small size birds/eggs, few eggs laid and low fertility/hatchability of eggs (Mapiye *et al*, 2008; Adomako 2009, Kirunda *et al*, 2010; King'ori, 2011).

Kilifi County projected population growth of 3.1 percent (CGK, 2018) was surpassed with the population census of 1,453,787 people in 2019 (KNBS, 2019). This population together with emerging trading centers' growth, towns and proximity to the city of Mombasa, provide ready market to livestock and livestock products. In the County, livestock rearing is a significant economic sector where cattle (dairy and beef), sheep, goats, poultry and beekeeping are the main enterprises CGK, (2015). Like in the global, continental regional and country level; the IC are the most common followed by exotic layers and broilers respectively as shown in figure 2.2. However, although the IC population is higher than the other birds, their effective offtake is low as reported by CGK., (2015, 2016, 2017). Going by KNBS, (2019) if a third of the population consume a chicken each per week, the IC population would be cleared within a month. According to CGK, (2015) this situation is caused by the farmers' culture not to target the market during production, and that they need to undertake all IC production enterprises as a business. A business focus would trigger the need for increasing flock sizes that have also been seen to leverage profits as established by Roothaert *et al.*, (2011); Hossen., (2010).

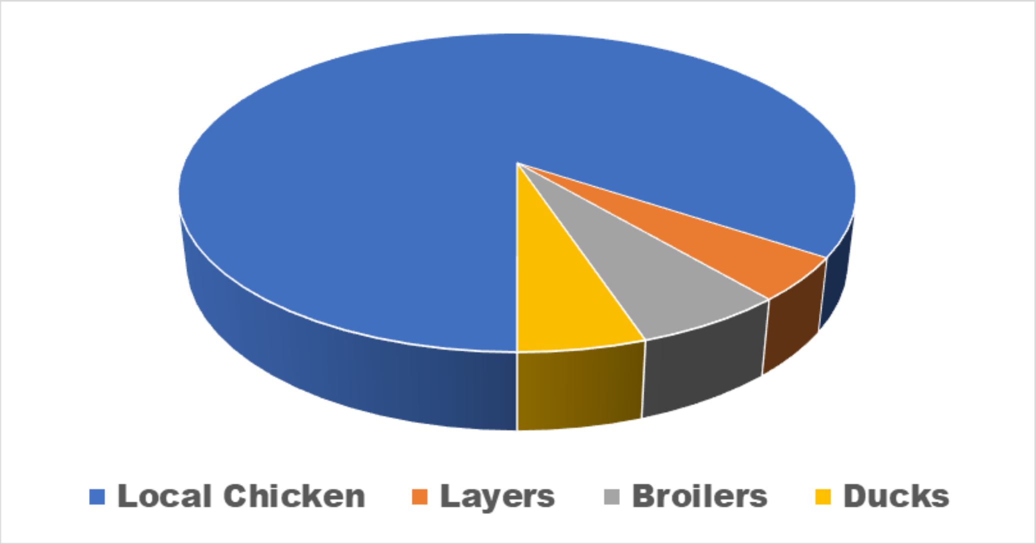


Figure 2.2: Kilifi County Comparative Poultry Population

Source: CGK, (2013; 2015; 2016)

Flock size could be increased by the adoption of simple technologies such as feed supplementation and early weaning of chicks that increase number of eggs laid, improve chick survival and profits (Hossen., 2010). The output and productivity of IC is effectively determined by the continual hatching of day-old chicks and their survival to maturity (Pedersen, 2002; Mapiye *et al.*, 2008; King'ori, 2011). The production and availability of day-old chicks is dependent on the delivery of fertile and hatchable eggs; while the chick survival to maturity is influenced by their vulnerability to the environment. Other factors that may affect output and production include birds' breed (IC lines) and environmental influences such as nutritional quality of feeds, diseases, predation, incubation process, brooding management and husbandry application (Kirunda *et al*, 2010; King'ori, 2011).

Embryonic development, after the egg is laid, is dependent on physical environment conditions of temperature, humidity and egg turning (French, 1997, Lourens *et al*, 2001; Hill 2001) during incubation. Although the chicks are self-sufficient in nutrition at hatch, after hatching they have limited thermoregulatory mechanism and are susceptible to cold and heat stress that is alleviated through brooding (Azharul *et al*, 2005). In IC production, brooding can be by the mother hens, naturally or using artificial techniques (Demeke, 2007). The IC parents teach the chicks about edible and inedible feeds and provide protection for the chicks during natural brooding (Mench, 2009).

After successful chick brooding, the continued growth to maturity of the birds depends on their genetic interaction in respect to local environmental conditions (Ojango & Pollott, 2002; N'Dri *et al*, 2007) and farmers' technical efficiency relative to experience in the IC production system: the management knowledge, skills and abilities (Wachira *et al*, 2011; Lemba *et al*, 2012). Application of principles, practices and strategies such as predator control, appropriate nutrition, vaccination against contagious diseases and enhanced husbandry improved the IC survival (Ahlers *et al*, 2009; Sørensen, 2010; Melesse, 2014).

2.2 Indigenous Chicken Lines and Physical Environment

The productivity of IC like any animal is a function of its genetic makeup and the environment. It translates to the potential to lay fertile and hatchable eggs, grow and put-up muscle and keep up with dynamic environmental conditions of temperature and humidity, nutrition and feeding, pests and diseases, among others (Ojango *et al.*, 2002; N'Dri *et al.*, 2007; Cheng, 2010). The Kenyan IC as in the majority of other developing countries worldwide have not yet been identified as independent breeds. They are commonly named according to geographical locality then called ecotypes; for example, Narok, Bomet, Bondo Kakamega, West Pokot, Lamu and Taita-Taveta (Magothe *et al.*, 2010; Okeno *et al.*, 2012). Naming is also by birds' phenotypic expression, a manifestation of adaptive genetic makeup. These adaptive genes are in three categories; feather- reducing or increasing, body size and plumage colour (Sørensen., 2010). Consequently, the birds have been clustered by these phenotypic traits as naked neck, frizzled feathered, feathered shanks, normal feathered, crested head; dwarf and or giant (Okeno *et al.,* 2012) and black, white, brown or mottled (Dessie *et al.,* 2003; Ngeno, 2011).

The IC genotypes are thus varied shown by their phenotypic expressions that may be in a combination of the traits which make them adapted to different environments. The naked neck and frizzled feather IC lines have higher productivity indices and are better adapted to hot environment as their reduced body cover offer better heat loss mechanism than the normal feather lines (Njenga ,2005; El-Gendy *et al*., 2007; Ngeno *et al.,* 2014). In the high-altitude ecological zones, for example the Mount-Kenya region and the highlands East and or West of the great Rift Valley, that experience cold and rainy climate, the normal-feathered, crested head, feathered shanks and bearded breed lines are more dominantly abundant (Njenga, 2005).

Phenotypically the Kenyan IC also exist in different morphological clad (Okeno *et al.,* 2012) that show corresponding adaptive, reproductive and productive variation (King'ori *et al.,* 2010). Gene differentiation grouped the IC in two ways. First, by molecular characterization that grouped the birds in four clads being, Northern, Western, Central and Coastal Kenya (Mwacharo *et al.,* 2007). Secondly, Mwacharo *et al*, (2013) placed them in two major groups by microsatellite markers on genomic Deoxyribonucleic Acid (DNA) as Eastern, made up of Marsabit, Meru, Kitui, Muranga, Kilifi, and Taita-Taveta; and Western, composing Kakamega, Homa Bay, Kisii, and Nandi.

Further, indigenous chicken genomic lines carrying the NN and FF alleles are commonly associated with higher rates of growth, bigger carcasses, bigger size of clutches and tolerant to disease outbreaks (Schou *et al*, 2007; Lwelamira *et al*, 2008; Mahrous *et al*, 2008; Islam & Nishibori, 2009; Magothe *et al*, 2010).

The main physical environment is currently experiencing climate change due to global warming that resulted in climate change variability scenario (CCVS) (Van den Bossche & Coetzer., 2008; Slenning., 2010; Pereira, 2017). The CCVS affects IC in three different direct and indirect ways, first; the air temperature, humidity and wind speed influence growth rate, feed intake, reproduction egg quality and development [Chase, 2006; Climate Change Science Program (CCSP), 2008; Seo & Mendelsohn, 2008; Pereira, 2017]. Secondly, it affects normal production and supply of livestock feeds both in physical amounts and qualitative values available (Dixon *et al.*, 2003; Hopkins., 2004) hence nutrition of the birds becomes wanting. Thirdly, there is increased conditioning in intensity and larger spread in space and time coverage of livestock diseases and parasites (Brooks & Hoberg., 2007; Thornton *et al.*, 2007; Seo & Mendelsohn, 2008). The CCVS has also not only led to the lager areas being affected and diseases emerging or spreading; but also changed the disease patterns (Elijah et al., 2006; Bhadauria *et al.,* 2014). All due to resultant unexpected droughts that are highly recurrent, dry periods extended, increased heat stress and sometimes floods, (IPCC., 2007; Brooks & Hoberg, 2007; USDA, 2013) where the IC, like other animals are equally negatively affected.

2.2.1 Naked Neck IC Phenotypic Line

The naked neck as IC Phonotype is caused by a gene (Na) that is autosomal and incompletely dominant, which causes bare skin in the neck region; and the skin becomes reddish at sexual maturity (Fathi, *et al*, 2013). They are of two types, the purebred having homozygous (NaNa) that possess completely bare neck (without feathers) including the crop region, while the other is not purebred and has a tassel of feather on the ventral side above the crop. The feather reduction is 30-40% compared to normal feather (nana) siblings according to Abou-Emera, (2017). Glenneis, (2020) reported that roosters weigh 1.5 kg at 16 weeks of age, 1.95 kg at 20 weeks and 3.5 kg when fully grown and the hens weigh around 1,1 kg 16 weeks old, 1.4 kg at 20 weeks and 3 kg when they are fully grown. They sexual maturity is attained at 155 days and lays eggs with mean weight of 55.5 grams. The genes that determine feather coverage of IC particularly naked neck (Na) and Frizzle (F) are observed to enhance heat tolerance (Fathi, *et al*, 2013) and conferring resistance to diseases greatly improving status of birds' immunity under hot tropical environments (Fathi, *et al*, 2014). The NN exhibits improvement in egg production and eggshell characteristics (Abou-Emera *et al*, 2017).

2.2.2 Frizzled Feather IC Phenotypic Line

Frizzle feather in IC has been described as varietal characteristic in which the contour feathers all curl upwards and outwards. The frizzling is due to an altered structure of the rachis morphology, and the feathers cannot lie flat against the body. This is caused by the gene (F) that is autosomal and exhibits incomplete dominance, underlying the frizzle feather trait in some domestic chickens. According to Ng *et al*, (2012) the chickens' frizzle feathers is due to mutation of an α-keratin (KRT75) that makes the rachis to be defective. The frizzle gene exhibits positively favorable influence on productivity on traits such as size of clutches, frequency of clutching, egg weight, egg mass, body weight and growth rate (Mathur, 2003).

2.3 Egg Laying

The IC usually lay eggs in batches called clutches, and the number of eggs they lay before the clutches are completed depends normally on several factors; genetic makeup, age and experience, feed supply and diet quality, health and altitude of the location (Sockman *et al.*, 2006). Young birds usually lay fewer eggs per clutch while older female have larger clutches from observation that older females over time acquire better foraging techniques, and thus could be in better condition than younger ones (Lorenz *et al*, 2013). It takes energy in the physiology of egg making and laying hence clutch sizes vary with nutritional status of feed. Egg production is intertwined with the quantity and or quality of the feed. Clutch sizes will be larger if the quantity of feed is increased, or higher quality feed is availed. Healthy birds in good condition laid more eggs per clutch than birds in poor health and condition, while size of clutches are characteristically greater at higher altitude than at lower altitudes, according to Sockman *et al*, (2006).

The mean maturity age for first egg laying varies from 5.35 months in a free-range backyard system while males mature in 6.25 months through 6.42 months (Halima *et al*, 2007; Assegie, 2009). The IC generally lay eggs with clutch size ranging 12 to 15 three times per year (Danda *et al*, 2010; Okeno *et al*, 2010; Daikwo *et al*, 2011; Kgwatalala *et al*, 2013; Dunya *et al*, 2014; Fotsa *et al*, 2014).

2.4 Egg Fertility and Hatchability

The main attributes to consider for IC egg fertility and hatchability are breed/strain/IC line, age, mating, health, egg quality and storage. In chickens, non-genetic factors have more influence on heritability ranging 0.6 to 0.13 for fertility and hatchability according to Sapp *et al.*, (2004). Fertility is higher for light compared to heavy breeds but hatchability is not influenced by the IC line (Islam *et al*, 2002). Age of the bird affects fertility negatively where it increases to a peak then decline (Brotherstone *et al*, 2000) but the effect is more evident in hens than in cocks (Brommer & Rattiste, 2008). Mating is such that poultry eggs generally become fertile after some time, about four days of introducing the fertile male to the hens. The correct cock to hen ratio ensures fertile egg production is being continued. This mating ratio ranges from 1:5 to 1:10 relative to the production system; higher for heavy breeds and free range than for light breeds and enclosed systems (Alsobayel & Albadry, 2012; Suthar *et al*, 2012, Molapo & Kompi, 2015)

Egg quality classification is in 2 major classes based on exterior egg quality and interior egg quality characteristics (Monira *et al*, 2003; Fayeye *et al*, 2005; Nonga *et al*, 2010). According to Bain, (2005) features of exterior egg qualitative characteristics are size (volume and mass), shape-index (maximum width to length ratio), shell thickness, shell colour and shell porosity; while the internal egg quality characters involve albumen, yolk and blastoderm size which also determine if the embryo would live fruitfully (Onagbesan *et al.*, 2007).

Egg size affects hatchability in a sigmoid relationship, low for small eggs, rising to maximum with medium sized eggs then drops with large eggs (Abiola *et al*, 2008). After the eggs are laid their quality would not be improved, rather they will deteriorate in quality due to unreliable storage and poor handling. The storage conditions of importance are temperature, humidity, duration (number of days before commencement of incubation) and sanitation. The ideal storage temperature is between 12ºC and 18ºC (Reijrink, 2010) where higher storage temperature will initiate incubation which may begin with the potential of decreasing the opportunity for normal embryonic development. When the temperature during egg storage is far too low, breakage of cell structures occurs and makes embryonic development impossible. The optimal level of humidity for egg storage ranges between 75% and 85%. This relative humidity levels ensures the eggs do not significantly dry out before incubation commences. The period of egg storage ought not be more than seven days before incubation. After seven up to fourteen days the ability of the eggs to hatch deteriorate significantly attributed to decay of vitamins and denaturing of membranes with time, where the developing embryo gets premature death.

Fertility Test: Fertility testing is based on changes in the internal composition of the fertile egg due to gradual development of the embryo. The embryo differentiates into tissue and organs as a result of nutrient absorption, moisture vaporization, metabolism and other factors in which the whole develops into a chick becoming opaque or dark gradually, a translucent or clear egg is infertile (Ernst *et al*, 2004; Kingori, 2011). Currently, various detection methods are available to distinguish hatching egg quality. All techniques apply characteristic differences at various stages of embryo development by:

i. Optical vision; commonly termed as candling (Ernst *et al*, 2004),
ii. Vibration and spectral characteristics or machine vision (XiuLian & ShuJuan, 2011; Wang, 2012),
iii. Near-infrared spectroscopy (Liu & Ngadi, 2013),
iv. Hyper-spectral images (Zhang, 2014) and or
v. Thermal imagery (Hai-ling *et al*, 2016).

Commonly, the manual optical vision method is employed, a practice called candling where the egg is viewed through a narrow light stream (Jacob *et al.*, 2000; Ernst *et al.*, 2004). When the developing embryo is growing healthy wise the egg contents appear pink in colour while eggs with a dead embryo have their contents having a mud-like or brown look. Embryos that are alive and developing ultimately fill completely the internal part of the egg and become opaque, the air sac would be visible when incubation is complete. Infertile eggs and early dead embryos can be detected readily because they appear clear. Eggs that appear clear indicate that either the embryos experienced mortality prematurely or they were infertile.

2.5 Incubation

Incubation is the procedure for provision of fertile eggs with optimum requirements to support embryos' life, growth, development and successful hatching, that may be by natural or artificial mode. Basically, egg incubation conditions include thermoregulation, control of humidity, ventilation, egg turning and sanitation.

Incubation Temperature: In most egg reproducing animal species, body heat from broody parents offers desired heat, but some animal species utilize other sources such as geothermal or decomposing organic matter. Temperature forms one of the highly considered microenvironmental factor in incubating chicken eggs (Meijerhof, 2009) that needs to be maintained at a constant. For chickens, the optimum temperature during the process of egg incubation is 37.8°C, but a range between 37°C to 38.9°C is recommended (Lourens *et al*, 2007; Leksrisompong *et al*, 2007; Clauer, 2009; Molenaar *et al*, 2010).

The chick embryonic development is however dynamic and exhibits two distinct metabolic phases; first an endothermic phase, from incubation day one followed by an exothermic phase from around day nine (Lourens *et al*, 2007; Meijerhof, 2009). The maintenance of temperature at a constant for developing embryos is thus a function of the balance between its heat demand and the heat exchange amongst immediate environment and the egg, which is influenced by prevailing humidity and ventilation, especially air velocity (Roovert-Reijrink, 2018). Incubation machine design requires that it has sufficient warming (prior to about day 9 of incubation) and cooling (after day 9, when embryonic heat production increases) capacity to maintain the optimal temperature. After commencement of incubation, embryonic mortality occurs when temperature falls under 35.6°C; similarly, if it increases past 39.4°C for more than sixty minutes (van der Pol, *et al.*, 2013). When temperatures are beyond the eggs' thermoneutral zone for long, the eggs fail to hatch. Temperatures that cause excess hotness are of more significance than those that result in coldness, as higher temperatures cause embryonic death while lower temperatures decelerate development that delays hatching (Lourens *et al*, 2005; Preez, 2007).

Incubation Humidity: Humidity commonly recorded as the Relative Humidity (RH) makes the next highly considered incubation condition after temperature, providing for egg water loss required for the formation of the air space. For a good hatch, up-to 14% of the initial egg weight has to be lost in the form of moisture to allow an air space size sufficient to support pulmonary respiration after internal piping (Meijerhof, 2009; Molenaar *et al.,* 2010). The range of RH optimal for chicken egg incubation has been established to be between 40 – 70% however, highest hatching rate was recorded at 50% (Bruzual *et al.*, 2000a; Molenaar *et al.*, 2010). According to report by Van der Pol *et al.*, (2013) chicken egg incubation by setting RH ranging 55-60% and a constant temperature adjusted at 37.8ºC yields high hatchability. The variation of RH to either extremes are detrimental to successful embryogenesis resulting in poor hatch due to dehydration or overhydration. Low level of RH causes dehydration of eggs, which leads to hatching chicks of reduced body weight and in other cases embryos get stuck to eggshell membranes that causes difficulties in hatching (Turblin, 2008; Van der Pol *et al*, 2013). Excess moist conditions (at higher RH) in incubators inhibits desired levels of water loss which leads to edema of chicks as the embryo develops. This leads to insufficiency in weight lost from the eggs, resulting in poor hatch due to unsealed navel (Bruzual *et al*, 2000b; Molenaar *et al*, 2010).

Incubation Ventilation: Correct ventilation is necessary to ensure the right incubation conditions of temperature, humidity and optimal CO_2 – to – O_2 balance; for the embryo to develop optimally, as reported by Green, (2014). In nature, the broody hen movements provide the optimal ventilation even as the abdominal feathers become fluffy to allow ease of airflow, for the same purpose. During artificial incubation, ventilation concerns are twofold, according to Green, (2014):

i. Hatchery room ventilation which is regulated to cater for uniform environment based on assumptions of the manufacturer and environmental variability.

ii. Incubator setter and hatcher ventilation; for optimizing successful embryo development.

The drift past the incubating eggs should be about 0.33980 cubic meters per minute (Clauer, 2009), using natural air from the atmosphere normally composing oxygen and carbon dioxide at 20 to 21 % and 0.4 % respectively. Supply of excess oxygen is not usual; however, a shortage of supply is likely. Thus, all the air circulation pathways have to be regulated well for optimal ventilation. The speed of air movement is critical particularly during the poikilothermic phase, during which eggs require warmth and over the exothermic period, where the embryos greatly raises release of heat that requires to be dissipated. If air velocity is low, eggs set in lower trays will be cooling poorly compared to eggs set in upper trays, leading to differentiated heat load (Elibol & Brake., 2008).

Non-ventilation, like low RH, results in lower weight loss (Fares *et al.*, 2012). However, it has been shown that manipulation of the concentration of CO_2 during incubation, could be beneficial; a gradual CO_2 pressure increase up to 1.5% during the poikilothermic phase improves growth and development of embryos, motivates earlier emergence of chicks and enhances rate of hatching (De Smit *et al.*, 2006 and Tona *et al.*, 2007). Immediately after hatching, the progress of hatchlings that hatched under increased carbon dioxide levels is greater during the initial 14 days of growth (De Smit *et a.l*, 2006).

Incubation egg turning: Broody hens regularly turn the incubating eggs by instinct. Turning of the eggs is a critical requirement in the incubation period to allow effective growth and progress of the embryos (Yoshizaki & Saito, 2002). Turning prevents embryonic mispositioning during incubation (Tona. *et al*, 2003). According to Mahmud *et al*, (2008), eggs must be turned during incubation as it purposes to either prevent the egg yolks from sticking to membranes of the eggshells or stop the allantois from sticking onto developing embryos. It similarly permits the progressive growth membranes of the chorioallantois and the vascular membrane (Cutchin *et al.*, 2009). Egg turning also helps to control temperature gradients within the egg, allow the proper utilization of growth nutrients and removal of waste. Egg turning is in five aspects; placement orientation, placement angle, angle of turning, frequency of turning and axis of turn. In nature, species specific egg turning frequency varies significantly up-to 6-turns per hour, but angular changes are not significant as observed by Cutchin *et al.*, (2009). In artificial incubators, setting eggs for hatching places them having the rounded end with the air sac above at 45^o horizontal tilt (Tona *et al.*, 2005; Elibol & Brake., 2006). According to Cutchin *et al.*, (2009) hatching eggs turning at an angle of forty-five degrees produced chicks with greater weight which had light and drier residual yolk. On the other hand, El-Hanoun *et al*, (2013) reported that horizontally egg placement and rounded end at angels about 20^o released smallest ($P<0.05$) loss in eggs' weight and resulted greatest ($P<0.05$) early embryo deaths.

Incubator Sanitation: Microbial infection in the incubator can significantly reduce hatchability of eggs and hence very critical for thorough cleanliness to be observed

(Donna & Inge, 2011). The incubators must be cleaned and disinfected prior to usage as well as after utilization. Sanitization of the incubator house and environs and the rooms that are used to store eggs is similarly important. Dirty incubator conditions result in undesirable hatchability as well as progressively causing costs in premature mortalities in the process of brooding the chicks and along the grower duration (Donna & Inge, 2011). It causes lingering morbidity problems that sometimes affect the birds during the grower period (Smith, 2004).

Meanwhile, it becomes impractical to sanitize unclean incubators because decomposing organic materials make all disinfectants lose efficacy on interaction. The more the organic dirt the target areas for sanitation, the lesser the effectiveness of applying any disinfecting agent (Turblin, 2008). The environmental factors met to support successful egg incubation in the incubator are equally perfect for multiplication of harmful microbes (Wineland & Carmen, 2007; Farzin & Ineke, 2011). Accordingly, there is need to put in place a biosecurity plan by having hazard analysis and critical control points (HACCP) for the hatchery functions involving:

i. **Identification of sources of contamination**: Infections generally arise from; incubator environment, housing and equipment design, attendants' education and grooming and quality of eggs for setting (Turblin, 2008, USDA, 2013).

   a. Incubator environment: Buildings housing the incubators should be sited well, a compromise between the pathogenic microbe infection risks of IC production, the carriage for delivery and supply of eggs and chicks, labour and worker accessibility and the access to general logistical system for market reach.

   b. Housing and equipment design: Design issues lie in the plan and workmanship of the floor and walls. The house plan should offer unidirectional flow of traffic (human and air current) from the clean areas to the dirty areas (USDA, 2013). The housing floor and walls be constructed of materials and surfaces that can be easily cleansed and disinfected or fumigated. Entry and exit to provide cleansing facilities to avoid biocontamination and ensure bio-exclusion (Donna & Inge, 2011).

c. Attendants education and grooming: All workers and visitors to be sensitized for awareness of the concerns, internalize the necessity for and adhere to the biosecurity plan.

d. Quality of eggs for setting: Hatching eggs may be infected by numerous pathogenic microorganisms before and after laying in what is called vertical and or horizontal contamination (Gast, 2005; Turblin, 2008). Keep only clean eggs for hatching by ensuring the breeding flock is healthy and that the hens lay eggs on sanitized nests. Conversely once eggs are laid, their successful hatchability may only be preserved, but cannot be enhanced. When mishandled, the hatchability invariably rapidly deteriorates (Ernst, 2004; Wineland & Carmen, 2007).

ii. **Incubator cleanliness:**

a. **Removal of all types of dirt especially organic matter in nature**.

Egg shells and debris, dead chicks, chick fluff and blood stains are the concerns for sanitation as they are the main perfect multiplication locations for harmful microorganisms provided by the equally favourable conditions set for egg incubation in the hatcheries (Donna & Inge, 2011). These contaminants can readily be distributed to other parts by equipment, streams of air, rodents and farm workers.

b. **Correct use of appropriate cleaning or sanitation reagents**:

Clean water, detergent or soap, elbow grease, disinfectants and fumigants can be applied depending on the extent of contamination. The level of infestation can be established by the use of auger to determine microbial count. Accordingly, after removal of the dirt, organic matter is best removed by soaking in detergent or soapy foam and latter rinse by sponge or muslin cloth to be followed by spread of elbow grease (Donna & Inge, 2011; Turblin, 2008). Sterilization through application of disinfectant can be made as a follow up stage; and lastly where it is deemed appropriate, fumigation.

iii. **Sterilization**; Sterilization aims at ensuring that pathogens that were present are removed to insignificant levels to eliminate risk of infection. It is accomplished by appropriately applying correct dosage of the right disinfectant or fumigant (Ernst, 2004; USDA, 2013).

Incubation Options

There are two main forms of incubation; 1) natural incubation or 2) artificial incubation.

Natural Incubation: Natural incubation provides the ideal scenario where the broody hens offer an intrinsic method to hatch eggs. Broodiness is observed as an innate phenotype for the majority of birds. In indigenous chickens the mean period of incubation is twenty-one days (Jiang *et al*, 2005). Different phenotypic lines have varied abilities for hatching eggs, some exhibit good broodiness while others have poor broodiness instincts. Signs of broodiness for incubation in IC comprise but not limited to clucking, staying away from rest of the flock, ruffling feathers, aggression plus nest protection, cessation of egg production and sitting on nest at night (Romanov *et al.*, 2002). Animal scientists have linked broodiness in poultry with reduction in number of eggs produced caused by the termination of laying the eggs in the process of egg incubation and the duration of chick brooding (Chen & Li, 2007). In this practice, one has to find a hen already sitting or induce the hen to become broody (Moore, 2013) to be able to plan and manage hatching time.

Artificial incubation: Artificial incubation employs the use of electric cabinet or kerosene incubator boxes; simulated in model duplicates the activities that produce ideal hatching conditions (Adid, 2008). The incubators are of two main types according to ventilation, still air types and forced air types. The forced air types are designed with an inbuilt fanning system to create air currents, while the still air types of incubators do not possess a fanning system and the aeration is permitted by gaseous stratification (Adewumi *et al.,* 2008; Clauer, 2009). The incubators may further be distinguished by egg turning capacity and method, either manual or automatic type.

2.6 Brooding

Brooding is the process of presenting chicks with the right environment (temperature, air quality, humidity, light and feed) for successful chicks' growth and development, which may be natural or artificial (Bolla, 2007). In IC, broodiness is linked to enhanced heat of the hen's bodies, shortened time for feeding hence inadequate nutrition, regular occupation of nesting position, egg turning, aggressivity and defensiveness conduct, distinctive vocal sounds, together with termination of laying eggs. Accordingly, during this time there is a reduction in yield of eggs caused by the termination of laying duration of broodiness (Chen & Li, 2007). The main need of newly hatched chicks is warmth; chicks will imprint with any source of heat if they are cold. Brooding is essential to keep the chicks away from heat or cold stress and predators which are major causes of losses in the IC production system (Olwande *et al.,* 2010; Kusina, 2001).

Brooding Options

Natural Brooding: On successful emergence the chicks are usually possess self-reliant nutritionally before their mothers to provide nurturing defensive functions and teaching selective feeding (Appleby *et al*, 2004; Mench, 2009). Survival of new hatchlings rely on quick interaction and association that creates a bond amongst the hen and its young ones, the bonds are formed when they can communicate with feedback. The young ones must acquire the ability to reply to the mother's calls for feed, danger as well as 'purring' sound for settling down. Mothers also needs to respond to chicks' fearful and or suffering calls. The IC usually develop a diverse vocal repertoire and their messages are intricate, composing over twenty-four varied sounds as well as visual displays which provide signals that are functionally referential (Smith & Evans, 2008; 2009), and representational (Evans & Evans, 2007). The hens guide their young to feed stuff using the appropriate vocal repertoire while they peck on the ground (Nicol, 2006). Naturally IC hens control chicks' temperature by providing warmth from their body heat. The mother hen brings the chicks together through clucking calls to hide while cuddling them under their wings (Appleby *et al*, 2004); however, the broody hen may expose the chicks to bad weather and predators as they move around scavenging for food.

Artificial Brooding: Artificial brooding involves enclosing the chicks in which temperature control is through heat supply fueled by varied options such as electricity, gas, kerosene and or charcoal. Variedly, infra-red bulbs, lanterns, and kilns (Jikos) are respectively used for electric, kerosene and charcoal. A hover is usually placed above the heat source (Bulb, lantern or jiko) to ensure that the heat does not easily escape from the brooder. In case of lantern and charcoal kiln, guard rails are placed to prevent the chicks from burning. Alternatively, the heat may be provided by conservation of energy using insulation in hay box brooders; dimensions as recommended by Demeke, (2007); or Trombe wall system, for solar energy utilization (Okonkwo & Akubuo, 2007) and improvised kitchen heat conduction as in the Uasin Gishu Chepkube brooder (ASDSP, 2015).

2.7 Chicken Nutrition

In the management of breeder poultry, feeds supplied are controlled in order that obesity is avoided. Excess gains in weight greatly causes poor-quality ejaculate and ovulation. Progressively, obesity at extremes is also a source of regressive ovaries and testicles for production of good quality and increased number of ova and sperm count (Brillard., 2006). Kenyan laying indigenous chickens needs dietary crude protein of 12%, which has no effect on rate of hatching (King'ori *et al.,* 2010). Locally, the IC breed lines need smaller amount of proteins in their diet as compared to commercial hybrid types (King'ori *et al.*, 2010). Linoleic acid improves egg fertility and hatchability as seen in layer fed on brewers' by-products which have 4-5% linoleic acid content (Levic *et al.*, 2010). If breeder chickens are to lay fertile eggs with enhanced ability to successfully hatch, organic supplements of selenium (Sel-Plex) are required (Petrosyan *et a.l*, 2006; Davtyan *et al.*, 2006; Maysa *et al.*, 2009). Cotton seed meal should be fed to laying breeder chickens cautiously as it may cause gossypol toxicity (Adeyemo *et al.*, (2007) through sperm immobility and eggs with rubbery or mottled albumen and increase in the permeability of the yolk sac membrane.

2.8 Growth Performance

The growth of the IC may be measured by rate of weight gain, maturity rate, survival rate, feed efficiency, population increment and offtake (Hagan *et al.*, 2013).

Characteristic of most biological systems, IC generally exhibit normal sigmoid growth pattern with a higher rate in early stages succeeded by a maximum but slow rate and then drop (N'dri *et al.,* 2006; Dourado *et al.,* 2009). This is caused by bodies structural development in the early life with the next phase being attributed to feed usage on sustaining developing organs of the bodies. The outcome reveals that efficiency of feeds supplied to the IC is higher during initial months of development but declines with enhanced body weight gains (Santos *et al.,* 2005). The parameters that determine growth are a function of the genetic makeup and the environment; while the inherent genetic composition may be static in the birds, the environment is a function of many measures such as nutrition, disease control, weather conditions and other husbandry practices (King'ori *et al.*, 2010).

Genotype (the breed and strain or line) of IC and the environment control the birds' growth performance (weight gain), carcass and meat quality (Jaturasitha *et al,* 2008). For progress in genetic improvement desirable outcomes are only obtained through two main strategies namely selective breeding or cross breeding. (Adebambo *et al*, 2011). Crossbreeding attributes results in genotype enhancement through heterosis an expression of improved performance exhibited by hybridization. Heterosis being the sum of entire dominant influence of total number of solitary loci which are typically advantageous, it possesses high probability to be on the desirable course (Keambou *et al.*, 2010).

After diet, the crucial environmental condition that affects utilization of nutrition in chickens is the variation in ambient temperatures of their shelter. The dynamism of ambient temperature notwithstanding, chickens always maintain their body temperature at a constant as they are homoeothermic. If the environmental temperature falls below the desired threshold, the birds consume extra feed. However, the energy from such feed is not applied in sustaining usual warmth and is thus not available to be used for growth and development. Heat stress occurs and causes decreased dry matter intake (DMI), decreased dry matter (DM) digestibility (Bernabucci *et al.*, 2010; Mashaly *et al.*, 2004) hence decreased rate of weight gain (Al-Aqil *et a.l*, 2009; Bernabucci *et al.*, 2009) at a higher than optimal ambient temperature, i.e., they convert ingested feed less efficiently. Along the optimal temperature range commonly called the thermoneutral zone (where birds are not required to be active in controlling their body heat) as depicted in figure 2.3, the IC are permitted to transform nutrition tissues instead of applying the energy in the control of body temperature.

2.9 Disease, Pest Control and Welfare

Contrary to ill chickens that will show undesirable productivity, the performance of IC is determined by the overall healthiness of the birds that influences nutritional efficiency. Similarly, parasitism and microbial infections also decrease the effectiveness of feed digestive and absorptive efficiencies (Forbes *et al.*, 2004; Klasing., 2007; Fiel *et al.*, 2012; Szyszka & Kyriazakis, 2013) Cautious use of control measures (vaccinations and treatment) is needed because reactions from improper administration of vaccines and medication could result in negative growth and eventually losses from deaths characteristic of small-scale IC systems in rural areas (Kusina *et al*, 2001; Pedersen, 2002).

The main cause of village IC productivity losses through reduced population and output is disease (Dessie & Ogle, 2001). The major disease that is utmost widely distributed and deadly in the IC production systems in the rural areas is Newcastle Disease (NCD) (Moreki *et a.l*, 2010).

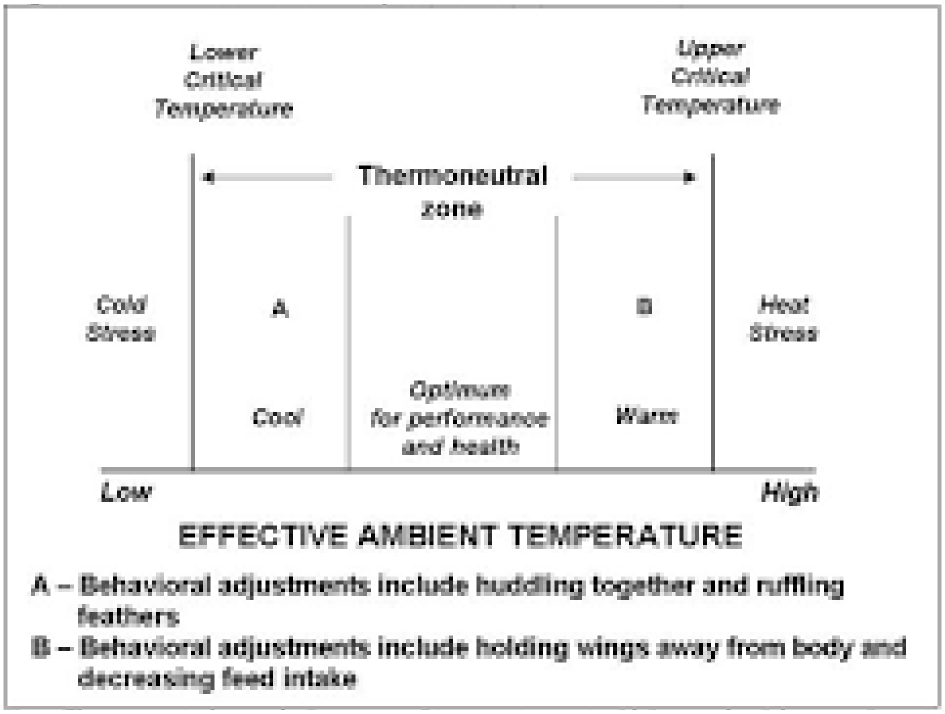


Figure 2.3: Thermoneutral Zone and Effective Ambient Temperature.

Source: www.ca.uky.edu

When the health and immunity of the birds is low, there occurs most deaths especially in IC populations that are not inoculated as reported by Farooq *et al*. (2002); who also adduced meagre productivity of backyard chicken under poor husbandry condition.

The IC like all animals have feelings and exhibit emotional behaviour as a result of instinct, cognition and learning in response to states elicited by rewards and punishment, a product of instrumental reinforcement by the birds (Rolls, 2005; Rolls, 2014). The main concern is to reduce stress in chickens which is behaviourally exhibited through aggressiveness or avoidance; they become aggressive as a result of anger and or avoid handlers, due to fear from management treatment (Roll, 2014)

The connection amongst animal husbandry and management manners, animal anxiety planes and performance of the birds expose the potential to enhance output and production through introduction of efforts at decreasing levels of fear in the IC production system. The farmers should emphasize on disease preventive measures, provision of a healthy balanced diet to the IC and reduce stressful situations that have an impact on health. The wellbeing and comfort of the IC must come before any other consideration.

2.10 Productivity of IC and Economic Efficiency

In agricultural systems of production, the common methods of analyzing productivity include: 1) growth accounting technique, 2) econometric estimation of production relationships, and 3) the nonparametric models (Dharmasiri, 2012). However, each of the procedures has pros and cons as expressed by Machek and Špička (2014) as follows:

i. The growth accounting technique: collects comprehensive accounts of inputs and outputs into input and output indexes to calculate of the coefficient of total factor productivity (TFP). It however emphasizes about technology and its reliability cannot be evaluated using statistical methods.

ii. The parametric approach: links econometric assessment of production relationships either based on the output, cost or profit function. It calculates the marginal contribution of inputs to the total production as suggested by Obasi *et al.* (2013) and does not emphasize on technology. The application of the econometric model, such as the Cob Douglas production function permits for evaluation using statistical methods (Dharmasiri, 2012), but it necessitates the use of large data.

iii. The nonparametric approach: applies linear programming techniques to calculate the TFP; though unlike growth accounting, it does not impose restrictive assumptions on production technology. However, it also cannot be statistically tested.

Low output and productivities are oftentimes quoted as contributing to low commercial potential in the IC sector, hence their less competitiveness compared to the industrial hybrid chickens. This low competitiveness is unfairly compared to their relatively low genetic potential for meat and egg production against commercialized hybrid types (Dolberg, 2007). Although low output could be caused by many factors some of which out of reach of farmers' control such as effects climate change, high level of inefficiencies is a significant contributory (Chimai, 2011; Wollie *et al*, 2018; Chepng'etich *et al*, 2014).

The productivity of IC is the ratio of the total output to total inputs used during production, and with other factors constant, it is a measurement of efficiency of the inputs used (Dharmasiri., 2012). Productivity and efficiency are also used to indicate or determine competitiveness and profitability (Organization for Economic Coorperation and Development [OECD]., 2011). This is reflected the practical method of determining efficiency, basically by quantifying the potential for input reduction or the possibility of increasing output relative to a set benchmark (Alvarez & Arias., 2014). On the other hand, profitability can be calculated arithmetically as the difference in total income from outputs and total cost of production inputs. For given enterprises, this is associated with the concept of opportunity cost and can be derived by simple gross margin analysis (GMA). This allows farmers to effectively make decisions on what is to be produced, how much to be produce and how to it will be produced (FAO, 2013). Some studies have been made to determine profitability of different enterprises that include livestock-based initiatives in emerging and developing economies (Emam & Salih 2011; Longwe-Ngwira *et al*, 2012; Njuguna *et al*, 2017).

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials of Research

3.1.1 Location of the Site

The study was planned and executed in Kilifi County at a farm belonging to the learning institution. The experimental housing units were put up in the poultry section of the farm, within the Pwani University land. Figures 3.1 through 3.3 illustrates the geographical location of the research site.

Pwani University is located in the beach resort town of Kilifi, sixty-two kilometres northward from the coastal city of Mombasa. It is at Kibaoni on the western side of the Mombasa – Malindi highway and at latitude 20^o S and longitude 40^o E. It lies at an altitude of about sixteen meters above the sea level. This area receives a mean yearly precipitation that averages between 900 mm and 1100 mm and has an average annual temperature range of 25^oC to 30^oC. The rainfall is received in two main seasons designated as long and short rains: the long rains are anticipated from April to June and the short rains are usually expected in October through December. However, variations in amount and distribution in space and time during the year are erratic.

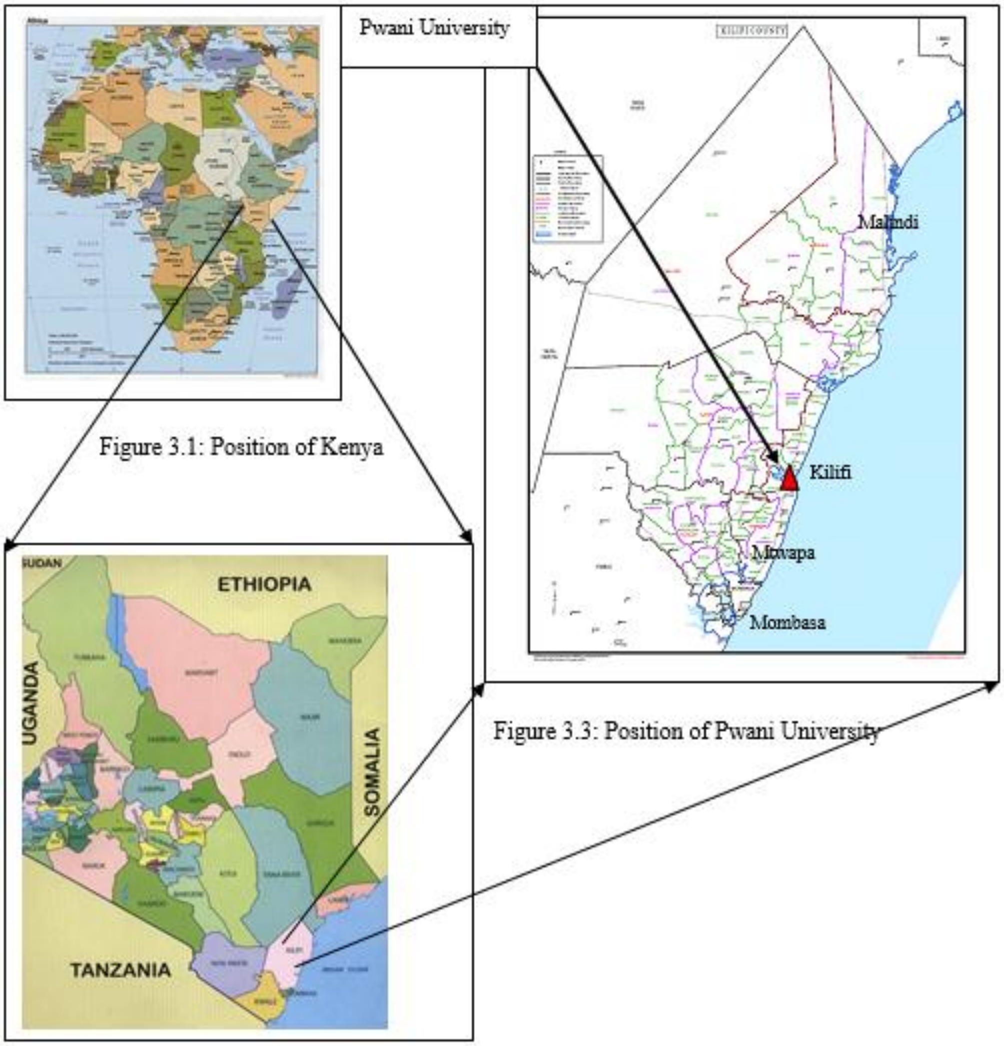


Figure 3.1: Position of Kenya

Figure 3.3: Position of Pwani University

Figure 3.2: Position of Kilifi County

Source of Figure 3.1: Ontheworldmap.org (Map of Africa)

Source of Figure 3.2: Textbookcentre.com (A new Counties map of Kenya)

Source of Figure 3.3: kilifi.go.ke (Kilifi County Government Boundaries)

3.1.2 Genomic IC Phenotypic Lines

Indigenous chickens are of various genetic lines and exhibit varied phenotypic traits. The phenotypic trait differences of interest in the study were cessation of egg laying when the mother hens became broody, sitting on eggs to start natural egg incubation and time used in rearing hatched chicks in natural chick brooding; before the cycle was repeated (Chen & Li, 2007). Therefore this study focused on three IC phenotypic lines that were selected on the basis of populatity and availability that is, naked neck (NN), frizzled feathers (FF) and normal feathers (NF). Approximately twenty-week-old pullets, and a corresponding equivalent number of males were obtained from local farmers' flocks. The number of cockerels and pullets were matched at a mating ratio of 1 to 8 according to recommendations by Suthar *et al.,* (2012) and Alsobayel *et al.,* (2012). The birds were sourced through contacts with livestock extension officers, who identified various farmers and farmer groups keeping IC in the county. The purchase engagement was open free-market which allowed negotiations on willing seller and willing buye. On purchase, the birds were transported in poultry-carrier cages mounted on a motorcycle or on the deck of a pick-up vehicle and then ferried to the research site.

3.1.3 Incubation Mode and Brooding Method

The study design identified two contrasting ways, natural and artificial incubation mode; and natural or artificial brooding method.

3.1.3.1 Mode of Incubation

i. **Natural Mode of Incubation:** The natural mode of incubation (NI) applied hens that had become broody. The hens were allowed to use their instinctive behaviour in nest management until the eggs hatched and chicks hatched for the brooding treatments.

ii. **Artificial Mode of Incubation**: In the artificial mode of incubation (AI) an automated egg incubator was employed. The incubator used for the study was model ECO 528 a forced-air electric type. It had automated regulation for thermal control, turning of eggs, and humidity monitor. The machine possessed a capacity for handling five hundred and twenty-eight eggs.

3.1.3.2 Method of Brooding

i. **Natural Method of Brooding:** In natural brooding (NB) the study allowed mother hens' natural instinctive behaviour to offer their body heat in the maintenance of chicks' warmth. Naturally IC hens control chicks' temperature by providing warmth from their body heat. The mother hen brings the chicks together through clucking calls to hide, while cuddling them under their wings (Appleby *et al.,* 2004) The broody hens were allowed to nurture the chicks while nursing them in the process. The mother hens demonstrate to the chicks about edible and inedible feeds and provide protection for the chicks (Mench, 2009).

ii. **Artificial Method of Brooding:** Under artificial brooding (AB) the study design applied a circular brooder that was made up of an external guard of circular bound three-ply board cutting. The height of the board was fifty centimetres with an initial radius of twenty-five centimetres that could be expanded. A kerosene lantern was used as heat and lighting source for the chicks. The lantern was placed at the centre. The floor was covered with fine wood shavings while feed and water were placed in alternate troughs radially.

3.2 Methods of Research

3.2.1 Organizational Approach of the Research

The methods applied in the study for biological efficiency were based on the principles that:

i. Indigenous chickens are of various phenotypic lines and differentially stop egg laying when they became broody. Afterwards they start natural egg incubation and later enter a natural chick rearing phase called brooding. Finally, the mother hens come back to lay when the chicks are of age and they behaviorally begin broodiness to restart the cycle (Chen & Li, 2007).

ii. Denial of natural egg incubation and or natural chick brooding could then allow the hens to break broodiness and come back to lay early (Lwesya *et al.,* 2004; Hossen, 2010)

iii. The production performance of IC, i.e. the size of clutches, the interval between clutches and the number of yearly clutches, that dictate output of IC replacement day old chicks, are comparatively lower than projected requirements. The weaned proportion of IC chicks is similarly relatively lower due to poor survival rate and thus warrants redress in the form of implementation of suitable contemporary technological packages for yield and output improvement (ASDS, 2010; Wachira *et al.,* 2010).

iv. GMA was employed to determine profitability of employing study findings from using the treatment combinations to analyze economic efficiency of the IC production system.

The organizational approach was also based on the technological innovations proposed for the study, set as: breed selection, artificial or natural egg incubation and artificial or natural chick brooding. These are common techniques that have been in use sporadically with the IC production systems, and widely employed in the commercial layer and broiler sector. For IC phenotypic line selection, the study identified three common lines: naked neck (NN), frizzled feathers (FF) and normal feathers (NF). While three combinations of artificial or natural egg incubationn (AI or NI) and artificial or natural chick brooding (AB or NB), mainly (AI*AB, NI*AB and NI*NB) were employed. The fourth combination of AI*NB was not involved because the natural behaviour of mother hens do not allow effective bonding with chicks they did not incubate. The responses of the birds' phenotypic lines to the combinations of egg incubation modes and chick brooding method in relation to the size of clutches, interval between clutches and number of yearly clutches were utilized as main means of testing biological efficiency for IC productivity improvement.

In the determination of economic efficiency, the study applied the principle of flock dynamics in stratifying age sets and micro-economic analysis of gross margins to calculate profitability

The study first modelled flock dynamics as follows:

a. Developed a flow chart depicting the various age sets in the life cycle of the IC

b. Employed production indices for modeling flock stratification

Secondly, the study performed a GMA and determined the economic efficiency by comparison of gross margin (GM) percentage attained; using profitability as a measure of economic efficiency.

3.2.2 Method of Experiments set up

The design of the experiment was a 2X3 factorial in a randomized complete block design (RCBD) with two factors, having factor one IC phenotypic lines (NF, NN and FF) as the blocking factor. The second factor was the combination of incubation mode and brooding method: which were also made in triad combination NI*NB; NI*AB and AI*AB. The design also embedded two sub-studies that used factorial treatments in a RCBD design involving the first factor (NN, FF, and NF) with the second factors as NI or AI and NB or AB.

Modelling of the Experiment

In modeling of the experiment, the study adopted the general linear model as follows:

$Y_{ij} = \mu_i + \alpha_i + \gamma_j + \beta_k + \alpha(\gamma\beta)_{ijk} + E_{ijkl}$

Whereas: Y_{ij} represents jth finding as a result of treatments in the ith subset;

μi denotes the average from treatments in ith sample;

α_i exhibits outcomes as a result of the IC phenotypic lines,

γ_j shows the results from modes of incubating eggs,

β_k represents the results from methods of brooding chicks,

$\alpha(\gamma\beta)_{ijk}$ displays the outcome interaction of α_i and combinations between γ_j and β_k,

E_{ijkl} exhibits the error in experimentation.

3.2.3 Method of Experimental Treatments

The experimental treatments were in two factors: IC phenotypic lines and incubation mode combination with brooding method.

Factor I: Indigenous Chicken Phenotypic Lines; shown in Figure 3.4-3.6

The birds were in three treatments by IC phenotypic lines, represented as;

i. Normal feathered (NF)
ii. Naked neck (NN) and
iii. Frizzled feathers (FF)

Figure 3.4: Normal Feather Figure 3.5: Naked Neck Figure 3.6: Frizzled Feather

Source of Figure 3.4: infornet-biodivision.com

Source of Figure 3.5: wichedfoodearth.co.za

Source of Figure 3.6: thechickenchick.com

Factor II: The birds were subjected to three treatments in terms of a combination of incubation mode (natural incubation (NI) or artificial Incubation (AI)) and brooding method (natural brooding (NB) or artificial brooding (AB)).

i. NI and NB;

ii. NI and AB;

iii. AI and AB.

iv. AI and NB; was left out due to IC instinctive behaviour as chick bonding with the hens was not possible.

The study also embedded individual treatments for incubation mode (NI and AI) and brooding method (NB and AB); as exhibited in Figure 3.7-3.10:

Figure 3.7: Natural Incubation

Source of Figure 3.7: tikafarm.com

Figure 3.8: Artificial Incubation

Source of Figure 3.8: Eco-chick Ltd

Figure 3.9: Natural Brooding

Source of Figure 3.9: howtodiys.com

Figure 3.10: Artificial Brooding

Source of Figure 3.10: Wachira, KALRO, Kenya

3.2.4 Method of Managing Experiment Birds

Size of Sample and Treatments: Based on ethical and cost cost considerations 59 pullets were used for the study. The block stocking was as shown in Table 3.1; emplying the 2X3 factorial in a Randomised Complete Block Design (RCBD).

The study also had inbuild treatment for incubation mode and brooding method independently, with samples as shown in tables 3.2 and 3.3 using a factorial treatment in a RCBD design.

Table 3.1 Size of Sample and Treatments for Combination of Incubation Mode and Brooding Method

Block	Combination of Incubation Mode and Brooding Method			Total
	NINB	NIAB	AIAB	
NF	8	8	8	24
NN	7	7	6	20
FF	5	5	5	15
Total	20	20	19	59

Table 3.2 Size of Sample and Treatments for Incubation Mode

Block	Incubation Mode		Total
	NI	AI	
NF	16	8	24
NN	14	6	20
FF	10	5	15

Total	40	19	59

Table 3.3 Size of Sample and Treatments for Brooding Method

Block	Brooding Method		Total
	NB	AB	
NF	8	16	24
NN	7	13	20
FF	5	10	15
Total	20	39	59

Sourcing and identification: All birds were sourced from the locally available ecotypes kept by individual farmers and farmers' groups within the County of Kilifi. For each treatment, the birds were put randomly in cubicles as per treatment upon arrival.

Experimental Birds Housing: The housing units were built in an east-west orientation and made using materials that were easily availed localy. The treatment partitioning rooms were 2 X 2 m cubicles in which were placed 2 laying boxes each with three compartments, 2 drinkers and 2 feeders. The walls were made up of a cover by three-ply wood board and or wire mesh. The board of three ply wood raised up to one meter of the height, the rest of next meter level was composed of wire mesh for adequate ventilation. Soil flooring was used and lined with a cover of 20 cm depth of deep-litter. A total of three shelters were built to house the experimental units; where one had 5 rooms while two had 4 rooms. The houses represented the blocks (NF, FF and NN) while the rooms in each house were placed in a random method the varied representative either AI*AB, NI*AB and NI*NB, as elaborated in section 3.2.3. The fourth room was used for the process of artificially brooding of the chicks, while the fifth cubicle was used as main store for inputs and accessories as illustrated in Figure 3.11. The envisaged plans for incubation mode and brroding method, as enbended in the main study are shown in figures 3.12 and 3.13 respectively.

Biosecurity for sourced birds: The experimental houses were enclosed in an exclusive chain link perimeter fence with a foot bath at the entrance. On arrival, all the chickens were inoculated against New Castle Disease (NCD), treated against possible bacterial infection using broad spectrum antibiotics, dewormed using wormicide and dusted to eradicate likely contaminations from sickness, and parasites.

Experimental accessories (Laying boxes/Natural incubation nests, Artificial incubator and Brooders): A total of 15 boxes were made and placed in the cubicles; enough for egg laying and for natural egg incubation nests.

Nutrition and Feeding of Birds: All pullets nutrition was supplied in a cafeteria arrangement of feeding system where they were allowed to choose feed relative to their craving requirements. The cafeteria feed system was achieved by offering of the main feed types on separate feeders as here under:

i. Feeds high in energy such as cereals (grains of sorghum, maize, millet etc.)

ii. Feeds rich in Protein for example fish meal, beans, peas, maggots, termites.

iii. Feeds rich in minerals e.g. bone meal, burned and crushed shells.

iv. Feeds high in vitamin such as vegetables.

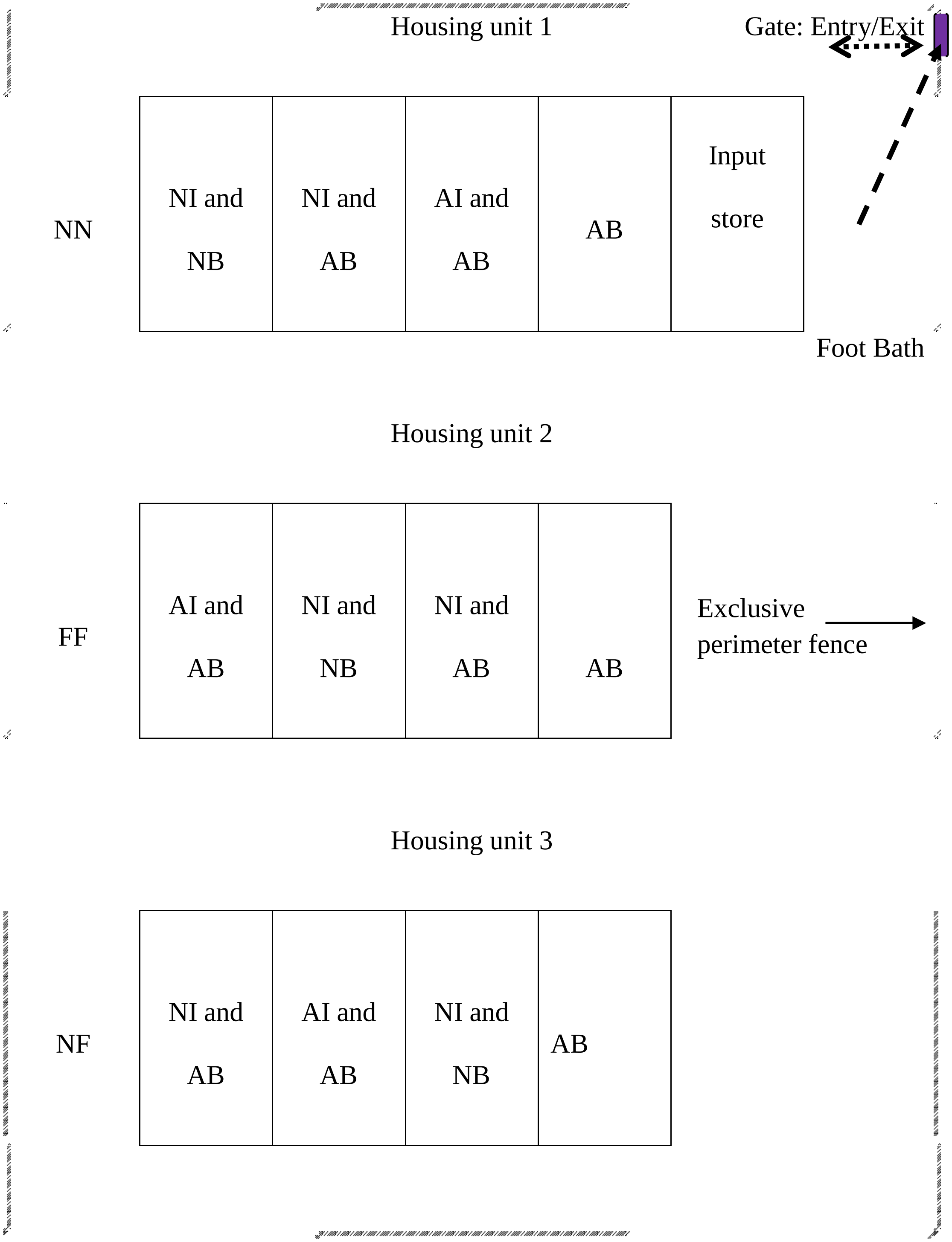
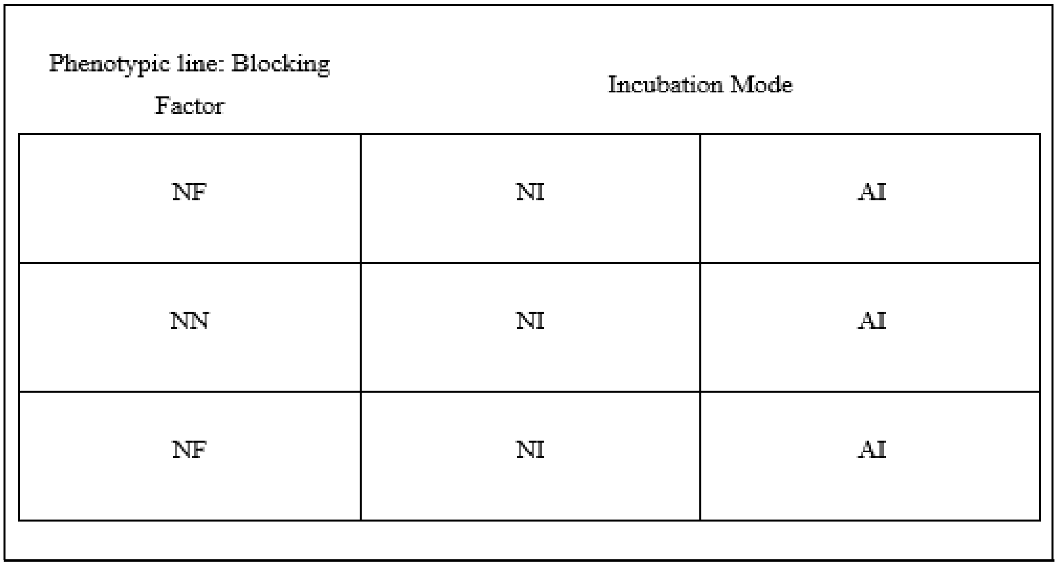
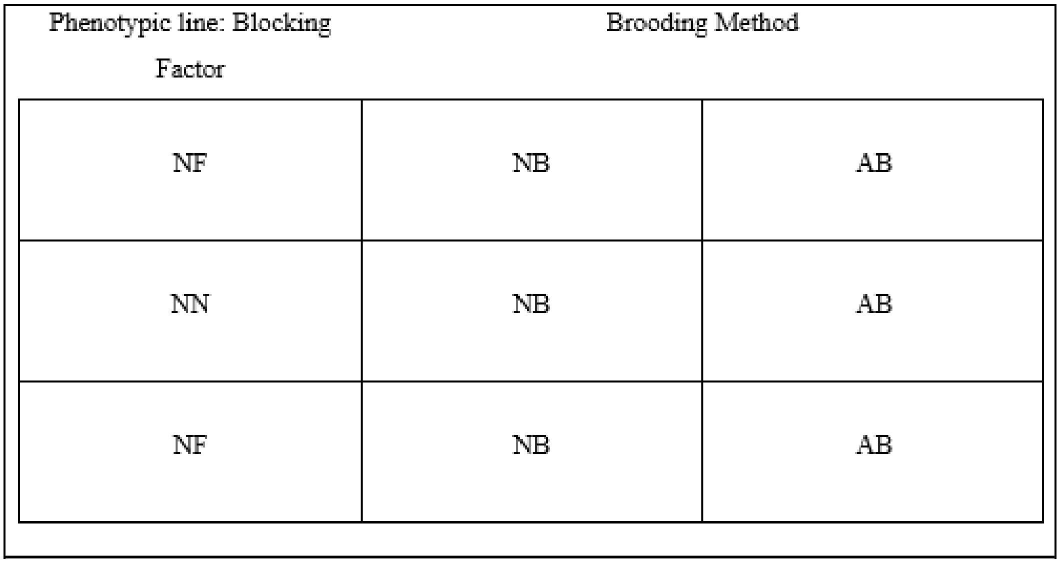


Figure 3.11: Diagrammatic Representation of Treatments and Housing Structural Plan



Phenotypic line: Blocking Factor	Incubation Mode	
NF	NI	AI
NN	NI	AI
NF	NI	AI

Figure 3.12: Diagramatic Representation of Treatments for Incubation Mode



Phenotypic line: Blocking Factor	Brooding Method	
NF	NB	AB
NN	NB	AB
NF	NB	AB

Figure 3.13: Diagramatic Representation of Treatments for Brooding Method

Handling of Eggs: As the birds commenced laying of eggs, the eggs were picked, identified recorded and preserved up to the time when the hens exhibited signs of sitting on the eggs. Storage of the eggs was done in a compartment that had air conditioning set at 18°C.

Chick Feeding and Nutrition: Commercial Kienyeji chick mash [(19.5%CP and 2800Kcal ME /Kg) from Faida Feeds milled by Mombasa Maize Millers Limited] and fresh drinking water was provided ad libitum. The feed and water troughs were placed alternately radially from the edge of the hover to allow the chicks access to feed and move freely in and out of the heat source.

Biosecurity for chicks: The chicks were inoculated against the following diseases, Gumboro, Newcastle, Fowl Pox and Fowl Typhoid. Antihemintic and vitamins supplement were adminstered three months alternately, through drinking water.

3.2.5 Method of Experimentation

The experiments were in three investigative studies as here under:

i. Egg Laying Prowess

ii. Egg Incubation

iii. Chick Brooding

iv. Gross Margin Analysis (GMA)

a. Experiment 1: Egg Laying Prowess

Laying Nests: The laying boxes were lined with fine wood shavings and the hens allowed to put other fine materials including those from behavioural shading of feathers to mark their laying nests. Each laying bird was supplied with two boiled eggs in the nest as their succeeding eggs laid were removed. Eggs from each of the hens in the specific treatments were marked for identification using pencil, recorded in a ledger and appropriately stored to tally for size of clutches. The information was used to finding out the effect of IC phenotypic lines on the prowess of laying eggs after subjecting to the mode of incubation and method of brooding. The egg laying prowess was determined by the yearly number of eggs laid from the product of parameters; their size of clutches and number of clutches per year.

b. Experiment 2: Egg Incubation

Egg incubation was in two forms, naturally and artificially.

Egg Incubation Naturally: In NI the investigation used broody mother hens.

Egg Incubation Artificially: In AI the study used an automatic incubation machine. The incubator used for the experiment was model ECO 528; a forced-air electric type which had automated regulation for thermal control, turning of eggs, and humidity monitoring.

Choice of Eggs for Incubation: The research planned to choose eggs to be set for incubation by evaluation of their conditions physically. The target was to incubate all eggs leaving only those that showed cracked shells, stains of blood or dirt on shells.

Egg Setting: All eggs chosen were set for incubation. The hens were supplied a set of ten eggs, and the rest were placed in the incubator.

c. Experiment 3: Chick Brooding

On completion of chick emergence, every clutch was placed for brooding either in natural or artificial way according to the preplanned contrasts treatments.

Chick Brooding Naturally: The chicks were left with or given to the hens for care, in which the broody hens provide the heat to keep the chicks warm.

Chick Brooding Artificially: The brooder was made up of an external guard from circular bound three-ply board cutting and kerosene lanterns, to provide light and the required heat for the artificial chick brooding.

Brood Period: Artificially brood chicks were brooded up to six weeks at which they were weaned; the natural brooded chicks were left with the hens until they were naturally weaned and the hen started to lay eggs again.

d. GMA for Economic Efficiency

In this study, the GMA was applied to determine profitability as a measure of economic efficiency of the IC production system while using combinations of incubation mode and brooding method. The GMA computed profits for comparison between NI*NB, NI*AB and AI*AB in the IC production system while other factors remained constant. Similar studies which were done using this approach include Okoh *et al.,* (2008); Sumy *et al.,* (2010); Kumar *et al.*, (2013); Etuah *et al.*, (2013). The gross margin was determined by computation of total revenue from sales IC products over the total cost of inputs or as profits over variable operational costs (Okoh *et al.,* 2008).

The functional equations used in the calculations are:

TC = TFC + TVC

GM = TR - TVC

NP = GM – TFC

Where TC = Total Costs

TFC = Total fixed Costs

TVC = Total Variable Costs

GM = Gross Margin

TR = Total Revenue

NP = Net Profit

3.2.6 Method of Managing Data Collection

i. Method of Gathering Data

The process of collecting data involved observation, counting and measuring experimental response parameters. This study employed assistance in data collection by one enumerator. The data collection assistant had received adequate supervision and training suitably to be able to make accurate and precise measurements, counts and or observations and to make a recording of parameters accordingly. The enumerator only stood in for the student's necessary absence during the progress of the experiments.

ii. Method of Main Experimental Response Variables

The central data points were according to the planned experiments as follows:

Experiment 1: Egg Laying Prowess

a. Beginning of laying eggs

b. Termination of laying eggs

c. Sum of eggs laid per clutching (Clutch size)

Experiment 2: Egg Incubation

a. Interval between clutching (Number of days before subsequent clutch first egg is laid)

Experiment 3: Chick Brooding

a. Interval between clutching (Number of days before subsequent clutch first egg is laid)

b. Yearly number of clutches (Extrapolated from interval between clutching)

GMA for Economic efficiency

Computation of gross margin or profits to determine economic efficiency of IC production.

3.2.7 Method of Analyzing Data

i. Collective Analysis of Data

The Analysis of Variance (ANOVA) was used in the collective analysis of data. In the processing of ANOVA, the research employed the General Linear Model (GLM) procedure in Statistical Analysis for Scientists (SAS) Software. Conclusions were drawn through applying separation of means by way of Least Square Means (LS-means) against preplanned treatment contrasts.

Because the raw data was mainly by counting, but the sample being from a large population and taken in repetitions, it was assumed to be normally distributed. The assumption could allow the study to apply ANOVA in the data analysis. However, the data was first to be checked for conformation to normality. If it was found ($P<0.05$) not to be normally distributed, the data was to be log transformed to ensure that it was normally distributed, to allow for the application of ANOVA.

ii. Preplanned Contrasting Treatment Combinations

a. NI*NB against NI*AB.

b. NI*NB against AI*AB.

c. NI*AB against AI*AB.

3.2.8 Method of Organizing Main Data Analysis Sets

Analysis for Biological Efficiency

i. **Effects of IC breed lines on clutch productivity**

    a. Influence of IC breed line on clutch size
    b. Influence of IC breed line clutch interval
    c. Influence of IC breed line on number of clutches per year

ii. **Effects of egg incubation mode on clutch productivity**

    a. Effects of egg incubation mode on clutch size
    b. Effects of egg incubation mode on clutch interval
    c. Effects of egg incubation mode on number clutches per year

iii. **Effects of chick brooding method on clutch productivity**

    a. Effects of chick brooding method on clutch size
    b. Effects of chick brooding method on clutch interval
    c. Effects of brooding chick method on number of clutches per year

iv. **Influence of combination of egg incubation mode and chick brooding method on clutch productivity**

    a. Influence of the combination of egg incubation mode and chick brooding method on clutch size
    b. Influence of the combination of egg incubation mode and chick brooding method on clutch interval

c. Influence of the combination of egg incubation mode and chick brooding method on number of clutches per year

Analysis for Economic Efficiency

i. Determination of egg output and production for Incubation Mode and Brooding Method Combinations

ii. Life cycle of IC in Production systems

a. Developed a flow chart depicting the various age sets in the life cycle of the IC

b. Employed production indices for modeling flock stratification

iii GMA for economic efficiency by comparison of percentage gross margin or profits attained.

CHAPTER 4

RESULTS

4.1 Analysis of Biological Efficiency

Normality Test

On testing for normality, the study found that the data was significantly ($P<0.05$) not normally distributed. The data was then transformed by applying natural logarithm on excel. Conclusions were drawn by taking the inverse logarithm achieved through an exponential function on excel, after the GLM analysis procedure in SAS.

4.1.1. Influence of IC Phenotypic Lines on Clutching Productivities

The sizes of clutches (Number of eggs per clutching) were evaluated for the three IC phenotypic lines (FF, NF, NN). The evaluation also included the interval between succeeding clutches (Number of days) as well as the yearly clutching (Number of clutches/year). Tables 4. 1 and 4.2 describe the outcomes exhibited.

4.1.2. Effect of Incubation Mode on Clutch Productivities

Investigations were done on the effect of incubation mode on the clutch productivities in relation to clutch size, interval of clutching and yearly clutching. Table 4.3 illustrates the results obtained on clutch size, clutch interval and the number of clutches per year using the two incubation modes.

4.1.3 Effect of Brooding Method on Clutching Productivities

The size of clutches, interval of clutching and number of yearly clutching were investigated using the two brooding methods; AB and NB. The results obtained are illustrated in Table 4.4 and 4.5, demonstrating the clutch productivity as influenced by the two brooding treatments.

4.1.4 Influence of Combination by Incubation Mode and Brooding Method on Clutch Productivity

The influences of three preplanned contrasts treatment combinations of AI*AB, NI*AB and NI*NB were examined for size of clutches, interval of clutching and yearly clutching. Table 4.6 and 4.7 illustrate the outcome obtained.

Table 4.1: The Clutch Productivities from the IC Phenotypic Lines.

Incubation Mode	IC Line	Size of Clutches	Std Dev	Clutch Interval	Std Dev	Number of Clutches	Std Dev
NI	NF	2.74	0.06	4.50	0.30	1.40	0.30
	FF	2.77	0.07	4.47	0.27	1.40	0.27
	NN	2.86	0.09	4.47	0.23	1.42	0.23
AI	NF	2.75	0.07	3.78	0.03	2.12	0.03
	FF	2.75	0.06	3.69	0.02	2.22	0.02
	NN	2.86	0.08	3.66	0.02	2.24	0.02

Table 4.2: The Clutch Productivities from the IC Phenotypic Lines.

IC lines	FF		NF		NN			
	Ln(x)	Exp(x)	Ln(x)	Exp(x)	Ln(x)	Exp(x)	E.M.S.	LSD
Clutch size	2.76^{a}		2.75^{a}		2.86^{b}		0.0055	0.0473
		15.77		15.64		17.44		
Clutch interval	4.08^{a}		4.14^{b}		4.07^{a}		0.0512	0.1475
		59.18		62.66		58.40		
Clutches/year	1.82^{a}		1.76^{b}		1.83^{a}		0.0512	0.1475
		6.17		5.82		6.25		

Means in the same row that have common superscripts (a or b) are not significant at ($P<0.05$).

E.M S. Refers to the average Error Mean Squares.

LSD is the Fishers Least Square Differnce

Table 4.3: Clutch Productivities by IC Incubation Mode

Parameters	Incubation mode				E.M S.	LSD
	NI		AI			
	Ln(x)	Exp(x)	Ln(x)	Exp(x)		
Clutch size (number)	2.79055^a	16.23	2.78514^a	16.20	0.005262	0.0405
Clutch interval (days)	3.71962^a	41.25	4.48109^b	88.33	0.051243	0.1265
Clutches/year (number)	1.41881^a	4.13	2.18027^b	8.85	0.051243	0.1265

Means in the same row that have common superscripts (a or b) are not significant at (P<0.05).

E.M S. Refers to the average Error Mean Squares.

LSD is the Fishers Least Square Differnce

Table 4.4: The Clutch Productivities from the IC Brooding Method.

Brooding Method	IC Line	Size of Clutch	Std Dev	Clutch Interval	Std Dev	Number of Clutches	Std Dev
NB	NF	2.75	0.07	4.79	0.01	1.11	0.01
	FF	2.75	0.07	4.72	0.01	1.18	0.01
	NN	2.85	0.08	4.69	0.01	1.21	0.01
AB	NF	2.75	0.07	3.99	0.22	1.91	0.22
	FF	2.76	0.06	3.95	0.23	1.94	0.23
	NN	2.86	0.08	3.98	0.31	1.92	0.31

Table 4.5: The Clutch Productivity by IC Brooding Method

Parameters	Brooding method				E.M S	LSD
	AB		NB			
	Ln(x)	Exp(x)	Ln(x)	Exp(x)		
Clutch size	2.79^{a}		2.79^{a}		0.006	0.040
		16.27		16.24		
Clutch interval	3.99^{a}		4.74^{b}		0.048	0.121
		53.41		114.28		
Clutches/year	1.92^{a}		1.16^{b}		0.048	0.121
		6.83		3.19		

Means in the same row that have common superscripts (a or b) are not significant at ($P<0.05$).

E.M S. Refers to the average Error Mean Squares.

LSD is the Fishers Least Square Differnce.

Table 4.6: The Clutch Productivities from Interaction of IC Phenotypic Lines and Combination of Incubation Mode and Brooding Method.

Combination	IC Line	Size of Clutch	Std Dev	Clutch Interval	Std Dev	Number of Clutches	Std Dev
NINB	NF	2.75	0.07	4.79	0.01	1.12	0.01
	FF	2.75	0.07	4.72	0.01	1.18	0.01
	NN	2.85	0.08	4.69	0.01	1.21	0.01
NIAB	NF	2.75	0.07	4.20	0.02	1.70	0.02
	FF	2.76	0.05	4.22	0.03	1.68	0.03
	NN	2.86	0.08	4.25	0.02	1.65	0.02
AIAB	NF	2.74	0.06	3.78	0.03	2.12	0.03
	FF	2.77	0.07	3.69	0.02	2.21	0.02
	NN	2.86	0.09	3.66	0.02	2.22	0.02

Table 4.7: The Clutch Productivity by Combination Between Incubation Mode and Brooding Method

	NI *NB		NI *AB		AI *AB		E.M.S.	LSD
	Ln(x)	Exp(x)	Ln(x)	Exp(x)	Ln(x)	Exp(x)		
Size of Clutch	2.79^a	16.20	2.79^a	16.32	2.79^a	16.27	0.0066	0.05
Interval of Clutching	4.74^a	114.29	4.22^b	68.27	3.72^c	41.25	0.0005	0.01
Yearly Clutching	1.16^a	3.19	1.67^b	5.33	2.18^c	8.85	0.0005	0.01

Means in the same row that have common superscripts (a or b) are not significant at ($P<0.05$).

E.M S. Refers to the average Error Mean Squares.

LSD is the Fishers Least Square Differnce.

4.2. Analysis of Economic Efficiency

The study first modeled flock dynamics by: i.) Determining measures of egg output and production for each combination of incubation mode and brooding method ii) Developing a flow chart depicting the various age sets in the life cycle of the IC, iii.) Employing production indices for modeling flock stratification and performed a GMA to obtain the economic efficiency by comparison of percentage gross margin (GM) attained; using profitability as a measure of economic efficiency.

4.2.1. Determination of egg output and production for Incubation Mode and Brooding Method Combinations

The final egg productivity was determined by the clutch size and the number of clutches per year; whose product give the total number of eggs laid. Accordingly, the results presented in Table 4.7 above, on clutch productivity by combination between incubation mode and brooding method are further analyzed as shown in Table 4.8.

Subsequently, if the results were to be assumed real and be extrapolated to the current IC hen population in the County, the increase in production would be adequate to jumpstart commercialization of the IC production system. Assuming NI*NB to be the control, at 52 eggs per hen per year; NI*AB yields 68.3% more efficiently, at 87 eggs per hen per year but is led by AI*AB that produces 178.6% more efficiency, at 144 eggs per hen per year than the control. Accordingly, the combination AI*AB is the best option to adopt for IC production in Kilifi County.

Table 4.8: Annual Egg Production per Hen per year by Incubation Mode and Brooding Method Combination

Parameters	Incubation and Brooding Combination		
	NI *NB	NI *AB	AI *AB
Clutch size (number)	16.20	16.32	16.27
Clutches/year (number)	3.19	5.33	8.85
Eggs per hen per year (number)	51.68	86.99	143.99
	(52)	(87)	(144)

4.2.2 Model IC Life Cycle, Input and Outputs

a. Model Life Cycle in Flock Dynamics Analysis Using Combinations of Incubation mode and Brooding Method

Figure 4.1 below depicts the flock dynamics for a self-replacing flock population of laying hens as employed also by Rewe, (2004) in development of bio-economic profit functions. It shows the flow of birds as parent stock mate to lay eggs, through incubation, brooding, growing chicken (pullets and cockerels) to market maturity. Accordingly, the proposed commercial IC flock can be classified into; chicks, growers, market stock, replacement stock, breeding hens and cull hens. Chicks, are young brood chickens up to 1 months of age; while growers are pullets and cockerels between 1 and 6 months old. Market stock are composed of cull pullets and all cockerels. Replacement stock represent mature pullets chosen to replace cull hens or increase breeding hens; and breeding hens are adult female birds aged over six months, that are egg laying. Replacement cocks will be sourced off farm to control inbreeding.

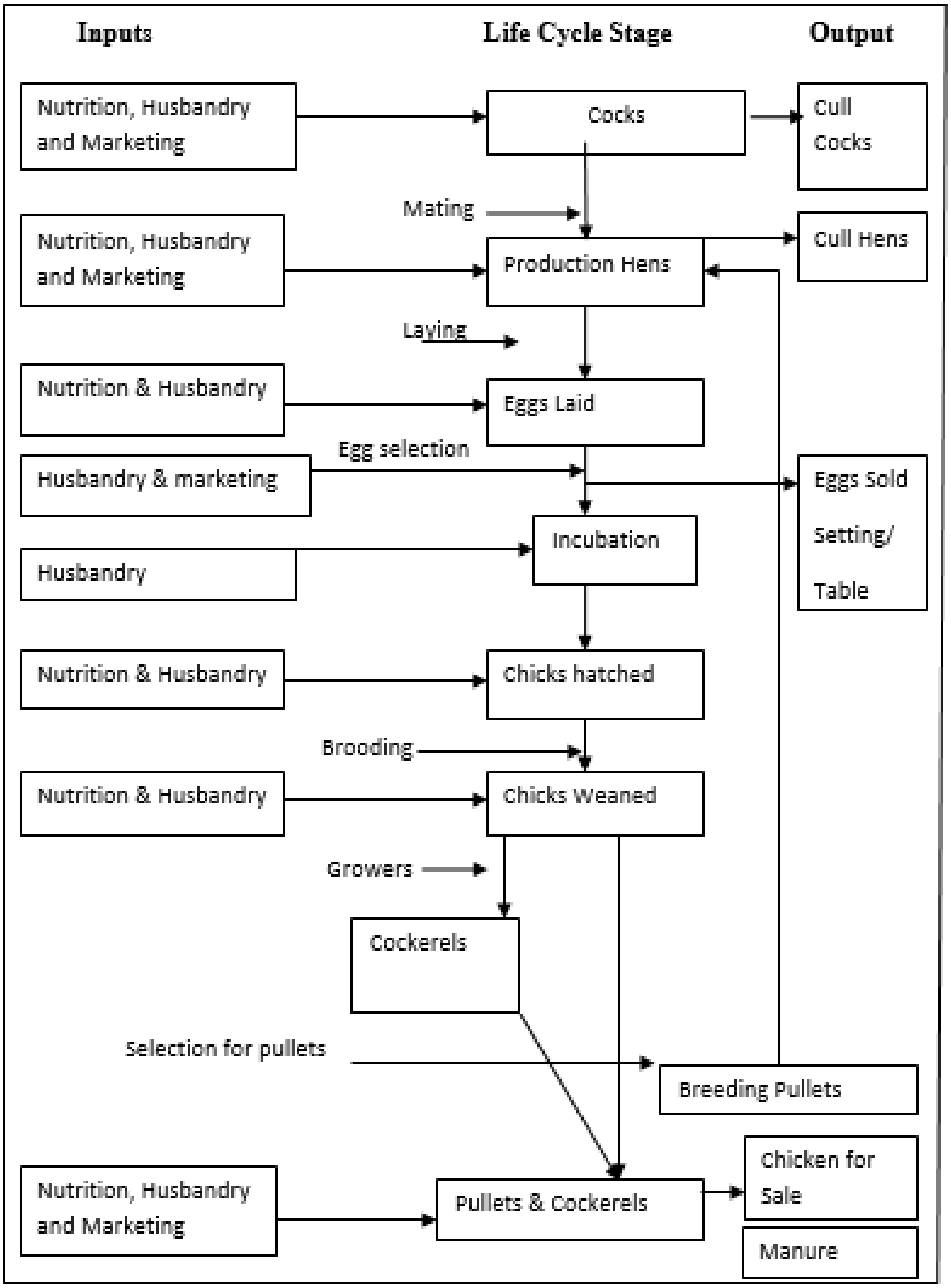


Figure 4.1: Typical IC Life Cycle in Flock Dynamics Based on Birds' Growth, Required Inputs and Expected Output.

b. Model Flock Structure Stratification by Combination of Incubation Mode and Brooding Method Adopted

The model employs either artificial or natural incubation in combination with solely artificial brooding method; and productivity parameter values according to ASDSP, (2015) as follows:

i. Laying percentage = 81;

ii. Percentage of eggs for setting = 80;

iii. Hatchability percentage = 80;

iv. Chick survival rate = 80; and Half (50%) of the offspring (chicks) are of either sex (pullets or cockerels)

Adoption of the model flock dynamics, the stratification of the flock can be calculated as in Table 4.9 and exhibited 4.2 below. Accordingly, it thus could be used to obtain the annual tally and flock structure, based on total number of hens denoted “N”. Any IC total flock population (PIC) could then be stratified accordingly by finding the value of “N”, the number of hens.

Table 4.9: Annual flock structure per incubation mode and brooding method combination based on “N” hens.

IC age set	Incubation Mode and Brooding Method Combination		
	AI*AB	NI*AB	NI*NB
Hens	N	N	N
Cocks	0.1N	0.1N	0.1N
Eggs laid	144N	87N	52N
Chicks	96N	58N	34N
Growers	77N	47N	27N
Pullets (sales)	38.25N	23.25N	13.25N
Cockerels (sales)	38.5N	23.5N	23.5N

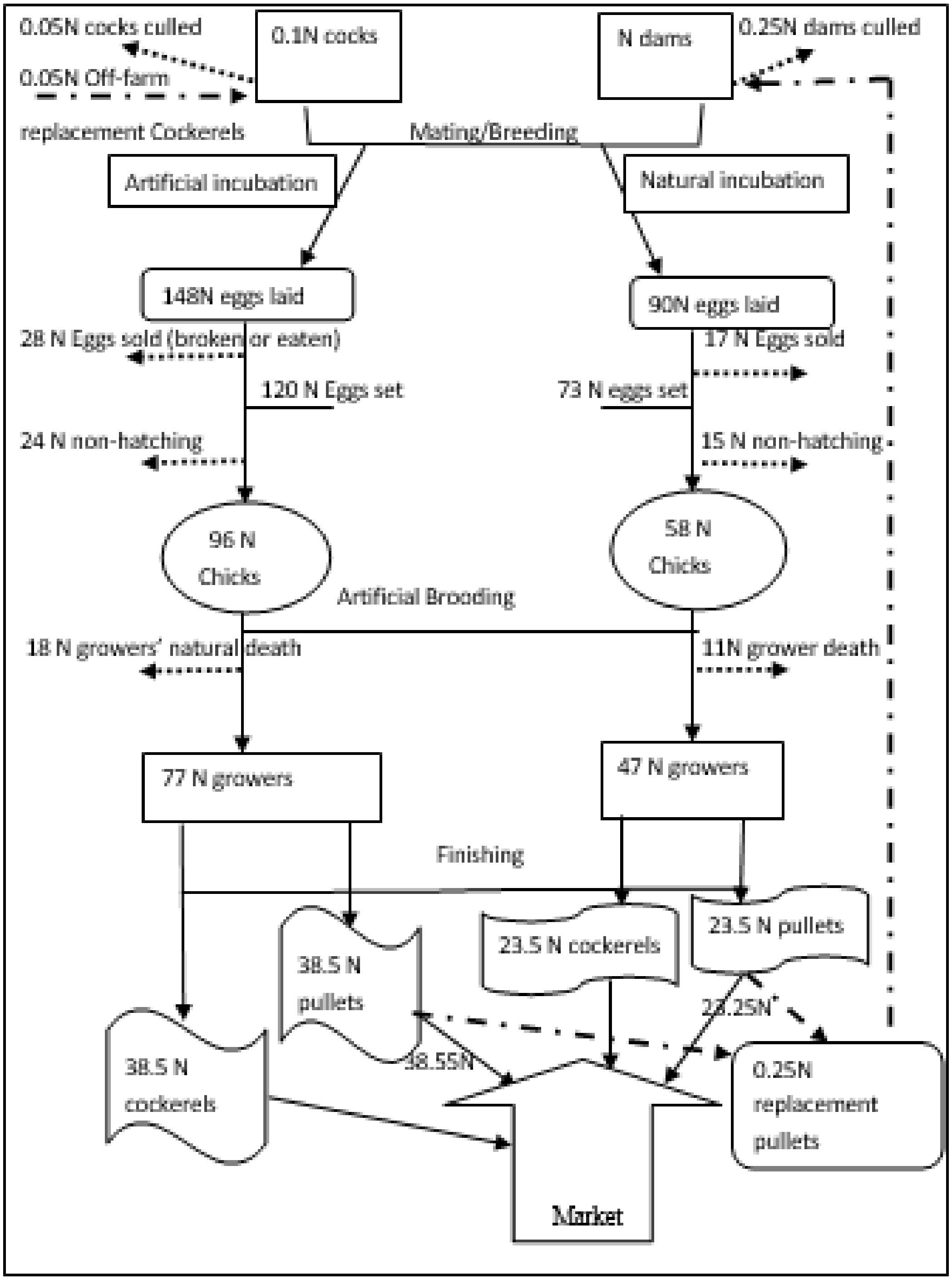


Figure 4.2: Extrapolation of Annual IC Population by Structural Stratification.

c. Determination of the structure of extrapolated Kilifi County 2016 Population of IC (PIC) by Combination adopted

The interaction currently commonly employed in the County is NI*NB. With the PIC standing at 672,356 CGK (2016) gives N at 7568. If this dam set is extrapolated for AI*AB and NI*AB would give rise to flock structure in Table 4.10, having a PIC of 1,898433 and 1,156769 respectively, adequate to start a sustainable commercial offtake.

Table 4.10: Extrapolation of Annual IC Population by Structural Stratification.

Flock age set	Incubation Mode & Brooding Interaction		
PIC = 672356 for			
NI*NB	AI*AB	NI*AB	NI*NB
Dams	7,568	7,568	7,568
Cocks	756.8	756.8	756.8
Chicks	726,528	438,944	257,312
Growers	582,736	355,696	204,336
Pullets	289,476	175,956	100,276
Cockerels	291,368	177,848	102,168
PIC	1,898,432.8	1,156,768.8	672,416.8

Assuming sales of all cockerels, non-breeding pullets, cull hens and cull cocks the AI*AB combination allows the highest offtake rate at 60% which leaves a balance of 759,373 representing a PIC growth of 12.9 %. On the other hand, the NI*AB combination can allow an offtake rate of up-to 40% that leaves a balance of 694,061 which makes a 3% PIC growth.

4.2.3 GMA for Model IC Production System GMA Using Combinations of Incubation mode and Brooding Method

The matrix in Table 4.11 shows the GMA of the IC production system. The data in the analysis is based on assumptions that all the other production parameters are the same except for the combination of egg incubation mode and IC chick brooding method combination as follows:

i. Cumulative feed intake adopted according to Jacob and Pescatore (2012).

ii. Feed and IC product prices according to CGK (2016).

Table 4.11: Comparative gross margin analysis matrix for using combinations of incubation mode and brooding method combination in the IC production system.

Activity/Item	Incubation Mode and Brooding Method Combination								
	AI*AB			NI*AB			NI*NB		
	No. of Units	Unit cost (KShs.)	Total cost (KShs.)	No. of Units	Unit cost (KShs.)	Total cost (KShs.)	No. of Units	Unit cost (KShs.)	Total cost (KShs.)
A: Production Costs									
("N" Breeding Hens)	100			100			100		
Housing Breeding (Square meters)	12.50	900	11250.00	20.00	900	18000.00	25.00	900	22500.00
Housing Incubation (Square meters)	12.50	600	7500.00	12.50	600	7500.00	20.00	600	12000.00
Housing Brooding (Kit	10.37	600	6220.42	6.92	600	4153.85	4.00	600	2400.00

Areas)									
Housing Rearing			43156.80						
(Rooms)	47.95	900		29.16	900	26244.00	16.85	900	15163.20
Equipment: Brood kits	10.37	900	9330.64	6.92	900	6230.77	4.00	900	3600.00
Feeders	959.04	300	287712.00	583.20	300	174960.00	336.96	300	101088.00
Drinkers	959.04	300	287712.00	583.20	300	174960.00	336.96	300	101088.00
Incubator	1.00	80000	80000.00	20.00	500	10000.00	33.33	500	16666.67
Incubator Run	12.00	5000	60000.00	60.00	100	6000.00	11.11	100	1111.11
Brooder	10.37	200	2073.47	34.62	200	6923.08	44.44	200	8888.89
Brooder Run	10.37	200	2073.47	34.62	200	6923.08	44.44	200	8888.89
Breeding Hens	100	300	30000.00	100.00	300	30000.00	100.00	300	30000.00
Breeding Cocks	10	500	5000.00	10.00	500	5000.00	10.00	500	5000.00
Breeders feed	125.84	3100	390104.00	125.84	3100	390104.00	125.84	3100	390104.00
Chick Feeds	10.44	2800	29228.68	9.86	2800	27599.82	7.91	2800	22142.94

Grower feeds	53.13	2400	127523.91	50.17	2400	120417.23	26.32	2400	63167.44
Pullet/Cockerel feed	26.97	2400	64722.70	25.46	2400	61115.82	20.04	2400	48089.42
Vet Supplies & service	4447.87	5	22239.36	4200.00	5	21000.00	3400.00	5	17000.00
Labour	12.00	7000	84000.00	12.00	7000	84000.00	12.00	7000	84000.00
Sum of A			1,549,847.45			1,181,131.63			952,898.55
Eggs available for hatching	12000.00			7300.00			4700.00		
Eggs setting capacity for hatching	6864.00			5400.00			3400.00		
B: Sales Income									
Eggs (Hatching)	5136.00	30	154080.00	1900.00	30	57000.00	1300.00	30	39000.00
Eggs (Table)	2800.00	20	56000.00	1700.00	20	34000.00	500.00	20	10000.00

DOC	5559.84		0.00	4374.00		0.00	2754.00		0.00
Grower	4447.87		0.00	3499.20		0.00	2203.20		0.00
Pullets	2112.74	450	950732.64	1662.12	450	747954.00	1046.52	450	470934.00
Cockerels	2223.94	600	1334361.60	1749.60	600	1049760.00	1101.60	600	660960.00
Cull hens	25.00	400	10000.00	25.00	400	10000.00	25.00	400	10000.00
Cull Cocks	5.00	550	2750.00	5.00	550	2750.00	5.00	550	2750.00
	Sum of B								
			2,507,924.24			1,901,464.00			1,193,644.00
C: Gross Margin = Sum of B- Sum of A			958,076.79			720,332.37			240,745.45

CHAPTER 5

DISCUSSION

5.1 Analysis of Biological Efficiency

5.1.1 Influence of IC phenotypic Lines

5.1.1.1 Influence of IC phenotypic Lines on Size of Clutches

The size of clutches among FF and NF were analogous but both had a significant difference from that of NN. The number of eggs per clutch from NN was highest recording 17.44, while FF and NF respectively achieved 15.77 and 15.64. According to the outcome, superiority in laying eggs is possessed by NN. The results are in conformity with that of Islam, (2006) and Idowu *et al*., (2019). This significantly different clutch size at $P < 0.05$ for FF and NF was similarly found by Danda *et al.*, (2010); Okeno *et al.*, (2010); Daikwo *et al.*, (2011); Kgwatalala *et al.*, (2013) and Dunya *et al.*, 2014 in characterization studies. However, the study result had a higher mean range (15.63 to 17.77 compared to 12 to 15). This variation may be attributed to improved feeding and nutrition during the research versus free range characterization of family farm conditions for the references.

5.1.1.2 Influence of IC Phenotypic Lines on Interval of Clutching

The interval of clutching for NF 62.66 days was the longest and significantly different from that observed for FF and NN which exhibited similarity in the clutch intervals of means at 58.42 and 59.18 respectively. Therefore, FF and NN breed lines produced succeeding clutches sooner than NF. This result display that FF and NN are the better IC phenotypic lines to be adopted for improvement in productivity of eggs that including chicks in the long run. The results are supported by those that were found by other scholars such as Islam and Nishibori, (2009); Magothe *et al.,* (2010); Okeno *et al.*, (2011). Their findings were explained as due to the breed lines' phenotypic conformation that is compatible with the area's ecological variations, besides having better feeding habits and convert the feed efficiently for reproduction (Islam and Nishibori, 2009; Magothe *et al.,* 2010 and Okeno *et al.,* 2011).

5.1.1.3 Influence of IC Phenotypic Lines on Yearly Clutching

The mean yearly clutching from each IC breed line was such that the results revealed similarity for FF and NN, but the two exhibited a significant variation from that of NF. The NF produced the least mean clutches reaching 5.82 times relative to 6.25 and 6.17 respectively for NN and FF. This result is corroborated by comparable outcomes as reported by Islam and Nishibori, 2009; Magothe *et al.,* 2010; Okeno *et al.,* 2011 who accredited it towards the birds' genetic composition. Accordingly, NN and FF therefore showed that they were the IC breed lines of choice to provide improvements in egg clutching in Kilifi county.

5.1.1.4 Appropriate IC Lines Selection

In this study, the use of IC phenotypic lines for productivity improvement has shown the bird in order of highest to least as NN, FF and NF. By the number of eggs laid per year, obtained as a product of the size of clutches and the number of clutches per year; the NN and FF respectively produced a mean of 19.66% and 6.81% more eggs than NF. This reveals that NN followed by FF are the most appropriate IC phenotypic lines in Kilifi County. This is also in cognizant of other studies in linking genetic by environment for the IC. Production of IC (like other animal species) without tallying consideration of genetic by environment interaction leads to reduced productivity due to loss of genetic gain (Ojango and Pallot, 2002, Kirunda *et al.,* 2010; King'ori, 2011). There is thus high need for selection of the IC lines to correspond to environmental adaptation. This is in cognizant to reproduction prowess of the IC phenotypic lines relative to the environmental conditions in the County of Kilifi that are classified as coastal lowland agroecological zones. The NN and FF extra exposed skin provides more surface area required for efficient temperature exchange mechanism, making them more superiorly adapted to the environment and thus perform better than other IC lines according to Essam *et al.,* (2007), King'ori *et al.,* (2010), and Ngeno *et al.,* (2014). This may imply that in cooler regions the IC keepers will have to choose the birds that have more feathers covering their skin to reduce heat loss to the environment. According to this study, in order of priority the IC phenotypic lines fair as follows NN, FF and NF, as they respectively have the largest size of clutches, lower interval of clutching and highest numbers of clutches per year.

5.1.2. Effect of Incubation Mode

5.1.2.1 Effect of Incubation Mode on Clutch Size

The method of incubation had no effect on the clutch size, the mean clutch sizes were not significantly different respectively at 16.29 and 16.20 eggs for NI and AI. The findings indicated that the mode of egg incubation did not affect the number of eggs laid per clutch meaning that it has no influence or correlation on IC clutch size. This implies that either mode AI or NI could be employed without significant change in egg production by clutch size. This observation is unique as the study did not find references for comparison. This new finding implies that the size of clutches could be a genetic function hence the reduction of incubation mode influence in a controlled environment.

5.1.2.2 Effect of Incubation Mode on Clutch Interval

Incubation mode affected clutch interval significantly. Hens came back to lay eggs in a shorter period with a rounded mean of 41.25 days using AI and longer duration for NI at a mean of 88.33 days. This inferred that AI is the better mode of incubation than NI for efficiency in IC egg productivity. It completed the production cycle in about one and half more clutching per year than using NI. This can be due to the actuality that, during incubation, there is reduced feeding while metabolism increases on average 3.4 times greater than the basal metabolism (Nord and Williams, 2015). This results in loss of body condition and makes mother hens take long to get back body condition for the next egg laying (Cunnighams and Klein, 2007). There was no documentation available for contrasting this conclusion. This gives a prospective area for further investigation; as it is a new finding for IC; as in commercial layers, the hens lost the incubation instinct during breeding for more egg production.

5.1.2.3 Effect of Incubation Mode on Yearly Clutching

The mean yearly clutching (number of times) for the 2 incubation modes was significantly different. Artificial incubation resulted in more clutches being laid, which had a mean of 8.85 against 4.13 clutches for natural incubation. The results illustrated that AI is the most efficient mode for clutch output than NI as it almost doubled the clutches peryear. According to Hossen, (2010) the energy that would otherwise be utilized for egg incubation is redirected to fecundity in increased egg production. The mean clutching per year was however similar to that found by Masaire, (2018) but different from that seen by Fotsa *et al*., (2014) and Mapiye *et al*., (2008) who reported 2 – 4 clutches per year. Applying NI as the control, AI yielded 81.4% more clutches to validate it as the better mode of incubation for improved IC productivity in Kilifi County.

5.1.2.4 Selection of NI Mode for IC Production

The natural forms are apparently easily implementable as the mother hens provide the services required and only husbandry options may vary for clutch productivity improvement. The study however, has revealed that natural incubation limits clutch productivity improvement. In natural incubation, the management options will have to vary in fourfold (clutch set and serial hatching) ways to ensure clutch productivity improvement. During natural incubation, the hens should be given only the optimal number of eggs (clutch set) they are able to handle. The clutch set depends on the size of the dam, where all the eggs have to be covered when the dam is seated, a range of 10 to 15 eggs is recommended (Kanyama-Chikoti, *et al.,* 2016; Azharul *et al.,* 2005). Serial hatching can be adopted to release some mother hens from NI (Ssalongo, 2003; Ondwasy *et al.,* 2006). The farmers may limit the number of times per mother hen for serial hatching. Usually two times is recommended and or provide highly nutritious feed during the incubation period (Ssalongo 2003, Ondwasy *et al* 2006) to cater for the metabolic requirements. This is to exploit economies of scale in husbandry applications, such as the artificial brooding, vaccination, feeding and nutrition, besides having many birds maturing simultaneously for ease of market access. This approach could be particularly appropriate for rural farmer groups; where individual members own private flocks, but share cooperative access to production inputs and marketing (Kyarisiima *et al.,* 2009).

5.1.3. Effect of Brooding Method

5.1.3.1 Effect of brooding method on clutch size

Clutch size was not significantly ($P < 0.05$) different between AB and NB, which was similarly concluded by Idowu *et al.,* (2019); and Lwesya *et al.,* (2004) at 16 eggs per clutch. However, Lañada, (2004) reported a lower tally of 8 eggs per clutch. The NB results were however similar to those found by Iyasere *et al.,* (2019); Sears *et al.,* (2011);

Roothaert, (2011); Hossen, (2010); Moges, (2010); Halima *et al.,* (2007) in their characterization studies. This implies that, when other parameters are constant clutch size is a function of phenotypic line and genetically controlled.

5.1.3.2 Effect of brooding method on clutch interval

Clutch interval was affected significantly by brooding method, where AB returned a shorter interval that had a mean of 53.41 days compared to 114.28 days for NB. The mean interval of clutching was completed 46 days less by AB compared to NB. The results imply that AB is more efficient than NB. Similar results were obtained by Hossen, (2010) while weaning chicks early. He reported that early chick weaning increased eggs laid and contributed to more cash income by reducing clutch interval from 9 to 5 weeks. While in Malawi, Lwesya *et al.,* (2004) found similar outcomes for partial chick enclosures.

5.1.3.3 Effect of brooding method on number of clutches per year

The brooding method affected the number of clutches laid significantly. The results revealed that AB gave rise to more clutches per year at 6.83 rounds relative to 3.19 clutching for NB. Once again AB was more efficient than NB, revealed by its prowess to allow release of more clutches per year than NB by 44 %. These results corroborated that AB like early weaning was better in efficiency for increased egg productivity by the number of clutches per year than NB, as also observed by Azharul *et al.,* (2005); Hossen, (2010); Idowu *et al.,* (2018); Idowu *et al.,* (2019).

5.1.3.4 Selection of NB Method for IC Production

Natural brooding has not fared well in this research but cannot be condemned for the farmers who cannot afford wholesome artificial brooding. Albeit we should do all in our ability to reduce the number of dams that roam with chicks in natural brooding for producers who cannot implement AB. This calls for the exploitation of foster mothering, as a management option (Ssalongo, 2003; Ondwasy *et al.*, 2006), to release some of the dams from natural brooding.

5.1.4. Influence of Interaction of IC Phenotypic lines and Combination of Incubation Mode and Brooding Method

The results of interactions of IC phonotypic lines and combination of incubation mode and brooding method were not different at (P = 0.05) and the inference were done by considering simple effects in differences of means that exhibited significant statistical variation.

5.1.4.1 Influence of Combining Incubation Mode and Brooding Method on Size of Clutches

The size of clutches was not influenced by the combination of incubation mode and brooding method as the results were not significantly ($P < 0.05$) different. The mean clutch sizes were 16.20, 16.32 and 16.27 correspondingly for NINB, NIAB and AIAB. This imply that these treatments have no influence on clutch size and that the IC phenotypic lines as the genetics is the main influencing factor.

5.1.4.2 Influence of Combining Incubation Mode and Brooding Method on Interval of Clutching

The mean interval of clutching for every combination showed significant difference. The combination AI*AB made the hens to exhibit the shortest clutch interval, and NI*AB was in succession, whereas the combination featuring NI*NB took the longest period in coming back to laying. The mean lag times demonstrated were 41.25, 68.27 and 114.29 days correspondingly for AI*AB, NI*AB and NI*NB. The combinations AI*AB and NI*AB completed the production cycle in respectively 2.8 and 1.7 times more than the control combination NI*NB, a clutch interval improvement of 40.1% and 64.2%

respectively. The combination NI*NB is practically poor for productivity improvement and should be avoided in the IC production system. The result is a new finding, as comparable data was not accessible for review. This finding links the state of hens' body condition needed for initiation of egg laying. In AI*AB, there is neither reduction in feed intake nor increased metabolism above basal metabolism (Nord and Williams, 2015). Accordingly, there is no loss of body condition and makes mother hens come back for the next egg laying early (Cunnighams and Klein, 2007). Similarly, in NI*AB, the mother hens easily gain lost body condition as they do not share feed with young ones and they do not use energy to nurse the chicks.

5.1.4.3 Influence of Combining Incubation Mode and Brooding Method on Yearly Clutching

The yearly clutching means for all the combinations were significantly different. The combination among AI*AB had the highest yield, giving a mean of 8.85 clutches while NI*AB and NI*NB, yielded 5.33 and 3.19 clutching respectively. Combining AI*AB produced about three times (2.7) more, on the other hand NI*AB gave about double (1.6 times) more clutching than NI*NB which is the normal practice. The adoption of these findings would provide a respective increase of 171.30% and 63.40% in clutches per year. In order to improve productivity NI*NB combination must be avoided in IC production systems. This result is generally new implying that with other conditions constant, releaving of birds from NI and NB improves egg production as seen in AI*AB which is reduced in NI*NB. This is also corroborated by Lwesya, *et al.,* (2004) and Hossen, (2010) partly, having left out incubation but used only AB in their research model. Cunnighams and Klein, (2007) attributed this to similar findings to mother hens' body condition and access to feed.

5.1.4.4 Appropriate Incubation Mode and Brooding Method Combinations Selection Analysis

The selection of technology combination depends mainly on the extent to which their adoption improves the productivity of the production system. For the IC production system, it was measured by increased output and hence productivity based on products (eggs and offtake) and their profitability. In the analysis for combination of incubation mode and brooding method, the output and productivity were determined by the number of eggs produced per hen per year. As shown in Table 4.8 the combination of choice in order of priority as AI*AB, NI*AB and lastly NI*NB.

5.2. Analysis of Economic Efficiency

5.2.1 Gross Margin Analysis

The GMA clearly illustrates the profitability and return on investment for adoption of either combination of incubation mode and brooding method chosen. The AI*AB combination option exhibited the highest profitability of Kenya Shillings 958,076 compared to 720,332 and 240,745 GM for NI*AB and NI*NB respectively. The AI*AB and NI*AB profits were 717,331and 479,586 respectively, more than the NI*NB respectively representing 298% and 199% more profits. These findings follow the same trend to those identified by Roothaert, (2011) in Uganda, and in Bangladesh by Riise *et al.*, (2005). In this study the return on investment was covered in one year, while the housing and equipment (incubator, feeders and drinkers) are re-usable over longer periods of up-to ten years depending on handling and maintenance.

5.2.2 Appropriate Incubation and Brooding Combinations Application

Going by the outcome of the research, the practical IC artificial egg incubation and artificial chick brooding schemes will need to change depending on the farmers' investment and production level (FAO, 2009). It could lead to stratification and varied production options pegged on resources and experience. Likely scenarios are; lives birds' production, ownership of incubator or brooder and source of eggs. Choices of adopted investment in live bird production will be relative to specialization in the stage of growth the birds are introduced into the farms. The incubation and brooding subsectors will be prescribed by regards to source of eggs for incubation and mode of access for day old chicks (DOC) or grower chicken meant for finishing into table birds or as replacement breeding stock. The eggs could be on-farm-bred or purchased. The brooding DOC may be hatched on-farm, from hatchery service or purchased; while the resultant grower pullets and cockerels could be finished on-farm or sold for onward table birds or replacement breeding parents. As shown in Figure 5.1, the incubation and brooding implementation strategies could be operated at individual farm level or as a commercial service for other farms as follows:

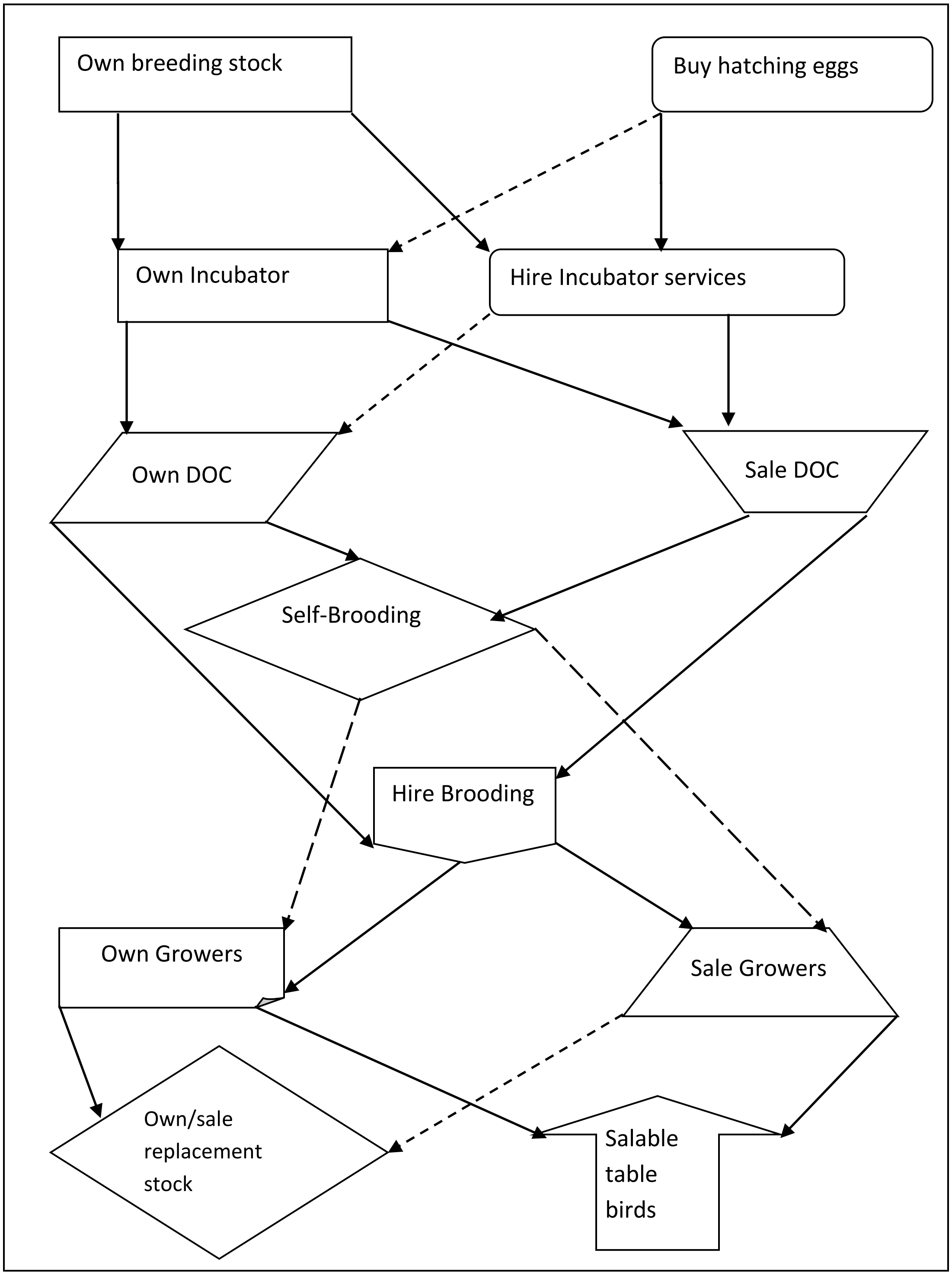


Figure 5.1: Incubation and Brooding Schemes Implementation Strategy Options

i. Own incubator and breeding stock to self-supply the hatching eggs; followed by self-chick-brooding or sale of DOC

ii. Own incubator but purchase hatching eggs; followed by self-chick-brooding or sale of DOC

iii. Hire egg incubation service for self-supply the hatching eggs; followed by self-chick-brooding or sale of DOC

iv. Hire egg incubation service for purchase hatching eggs; followed by self-chick-brooding or sale of DOC

The artificial chick brooding has elicited four (4) strategic implementation options as follows;

i. Own brooder for own firms growing birds into both salable table birds and or replacement breeding stock

ii. Own brooder for salable growing birds into table birds and or replacement breeding stock

iii. Hire brooding service for own growing birds into table birds and or replacement breeding stock

iv. Hire brooding service for salable growing birds into table birds and or replacement breeding stock.

However, the success of IC productivity improvement lies not only in the practice of improved innovations, as shown by this research, but also other factors such as the involvement and support of all stakeholders and actors in the industry’s value chain.

Our farmers are rational investors; hence all the stakeholders should be able to see and be assured of the envisaged benefits (immediate and long term, plus direct and indirect) for capitalizing in the proposed IC production models. The principle calls for collaborative support and cordial partnership of the IC actors and other stakeholders including both public and private sectors (Reardon *et al.,* 2009). This would need the actors to understand that they require each other in the industry value chain and that any weak establishment would be detrimental to all, which involves inspiring one another to be supportive rather than being competitive with one and the other (Thiele *et al.,* 2005, Thomann *et al.,* 2009). The stakeholders and actors need to install institutional structures that would coordinate the affairs, needs and aspiration of their members that could include but not limited to cooperative initiatives, value chain platform, trust and or federation.

Indigenous Chicken Institutional structures

In whatever form, the institutional structures should be market-focused collaboration and partnership among actors in the value chain, established uniquely in participatory, inclusive and consensus-based action (Thiele *et al.,* 2005).

They are mainly meant to redress common and or, systemic challenges and opportunities within the value chain system. The sustainability of the institutions is based on transparent openness, honesty and mutual trust that support consented agreements in the complex underlying issues (Bernet *et al.,* 2006). For example; the sales and service of incubators and accessories, the quality of breeding stock or hatching eggs and grower chicken for sales as replacement breeding stock or table birds.

5.2.3 Model IC Production System Implementation Analysis with IC Breeding in Combination of AI*AB

The need for systemic changes of the production traditions in all the IC production system classes, to conform to the emerging realities and to cash into the growing demand for the indigenous chicken products, has now been exposed in order to commercialize the enterprise. It calls for advocacy to adopt and integrate the rapid multiplication innovations exhibited by the findings of this study. Ideally to select appropriate IC lines by environment coupled with relevant techniques for incubation-to-brooding combination strategies in line with continually and mutually beneficial actors support in the industry.

The main activities in the proposed production system for IC supply productivity improvement include breeding (IC lines for chick production), Multipliers (hen keepers for hatching egg production), hatching (incubator operators), brooding and finishing. In current practice, these activities are performed by one actor, the farmer, who operates a self-replacing breeding flock. The proposed system however, suggests a stratified structure unless the producers possess requisite technical capacities for each section in what can be called farm-to-table system as shown in Figure 5.2.

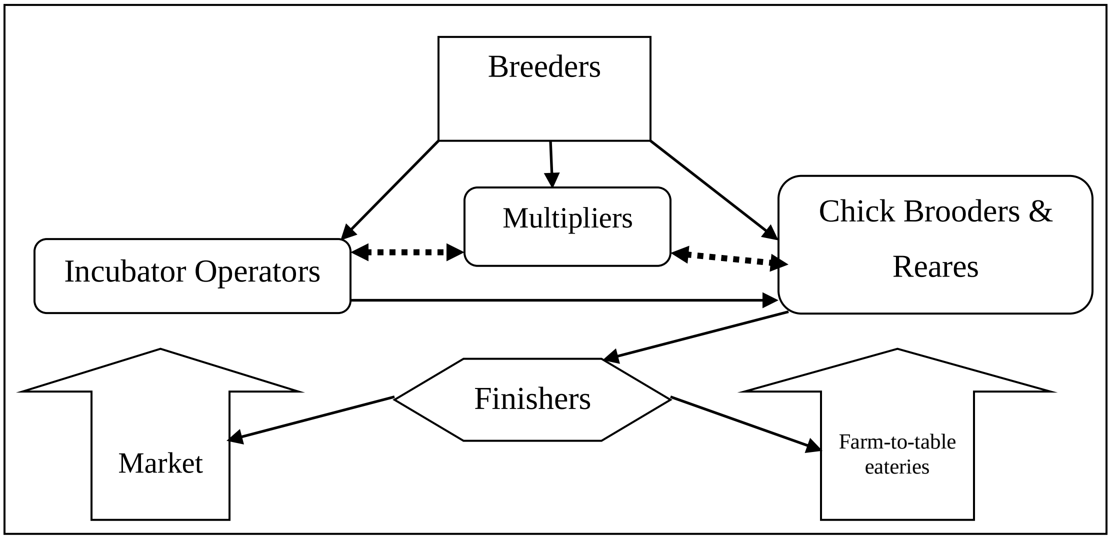


Figure 5.2: Model IC Production Systems Using AI and AB

Breeders: The breeding flock from IC lines of choice need be raised according to prescribed standardsl for both the hens and the cocks, especially with regards to their welfare, biosecurity and nutrition. Care must also be observed on the safety of eggs laid to ensure all eggs intended for hatching are not contaminated before incubation. In the envisaged system, some actors could specialize as breeders, to be suppliers of terminal replacement breeding birds, day old chicks and or hatching eggs.

Multipliers: Producers in this group will keep terminal breeding birds to supply replacement production flocks for finishing birds to feed the markets.

Incubator Operators: Incubator operation will entail investment in hatchery services which could be singly, standalone business, to access eggs from breeders, provide hatching service to producers and or be integrated with breeders to sell day old chicks to other actors.

Rearing (brooders, growers; pullets and cockerels): Rearing in this proposed system will be composed of raising chicks through the brooding phase until they reach grower level, at which stage they would be selected for finishing as table birds or replacement breeding flock. This activity can be done by the same initial actors or other new or specialized farmers. The growing birds can then be reared to maturity or be sold to other actors mainly finishers and or breeders.

Finishers: These are actors who specialize in finishing growing birds that have been selected as table birds. They could procure growing birds from rearing actors or continue rearing chicks from brooding stage having been such actors themselves. The finished birds can then be sold to chicken traders, butchers, households and hotels for final kitchen preparation in readiness to be set on the table.

Farm-to-table: Farm-to-table is a system in which the actor exploits all stages of the value chain from production to consumption. In this proposition, the actors would also cash into eatery business where the finished chicken is prepared in different recipes for revelers to buy ready to eat birds’ products. In this plan, the consumers can access cafe services as well as take away or carry home and home deliveries could be arranged. On the other hand, with current digital developments, online café orders could be exploited.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

This study has shown practical options for commercial improvement of IC production systems. The IC production system is subjectively known for low input low output, while the results of this study have shown otherwise. This study has established that with a suitably planned IC phenotypic line selection, coupled with appropriate artificial incubation and artificial brooding would improve output and production efficiency for a market-based business system. The IC Phenotypic line effects, as biological efficiency, were analyzed in terms of genetic productive supremacy and differences in response to incubation mode and brooding method relative to clutch size, clutch interval and clutches per year.

According to the findings of the study, NN was the best line for clutch size; while both NN and FF were better lines for short clutch interval and more clutches per year in the IC production system. The breeds are well adapted to the ecological conditions than NF, because most of Kilifi County is in ecological zones classified as coastal lowland, characterized by high temperatures and humidity especially in the coastal strip; while in the hinterland it is arid and semi-arid. The NN and FF have exposed skin and easily dissipate heat than NF making them more suitable to the region’s heat load especially with continued drought conditions eminent as a result of climate change scenario. Accordingly, there is need to promote NN and FF that could improve productivity by 12.6% more eggs per hen per year compared to NF.

Incubation mode did not affect clutch size; but influenced the rate of clutching. The AI improved biological efficiency of IC productivity with a reduced interval of clutching which in turn increased frequency clutches per year. The AI resulted in more eggs and proportionately more chicks per hen per year by 81.4%.

The IC productivity was improved by implementation of AB. The brooding method affected clutch productivity indices such that AB made the IC biologically more efficient than NB. It did not influence clutch size but, reduced clutch interval hence enhanced clutches per year productivity. Accordingly, farmers should embrace AB increased egg productivity by 44 %.

The combination of employing incubation mode and brooding method showed that the combination produced compounded productivity effect. The combination AI*AB demonstrated to be the best option for productivity improvement and profitability, followed by NI*AB. The results showed NI*AB yielded 73% more efficiently, at 87 eggs per hen per year but was led by AI*AB that produced 186% more efficiently, at 144 eggs compared to NI*NB with 52 eggs per hen per year. Extrapolation of results to the County flock by analysis of GM gave 298% and 199% more profits, respectively for AI*AB and NI*AB combinations.

6.2 Recommendations

As far as IC lines are concerned, farmers should choose birds with NN and or FF blood for improved clutch productivity. Accordingly, with purposeful breeding accruing from IC phenotypic nines differences should be taken advantage.

Adoption of AI is appropriate to improve productivity in the IC industry, however further research is recommended to ascertain the economic efficiency and break-even production levels.

Embracing AB is suitable for productivity improvement as in nature brodiness is linked to cessation of egg production among other traits, and accordingly reduces egg production. At the minimum, IC producers should adopt AB to break broodiness early where AI was not able to be practiced.

In addition, farmers ought to adopt AI in combination with AB for more efficiency in IC production. At the minimum, IC keepers should adopt AB where AI is not practically applicable.

The study design and scope however did not analyze relationships that may exist between the output and input economic values except for profitability. Accordingly, there is need to refine it further to establish the appropriate economic threshold involving all required input and output relationships of genetics, innovations, nutrition and management options for tangible and rational investment decision making.

Bearing in mind the different uses provided by the IC in the current and proposed production systems, it will be prudent to evaluate the impact of proposed changes on the economic gains and the overall output and productivity profitability of the system. Like all other businesses, the return on investment is of critical consideration. Nonetherless, for establishing any form of IC production system change is of major concern. Therefore, this study proposes the need for a detailed analysis of economic efficiency for the IC production system with use of AI*AB because its adoption calls for greater change. Hence, there is an emerging need to biologically and economically evaluate the set objectives not only for IC, but to include other indigenous poultry and emerging ones like Guinea fowls. Further, variations in climatic and environmental conditions and the set research objectives could influence the results differentially; hence calling for similar investigations in the different ecological zones and seasons.

REFERENCES

Abdelqader, A., Wollny, C. B. A., & Gauly, M. (2007). Characterization of local chicken production systems and their potential under different levels of management practice in Jordan. *Tropical Animal Health and Production, 39*(3), 155–164.

Abdelqader, A., Wollny, C. B. A., & Gauly, M. (2008). On-farm investigation of local chicken biodiversity and performance potentials in rural areas of Jordan. *Animal Genetic Resources Information*, *43*, 49–57.

Abiola, S. S., Meshioye, O. O., Oyerinde, B. O., & Bamgbose, M. A. (2008). Effect of egg size on hatchability of broiler chicks. *Archivos de Zootecnia, 57*(217), 83–86.

Abou-Emera, O. K., Ali, U., Galal, A., El-Safty, S., Abdel-Hame, E. F., & Fathi, M. M. (2017). Evaluation of Genetic Diversity of Naked Neck and FrizzleGenotypes Based on Microsatellite Markers. *International Journal of Poultry Science*, *16*(4), 118–124. https://doi.org/10.3923/ijps.2017.118.124

Adebambo, A. O., Ikeobi, C. O. N., Ozoje, M. O., Oduguwa, O. O., & Adebambo, O., A. (2011). Combining Abilities of Growth Traits Among Pure and Crossbred Meat Type Chickens. *Archivos De Zootecnia*, *60*(232), 953–963. https://www.redalyc.org/pdf/495/49521125012.pdf

Adewumi, A. A., Ayodele, I. A., & Lameed, G. A. (2008). The effect of incubator type on hatchability and chick survival of emu dromaius novae hollandiae (Le Souef 1907). *Journal of Applied Sciences and Environmental Management*, *12*(2).

Adeyemo, G. O., Longe, O. G., & Adejumo, D. O. (2007). The Reproductive Performance of Breeder Cocks Fed Cottonseed Cake-based Diets. *International Journal of Poultry Science*, *6*(2), 140–144. https://doi.org/10.3923/ijps.2007.140.144

Adid, A. M. M. (2008). *Development of Smart Egg Incubator System for Various Types of Egg (SEIS)* [PhD Thesis, Universiti Malaysia Pahang]. http://umpir.ump.edu.my/id/eprint/102/1/cd3225.PDF

Adomako, K. (2009). *Local domestic chickens: Their potential and improvement* [Ph.D Thesis, Kwame Nkrumah University of Science and Technology]. http://ir.knust.edu.gh/bitstream/123456789/361/1/Binder1.pdf

Ahlers, C., Alders, R., Bagnol, B., Cambaza, A. B., Harun, M., Mgomezulu, R., Msami, H., Pym, B., Wegener, P., & Wethli, E. (2009). *Improving village chicken production: A manual for field workers and trainers.* Australian Centre for International Agricultural Research (ACIAR).

Akinola, L. A. F., & Essien, A. (2011). Relevance of rural poultry production in developing countries with special reference to Africa. *World's Poultry Science Journal*, *67*(4), 697–705.

Al-Aqil, A., Zulkifli, I., Sazili, A. Q., Omar, A. R., & Rajion, M. A. (2009). The Effects of the Hot, Humid Tropical Climate and Early Age Feed Restriction on Stress and Fear Responses, and Performance in Broiler Chickens. *Asian-Australasian Journal of Animal Sciences*, *22*(11), 1581–1586. https://doi.org/2009.22.11.1581

Alsobayel, A. A., & Albadry, M. A. (2012). Effect of age and sex ratio on fertility and hatchability of Baladi and Leghorn laying hens. *The Journal of Animal & Plant Sciences*, *22*(1), 15–19.

Alvarez, A., & Arias, C. (2014). A selection of relevant issues in applied stochastic frontier analysis. *Economics and Business Letters*, *3*(1), 3–11. https://doi.org/10.17811/ebl.3.1.2014.3-11

Appleby, M. C., Mench, J. A., & Hughes, B. O. (2004). *Poultry Behaviour and Welfare*. CABI.

ASDS. (2010). *Agricultural Sector Development Strategy 2010–2020*. Government of Kenya; Agricultural Development Strategy 2010-2020. Retrieved on 25th August, 2020 from http://www.kenyagreece.com/sites/default/files/agricultural-sector-ds-2020.pdf

ASDSP. (2015). *Agricultural Sector Development Support Programme (ASDSP) Mid Term Review* [Final Report]. Swedish International Development Cooperation Agency. Retrieved on 25th August, 2020 from https://publikationer.sida.se/contentassets/4bb7f5356c634b9ab3df186e994ae6a9/d0b7933f-1971-43f9-b3f4-499667e0c802.pdf

Assegie, F. M. (2009). *Studies on Production and Marketing Systems of Local Chicken Ecotypes in Bure Woreda, North-West Amhara* [Master's Thesis, Hawassa University]. Retrieved on 25th August, 2020 from https://cgspace.cgiar.org/bitstream/handle/10568/76/bitstream?sequence=2

Azharul, I. M., Ranvig, H., & Howlider, M. A. R. (2005). Incubating capacity of broody hens and chick performance in Bangladesh. *Livestock Research for Rural Development*, *17*(2), 1–10.

Bain, M. M. (2005). Recent advances in the assessment of eggshell quality and their future application. *World's Poultry Science Journal*, *61*(2), 268–277. https://doi.org/10.1079/WPS200459

Bernabucci, U., Lacetera, N., Danieli, P. P., Bani, P., Nardone, A., & Ronchi, B. (2009). Influence of different periods of exposure to hot environment on rumen function and diet digestibility in sheep. *International Journal of Biometeorology*, *53*(5), 387–395. https://doi.org/10.1007/s00484-009-0223-6

Bernabucci, Umberto, Lacetera, N., Baumgard, L., Rhoads, R., Ronchi, B., & Nardone, A. (2010). Metabolic and hormonal acclimation to heat stress in domesticated ruminants. *The Animal Consortium*, *4*(7), 1167–1183. https://doi.org/10.1017/S175173111000090X

Bernet, T., Thiele, G., & Zschocke, T. (Eds.). (2006). *Participatory Market Chain Approach (PMCA): User Guide*. International Potato Center (CIP) – Papa Andina.

Besbes, B., Thieme, O., Rota, A., Guèye, E. F., & Alders, R. G. (2012). Technology and programmes for sustainable improvement of village poultry production. *Alternative Systems for Poultry: Health, Welfare and Productivity*, 110–127.

Bett, H. K., Bett, R. C., Peters, K. J., & Bokelmann, W. (2012). Linking utilisation and conservation of indigenous chicken genetic resources to value chains. *Journal of Animal Production Advances*, *2*(1), 33–51.

Bett, H. K., Musyoka, M. P., Peters, K. J., & Bokelmann, W. (2012). Demand for meat in the rural and urban areas of Kenya: A focus on the indigenous chicken. *Economics Research International*, *2012*. https://doi.org/10.1155/2012/401472

Bett, H. K., Peters, K. J., & Bokelmann, W. (2011). Hedonic price analysis to guide in breeding and production of indigenous chicken in Kenya. *Livestock Research for Rural Development*, *23*(6), 142.

Bhadauria, P., Majumdar, S., & Kolluri, G. (2014). Impact of Hot Climate on Poultry Production System-A Review. *Journal of Poultry Science and Technology*, *2*(4), 56–63.

Bolla, G. (2007). *Lighting of Poultry*. NSW Department of Primary Industries Primefact 604. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/212974/Lighting-of-poultry.pdf

Bossche, V. den P., & Coetzer, J. A. (2008). Climate change and animal health in Africa. *Revue Scientifique et Technique (International Office of Epizootics)*, *27*(2), 551–562.

Brillard, J. P. (2006). Control of fertility in turkeys: The impact of environment, nutrition and artificial insemination technology. *Nutritional Biotechnology in the Feed and Food Industries: Proceedings of Alltech's 22nd Annual Symposium, Lexington, Kentucky, USA, 23-26 April 2006*, 207–212.

Brommer, J. E., & Rattiste, K. (2008). "Hidden" Reproductive Conflict Between Mates in a Wild Bird Population. *Evolution*, *62*(9), 2326–2333. https://doi.org/10.1111/j.1558-5646.2008.00451.x

Brooks, D. R., & Hoberg, E. P. (2007). How will global climate change affect parasite–host assemblages? *Trends in Parasitology*, *23*(12), 571–574. https://doi.org/10.1016/j.pt.2007.08.016

Brotherstone, S., White, I. M. S., & Meyer, K. (2000). Genetic modelling of daily milk yield using orthogonal polynomials and parametric curves. *Animal Science*, *70*(3), 407–415. https://doi.org/10.1017/S1357729800051754

Bruzual, J. J., Peak, S. D., Brake, J., & Peebles, E. D. (2000a). Effects of relative humidity during incubation on hatchability and body weight of broiler chicks from young breeder flocks. *Poultry Science*, *79*(6), 827–830.

Bruzual, J. J., Peak, S. D., Brake, J., & Peebles, E. D. (2000b). Effects of relative humidity during the last five days of incubation and brooding temperature on performance of broiler chicks from young broiler breeders. *Poultry Science*, *79*(10), 1385–1391.

Byarugaba, D. K. (2007). The structure and importance of the commercial and village based poultry systems in Uganda. *Rome: FAO-Consultancy Report, Food and Agriculture Organization of the United Nations*.

CCSP. (2008). *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States* (Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research 4.3; Synthesis and Assessment Product). U.S. Climate Change Science Program (CCSP). Retrieved on 15th February, 2020 from http://climatechange.lta.org/wp-content/uploads/cct/2015/03/CCSPFinalReport.pdf

CGK. (2013). *Annual Report 2013* (Department of Agriculture, Livestock Development and Fisheries). County Government of Kilifi.

CGK. (2015). *Annual Report 2014-2015* (Department of Agriculture, Livestock Development and Fisheries; The County Government of Kilifi).

CGK. (2016). *Fourth Quarter Report 2015-2016* (Department of Agriculture, Livestock Development and Fisheries). County Government of Kilifi.

CGK. (2017). *Annual Report 2016-2017* (Department of Agriculture, Livestock Development and Fisheries). County Government of Kilifi.

CGK. (2018). *County Integrated Development Plan 2018-2022: "Towards Realizing People-Focused Transformation for Wealth Creation."* County Government of Kilifi.

Chase, L. E. (2006). Climate change impacts on dairy cattle, Fact sheet,. In *Climate Change and Agriculture: Promoting Practical and Profitable Responses* (pp. 17-23.).

Chen, S. J., & Li, W. B. (2007). Studies on the broodiness in Wumeng black-bone chicken. *Bulletin of Shanghai Husbandry and Veterinary*, *5*, 84.

Cheng, H.-W. (2010). Breeding of tomorrow’s chickens to improve well-being1. *Poultry Science*, *89*(4), 805–813. https://doi.org/10.3382/ps.2009-00361

Chepng’etich, E., Bett, E. K., Nyamwaro, S. O., & Kizito, K. (2014). *Analysis of Technical Efficiency of Sorghum Production in Lower Eastern Kenya: A Data Envelopment Analysis (DEA) approach*. 8.

Chimai, B. C. (2011). *Determinants of Technical Efficiency in Smallholder Sorghum Farming in Zambia* [Masters Thesis, The Ohio State University].

Choprakarn, K., & Wongpichet, K. (2007). Village chicken production systems in Thailand. *Proceedings of the International Poultry Conference, Bangkok, Thailand*, 63–64.

Clauer, P. J. (2009). Incubating Eggs. *Virginia Cooperative Extension*, 1–5.

Cunningham, J. G., & Klein, B. G. (2007). *Veterinary physiology*. Saunders Elsevier Philadelphia.

Cutchin, H. R., Wineland, M. J., Christensen, V. L., Davis, S., & Mann, K. M. (2009). Embryonic development when eggs are turned different angles during incubation. *Journal of Applied Poultry Research*, *18*(3), 447–451.

Daghir, N. J. (Ed.). (2008). *Poultry production in hot climates* (2nd ed.). CAB International.

Daikwo, I., Dim, N., & Ojoh Momoh, M. (2011). Hatching Characteristics of Japanese Quail Eggs in a Tropical Environment. *International Journal of Poultry Science*, *10*(11), 876–878. https://doi.org/10.3923/ijps.2011.876.878

Dana, N., Van der Waaij, L. H., Dessie, T., & van Arendonk, J. A. (2010). Production objectives and trait preferences of village poultry producers of Ethiopia: Implications for designing breeding schemes utilizing indigenous chicken genetic resources. *Tropical Animal Health and Production*, *42*(7), 1519–1529.

Danda, M. K., Mwamachi, D. M., Lewal, K., & Jefa, F. (2010). Characterization of the indigenous chicken sub-sector in the Coastal lowlands of Kenya. *Proceedings of the 12th Kenya Agricultural Research Institute Biennial Scientific Conference, Nairobi, Kenya*, 898–905.

Davtyan, D., Papazyan, T., & Nollet, L. (2006). Dose response of Se added as sodiumselenite or Sel-Plex on male sperm quality and breeder productivity. *EPC 2006-12th European Poultry Conference, Verona, Italy, 10-14 September, 2006*.

De Smit, L., Bruggeman, V., Tona, J. K., Debonne, M., Onagbesan, O., Arckens, L., De Baerdemaeker, J., & Decuypere, E. (2006). Embryonic developmental plasticity of the chick: Increased CO2 during early stages of incubation changes the developmental trajectories during prenatal and postnatal growth. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *145*(2), 166–175. https://doi.org/10.1016/j.cbpa.2006.06.046

Demeke, S. (2007). Suitability of hay-box brooding technology to rural household poultry production system. *Livestock Research for Rural Development*, *19*(1), 1–9.

Dessie, T., & Ogle, B. (2001). Village poultry production systems in the central highlands of Ethiopia. *Tropical Animal Health and Production, 33*(6), 521–537.

Dessie, T., Tadesse, M., Yami, A., & Peters, K. J. (2003). Village chicken production systems in Ethiopia: 1. Flock characteristics and performance. *Livestock Research for Rural Development*, *15*(1).

Dharmasiri, L. M. (2012). Measuring Agricultural Productivity Using the Average Productivity Index (APl). *Sri Lanka Jaumal of Advanced Social Studies, 1*(2), 25–44. Retrieved on 23rd August, 2020 from http://www.ncas.ac.lk/journal/Journal_2011_2/PDFs/25.PDF

Dixon, R. K., Smith, J., & Guill, S. (2003). Life on the Edge: Vulnerability and Adaptation of African Ecosystems to Global Climate Change. *Mitigation and Adaptation Strategies for Global Change*, *8*(2), 93–113. https://doi.org/10.1023/A:1026001626076

Dolberg, F. (2007). *Poultry production for livelihood improvement and poverty alleviation*. FAO Animal Production and Health Division. Retrieved on 25th August, 2020 from http://www.fao.org/WAICENT/FaoInfo/Agricult/AGAInfo/home/events/bangkok2007/docs/part3/3_1.pdf

Dourado, L. R. B., Sakomura, N. K., Nascimento, D. C. N. do, Dorigam, J. C., Marcato, S. M., & Fernandes, J. B. K. (2009). Crescimento e desempenho de linhagens de aves pescoço pelado criadas em sistema semi-confinado: Growth and performance of Naked Neck broiler reared in free-range system. *Ciência e Agrotecnologia*, *33*(3), 875–881. https://doi.org/10.1590/S1413-70542009000300030

Dunya, A., Husa, H., Yusuf, S. Z., Usman, Y., & Makinta, A. A. (2014). Fertility and hatchability in local chicken of Borno state, Nigeria. *Journal of Agricultural Science and Applications*, *3*(1), 20–23. https://doi.org/10.14511/jasa.2014.030104

El-Gendy, E., Nassar, M., & Ahmed, M. (2007). Genotype-Environment Interaction in Relation to Heat Tolerance in Chickens 2. Variation in Juvenile Growth of Warm Regions` Oriented Breeds. *International Journal of Poultry Science*, *6*(5), 322–328. https://doi.org/10.3923/ijps.2007.322.328

El-Hanoun, A. M., Rizk, R. E., Fares, W. A., & El-Komey, A. E. (2013). Duck eggs position and turning in the incubator and their effects on the hatching traits and duckling growth. *Egyptian Poultry Science Journal*, *33*(2), 393–406.

Elibol, O., & Brake, J. (2006). Effect of egg turning angle and frequency during incubation on hatchability and incidence of unhatched broiler embryos with head in the small end of the egg. *Poultry Science*, *85*(8), 1433–1437.

Elibol, O., & Brake, J. (2008). Effect of egg position during three and fourteen days of storage and turning frequency during subsequent incubation on hatchability of broiler hatching eggs. *Poultry Science*, *87*(6), 1237–1241.

Elijah, O. A., & Adedapo, A. (2006). The Effect of Climate on Poultry Productivity in Ilorin Kwara State, Nigeria. *International Journal of Poultry Science*, *5*(11), 1061–1068.

Emam, A. A., & Salih, M. H. (2011). Measuring of Competitiveness of Sudanese Sheep Export. *Journal of Experimental Agriculture International*, *1*(3), 69–78. https://doi.org/10.9734/AJEA/2011/165

ERA. (2015). *Economic Review of Agriculture [ERA] 2015*. The Central Planning and Project Monitoring Unit Ministry of Agriculture, Livestock and Fisheries.

Ernst, R. A. (2004). Hatching egg sanitation: The key step in successful storage and production. *University of California Division of Agriculture and Natural Resources*, 1–4.

Ernst, R., Bradley, F., Delany, M., Abbott, U., & Craig, R. (2004). *Egg candling and breakout analysis*. UCANR Publications.

Etuah, S., Nurah, G. K., & Ohene-Yankyera, A. (2013). Profitability and constraints of broiler production: Empirical evidence from Ashanti Region of Ghana. *Journal of Business & Economics*, *5*(2), 228.

Evans, C. S., & Evans, L. (2007). Representational signalling in birds. *Biology Letters*, *3*(1), 8–11.

FAO. (2008). *Poultry sector country review* (Emergency Centre for Transboundary Animal Diseases Socio Economics, Production and Biodiversity Unit, p. 39). Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-ai355e.pdf

FAO. (2009). *Poultry Genetic Resources and Small Poultry Production Systems in Uganda* (p. 22). Food and Agriculture Organization of the United Nations. http://www.fao.org/3/al689e/al689e00.pdf

FAO. (2013). *Farm Management Extension Guides*. Food and Agriculture Organization of the United Nations (FAO). Retrieved on 17th June, 2020 from http://www.fao.org/sustainable-food-value-chains/training-and-learning-center/details/en/c/274677/

FAO. (2014). *Family poultry development − Issues, opportunities and constraints.* (Animal Production and Health Working Paper No. 12). Food and Agriculture Organization of the United Nations.

Fares, W. A., Shahein, E. H. A., Rizk, R. E., & El-Hanoun, A. M. (2012). Carbon dioxide as affected by ventilation process during early stage of incubation and its relation with embryonic development, hormone levels, hatching parameters and post-hatch chicks growth. *Egyptian Poultry Science Journal*, *32*(1), 23–41.

Farooq, M., Gul, N., Chand, N., Durrani, F. R., Khurshid, A., Ahmed, J., Asghar, A., & Zahir-ud-Din. (2002). Production performance of backyard chicken under the care of women in Charsadda, Pakistan. *Livestock Research for Rural Development*, *14*(1). https://www.lrrd.cipav.org.co/lrrd14/1/faro141.htm

Farzin, W., & Ineke, P. (2011). *Improving hatching and brooding in small-scale poultry keeping. Agrodok-series No. 34* (6th ed.). Agrodok.

Fathi, M. M., Galal, A., El-Safty, S., & Mahrous, M. (2013). Naked neck and frizzle genes for improving chickens raised under high ambient temperature: I. Growth performance and egg production. *World's Poultry Science Journal*, *69*(4), 813–832. https://doi.org/10.1017/S0043933913000834

Fathi, M. M., Galal, A., El-Safty, S., & Mahrous, M. (2014). Naked neck and frizzle genes for improving chickens raised under high ambient temperature: II. Blood parameters and immunity. *World's Poultry Science Journal*, *70*(1), 165–172. https://doi.org/10.1017/S0043933914000142

Fayeye, T. R., Adeshiyan, A. B., & Olugbami, A. A. (2005). Egg traits, hatchability and early growth performance of the Fulani-ecotype chicken. *Livestock Research for Rural Development*, *17*(8). Retrieved on 25th August, 2020 from http://lrrd.cipav.org.co/lrrd17/8/faye17094.htm

Fiel, C. A., Fernández, A. S., Rodríguez, E. M., Fusé, L. A., & Steffan, P. E. (2012). Observations on the free-living stages of cattle gastrointestinal nematodes.

Veterinary Parasitology, *187*(1), 217–226. https://doi.org/10.1016/j.vetpar.2012.01.011

Forbes, A. B., Huckle, C. A., & Gibb, M. J. (2004). Impact of eprinomectin on grazing behaviour and performance in dairy cattle with sub-clinical gastrointestinal nematode infections under continuous stocking management. *Veterinary Parasitology*, *125*(3), 353–364. https://doi.org/10.1016/j.vetpar.2004.07.025

Fotsa, J.-C., Sørensen, P., & Pym, R. A. (2014). Breeding and Reproduction. In FAO, IFAD, & KF (Eds.), *Decision Tools for Family Poultry Development*. Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development and KYEEMA Foundation.

Fowler, B. (2004). *Analysis of the Indigenous Poultry Sub-sector in Kwale and Kilifi Districts of Kenya; Preliminary Findings*. Coastal Rural Support Programme – Kenya, Mariakani.

French, N. A. (1997). Modeling incubation temperature: The effects of incubator design, embryonic development, and egg size. *Poultry Science*, *76*(1), 124–133.

Gast, R. K. (2005). Bacteria Infection of Eggs. In G. C. Mead (Ed.), *Food Safety Control in the Poultry Industry*. CRC Press.

Glenneis, K. (2020). *Indigenous Chicken Breeds*. http://southafrica.co.za/indigenous-chicken-breeds.html

GoK. (2008). *Ministry of Livestock Development Strategic Plan*. Government of Kenya. http://extwprlegs1.fao.org/docs/pdf/ken147764.pdf

Gondwe, T. N., & Wollny, C. B. A. (2007). Local chicken production system in Malawi: Household flock structure, dynamics, management and health. *Tropical Animal Health and Production, 39*(2), 103–113.

Gonsalves, J. F. (2005). *Participatory research and development for sustainable agriculture and natural resource management: A sourcebook* (Vol. 1). IDRC.

Green, B. (2014). *Hatchery Ventilation Essentials*. Aviagen. http://eu.aviagen.com/assets/Tech_Center/Broiler_Breeder_Tech_Articles/English/AviagenHatcheryVentilationEssentials2014-EN.pdf

Guèye, E. F. (2005). Gender aspects in family poultry management systems in developing countries. *World's Poultry Science Journal*, *61*(1), 39–46.

Gueye, E. F. (2009). The role of networks in information dissemination to family poultry farmers. *World's Poultry Science Journal*, *65*(1), 115–124.

Hagan, J. K., Bosompem, M., & Adjei, I. A. (2013). The Productive Performance of Local Chickens in Three Ecological Zones of Ghana. *ARPN Journal of Agricultural and Biological Science*, *8*(1), 51–56.

Hai-ling, L., Jian-rong, C., Li, S., Lei-ming, Y., & Meng-lei, L. (2016). Research on the discrimination of hatching eggs activity based on thermal imaging: A food nondestructive testing practice. *International Journal of Smart Home*, *10*(2), 175–186.

Halima, H., Neser, F. W. C., Van Marle-Koster, E., & De Kock, A. (2007). Village-based indigenous chicken production system in north-west Ethiopia. *Tropical Animal Health and Production*, *39*(3), 189–197. https://doi.org/10.1007/s11250-007-9004-6

Hill, D. (2001). Chick length uniformity profiles as a field measurement of chick quality. *Avian Poult. Biol. Rev*, *12*, 188.

Hill, D., & van Roovert-Reijrink, I. (2011). *Hatchery Sanitation: Basics and Innovations*. https://hatchtech.com/article/hatchery-sanitation/

Hopkins, A., Richter, G. M., Coleman, K., Jaggard, K. W., Glendining, M. J., Semenov, M. A., Qi, A., Audsley, E., Hossell, J. E., Clemence, B., Fuller, M., Winter, D. M., & Butler, A. (2004). *Impacts of climate change on the agricultural industry: A review of research outputs from DEFRA's CC03 and related research programmes* (DEFRA Final Report CC0366, p. 78) [D1 - Technical reports: non-confidential]. Behavioural and Community Ecology (BCE). Retrieved on 4th January, 2020 from https://repository.rothamsted.ac.uk/item/85990/impacts-of-climate-change-on-the-agricultural-industry-a-review-of-research-outputs-from-defra-s-cc03-and-related-research-programmes

Hossen, M. J. (2010). Effect of management intervention on the productivity and profitability of indigenous chickens under rural condition in Bangladesh. *Livestock Research for Rural Development*, *22*(10), 73–81.

Idowu, P. A., Mpayipheli, M., & Muchenje, V. (2018). Practices, housing and diseases within indigenous poultry production in Eastern Cape, South Africa. *Journal of Agricultural Science*, *10*(11), 111–122.

Idowu, P. A., Mpayipheli, M., & Muchenje, V. (2019). A Survey Study on Productive and Reproductive Performance of Indigenous Poultry. *American Journal of Animal and Veterinary Services*.

IPCC. (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability* (Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report, p. 22) [Summary for Policymakers]. Intergovernmental Panel on Climate Change.

Islam, M. A. (2006). Comparative egg production and egg quality of indigenous full feathered and naked neck chicken at hot-humid climate. *Bangladesh Journal of Animal Science*, *35*, 99–105.

Islam, M. A., & Nishibori, M. (2009). Indigenous naked neck chicken: A valuable genetic resource for Bangladesh. *World's Poultry Science Journal*, *65*(1), 125–138. https://doi.org/10.1017/S0043933909000105

Islam, M. S., Howlider, M. A. R., Kabir, F., & Alam, J. (2002). Comparative Assessment of Fertility and Hatchability of Barred Plymouth Rock, White Leghorn, Rhode Island Red and White Rock Hen. *International Journal of Poultry Science*, *1*(4), 85–90. https://doi.org/10.3923/ijps.2002.85.90

Iyasere, O. S., Ajayi, O. D., Alade, S. O., & Akinbode, V. O. (2019). Behaviour, physiology and body mass of Nigerian indigenous hens during brooding. *Agricultura Tropica et Subtropica*, *52*(2), 43–47.

Jacob, J. P., Miles, R. D., & Mather, F. B. (2000). Egg quality. *Cooperative Extension Service, Institute of Food and Agricultural Sciences (IFAS), University of Florida PS*, *24*.

Jacob, J., & Pescatore, T. (2012). *How much will my chickens eat?* Cooperative Extension Service, University of Kentucky College of Agriculture, Food and Environment. http://www2.ca.uky.edu/agcomm/pubs/ASC/ASC191/ASC191.pdf

Jaturasitha, S., Srikanchai, T., Kreuzer, M., & Wicke, M. (2008). Differences in Carcass and Meat Characteristics Between Chicken Indigenous to Northern Thailand (Black-Boned and Thai Native) and Imported Extensive Breeds (Bresse and Rhode Island Red). *Poultry Science*, *87*(1), 160–169. https://doi.org/10.3382/ps.2006-00398

Jiang, R. S., Xu, G. Y., Wang, X. L., & Yang, N. (2005). Broody traits of Dongxiang Blue-shell chickens under floor system. *China Poult.*, *27*(2005), 17–18.

Kanyama-Chikoti, J. C., Chikagwa-Malunga, S. K., & Jere, J. A. (2016). Brooding capacity of indigenous chicken. *Procedings of the 1st World Congress on Innovation for Livestock Development 26th -to-30th June 2016*.

Keambou, T. C., Manjeli, Y., Boukila, B., Mboumba, S., Mezui, T. M., & Touko, B. A. H. (2010). Heterosis and reciprocal effects of growth performances in F1 crosses generations of Local x Hubbard chicken in the Western Highlands of Cameroon. *Livestock Research for Rural Development*, *22*(1), 9.

Kgwatalala, M., Bolowe, A. M., & Pene, T. (2013). Laying performance and egg traits of indigenous Tswana chickens under traditional management. *Global Advanced Research Journal of Agricultural Science (GARJAS)*, *2*(6), 148–152.

King'ori, A. M. (2011). Review of the factors that influence egg fertility and hatchability in poultry. *International Journal of Poultry Science*, *10*(6), 483–492.

Kingori, A. M., Tuitoek, J. K., Muiruri, H. K., Wachira, A. M., & Birech, E. K. (2007). Protein intake of growing indigenous chickens on free-range and their response to supplementation. *International Journal of Poultry Science*, *6*(9), 617–621.

Kingori, A. M., Wachira, A. M., & Tuitoek, J. K. (2010). Indigenous chicken production in Kenya: A review. *International Journal of Poultry Science*, *9*(4), 309–316.

Kirunda, H., Muwereza, N., Kasaija, D. P., Kerfua, D. S., & Jumanyol, K. (2010). Infectious and non-infectious factors affecting hatchability in indigenous chickens in Eastern Uganda. *Africa Journal of Animal and Biomedical Sciences*, *5*(3), 51–59.

Klasing, K. C. (2007). Nutrition and the immune system. *British Poultry Science*, *48*(5), 525–537. https://doi.org/10.1080/00071660701671336

KNBS. (2009). *The 2009 Kenya Population and Housing Census: Population Distribution by Age, Sex and Administrative Units: Vol. IC*. Kenya National Bureau of Statistics. Retrieved on 19th October, 2020 from https://s3-eu-west-1.amazonaws.com/s3.sourceafrica.net/documents/21195/Census-2009.pdf

KNBS. (2019). *2019 Kenya Population and Housing Census Volume II: Distribution of Population by Administrative Units* (Vol. 2). Kenya National Bureau of Statistics. https://isaackalua.co.ke/posts/docs/Merge_Volume_II_-_17-12-2019.pdf

Kondombo, S. R. (2005). *Improvement of village chicken production in a mixed (chicken-ram) farming system in Burkina Faso* [PhD Thesis, Wageningen University]. Retrieved on 19th October, 2020 from https://library.wur.nl/WebQuery/wurpubs/fulltext/121722

Kumar, A., Sexana, A., Mir, I. A., Misger, F. A., & Ahad, I. (2013). Technology adoption studies on different extension methods for enhancing fruit production in District Pulwama of Jammu and Kashmir. *African Journal of Agricultural Research*, *8*(38), 4882–4886.

Kusina, J., Kusina, N. T., & Mhlanga, J. (2001). A survey on village chicken losses: Causes and solutions as perceived by farmers. In R. G. Alders & P. B. Spradbrow (Eds.), *Proceedings No. 113 on SADC Planning Workshop on Newcastle disease control in village chickens* (pp. 148–155). ACIAR.

Kyarisiima, C. C., Kugonza, D. R., & Magala, H. (2009). *Analysis of production and the marketing chain of local chickens in central Uganda.* (p. 50) [Final research project report.]. Network of Ugandan Researchers and Research Users (NURRU).

Lañada, E. B., Rola-Rubzen, M. F., Edgar, Y., Morbos, C. P., Espinosa, E. A., & Pym, R. A. (2004). A longitudinal analysis of chicken production systems of smallholder farmers in Leyte, Philippines. *XXII World's Poultry Congress Book of Abstracts*, 900.

Leksrisompong, N., Romero-Sanchez, H., Plumstead, P. W., Brannan, K. E., & Brake, J. (2007). Broiler incubation. 1. Effect of elevated temperature during late incubation on body weight and organs of chicks. *Poultry Science*, *86*(12), 2685–2691.

Lemba, J., D'Haese, M., D'Haese, L., Frija, A., & Speelman, S. (2012). Comparing the technical efficiency of farms benefiting from different agricultural interventions in Kenya's drylands. *Development Southern Africa*, *29*(2), 287–301.

Levic, J., Djuragic, O., & Sredanovic, S. (2010). Use of new feed from brewery by-products for breeding layers. *Romanian Biotechnological Letters*, *15*(5), 5559–5565.

Liu, L., & Ngadi, M. O. (2013). Detecting fertility and early embryo development of chicken eggs using near-infrared hyperspectral imaging. *Food and Bioprocess Technology*, *6*(9), 2503–2513.

Longwe-Ngwira, A., Simtowe, F., & Siambi, M. (2012). Assessing the Competitiveness of Groundnut Production in Malawi: A Policy Analysis Matrix Approach. *AgEcon*, Article 1007-2016–79437. https://doi.org/10.22004/ag.econ.126429

Lorenz, C., Kany, T., & Grashorn, M. (2013). Method to estimate feed intake from pasture in broilers and laying hens. *Archiv Für Geflügelkunde*, *77*(3), 160–165.

Lourens, A. (2001). The importance of air meteorology in animal production. *International Journal of Biometeorology*, *1*, 139–156.

Lourens, A., Van den Brand, H., Heetkamp, M. J. W., Meijerhof, R., & Kemp, B. (2007). Effects of eggshell temperature and oxygen concentration on embryo growth and metabolism during incubation. *Poultry Science*, *86*(10), 2194–2199.

Lwelamira, J., Binamungu, H. K., & Njau, F. B. (2010). Contribution of small scale dairy farming under zero-grazing in improving household welfare in Kayanga ward, Karagwe District, Tanzania. *Livestock Research for Rural Development*, *22*(2), 30–39.

Lwelamira, James, Kifaro, G., & Gwakisa, P. (2008). Breeding strategies for improving performance of Kuchi chicken ecotype of Tanzania for production under village conditions. *Livestock Research for Rural Development*, *20*(11).

Lwesya, H., Phoya, R. K. D., Safalaoh, A. C. L., & Gondwe, T. N. P. (2004). Rearing chicks in enclosures under village conditions: Effect on chick growth and reproductive performance of mother hens. *Livestock Research for Rural Development*, *16*(11).

Machek, O., & Špička, J. (2014). Productivity and Profitability of the Czech Agricultural Sector After the Economic Crisis. *WSEAS Transactions on Business and Economics*, *11*, 700–706. Retrieved on 19th October, 2020 from http://www.wseas.us/journal/pdf/economics/2014/a265707-083.pdf

Magothe, T. M., Okeno, T. O., Muhuyi, W. B., & Kahi, A. K. (2012). Indigenous chicken production in Kenya: II. Prospects for research and development. *World's Poultry Science Journal*, *68*(1), 133–144.

Magothe, Thomas M., Muhuyi, W. B., & Kahi, A. K. (2010). Influence of major genes for crested-head, frizzle-feather and naked-neck on body weights and growth patterns of indigenous chickens reared intensively in Kenya. *Tropical Animal Health and Production*, *42*(2), 173–183.

Mahmud, A., & Pasha, T. N. (2008). Effect of storage, pre-heating and turning during holding period on the hatchability of broiler breeder eggs. *Pakistan Veterinary Journal*, *28*(3).

Mahrous, M., Galal, A. A., Fathi, M. M., & Ali, Z. E.-D. (2008). Impact of Naked Neck (Na) and Frizzle (F) Genes on Growth Performance and Immunocompetence in Chickens. *International Journal of Poultry Science*, *7*. https://doi.org/10.3923/ijps.2008.45.54

Maina, J. M., Chemwetich, J., & Eunice, J. K. (2015). *Poultry keeping and management: A flexible learning course*. Commonwealth of Learning (COL).

Mapiye, C., Mwale, M., Mupangwa, J. F., Chimonyo, M., Foti, R., & Mutenje, M. J. (2008). A research review of village chicken production constraints and opportunities in Zimbabwe. *Asian-Australasian Journal of Animal Sciences*, *21*(11), 1680–1688.

Masaire, E., Madzingira, O., Samkange, A., Kandiwa, E., Mushonga, B., & Bishi, A. S. (2018). *Characterization of poultry production and management systems in the communal areas of Namibia*.

Mashaly, M. M., Hendricks, G. L., Kalama, M. A., Gehad, A. E., Abbas, A. O., & Patterson, P. H. (2004). Effect of Heat Stress on Production Parameters and Immune Responses of Commercial Laying Hens1. *Poultry Science*, *83*(6), 889–894. https://doi.org/10.1093/ps/83.6.889

Mathur, P. K. (2003). Genotype-Environment Interactions: Problems Associated with Selection for Increased Production. In W. M. Muir & S. E. Aggrey (Eds.), *Poultry Genetics, Breeding, and Biotechnology*. CABI.

Maysa, M. H., El-Sheikh, A. M. H., & Abdalla, E. A. (2009). The effect of organic selenium supplementation on productive and physiological performance in a local strain of chicken. 1—The effect of organic selenium (Sel-PlexTM) on productive, reproductive and physiological traits of Bandarah local strain. *Egyptian Poultry Science Journal*, *29*(4), 1061–1084.

Meijerhof, R. (2009). Incubation principles: What does the embryo expect from us. *Proceedings of the 20th Australian Poultry Science Symposium*, 106–110.

Melesse, A. (2014). Significance of scavenging chicken production in the rural community of Africa for enhanced food security. *World's Poultry Science Journal*, *70*(3), 593–606.

Mench, J. A. (2009). Behaviour of fowl and other domesticated birds. In P. Jensen (Ed.), *The Ethology of Domestic Animals: An Introductory Text* (2nd ed.). CABI.

Mengesha, M. (2011). Climate Change and the Preference of Rearing Poultry for the. *Asian Journal of Poultry Science*, *5*(4), 135–143.

Moges, F., Mellesse, A., & Dessie, T. (2010). Assessment of village chicken production system and evaluation of the productive and reproductive performance of local chicken ecotype in Bure district, North West Ethiopia. *African Journal of Agricultural Research*, *5*(13), 1739–1748.

Moiseyeva, I. G., Romanov, M. N., Nikiforov, A. A., Sevastyanova, A. A., & Semyenova, S. K. (2003). Evolutionary relationships of Red Jungle Fowl and chicken breeds. *Genetics Selection Evolution*, *35*(4), 403–423. https://doi.org/10.1051/gse:2003031

Molapo, S. M., & Kompi, P. (2015). The Effect of Cock: Hen Ratio on Reproduction Performance of Koekoek Chickens in the Lowlands of Lesotho. *Theriogenology Insight - An International Journal of Reproduction in All Animals*, *5*(2), 139. https://doi.org/10.5958/2277-3371.2015.00015.7

Molenaar, R., Reijrink, I. A. M., Meijerhof, R., & Van den Brand, H. (2010). Meeting embryonic requirements of broilers throughout incubation: A review. *Brazilian Journal of Poultry Science*, *12*(3), 137–148.

Monira, K. N., Salahuddin, M., & Miah, G. (2003). Effect of Breed and Holding Period on Egg Quality Characteristics of Chicken. *International Journal of Poultry Science*, *2*(4), 261–263.

Moore, G. (2013). *Poultry Incubation Hatching for Success*. Carolina Heritage Farms. https://livestockconservancy.org/images/uploads/docs/PoultryIncubation.pdf

Moreki, J. C., Poroga, B., Dikeme, R., & Seabo, D. (2010). Ethnoveterinary medicine and health management in poultry in Southern and Western Districts, Botswana. *Age*, *15*(60), 26.

Mtileni, B. J., Muchadeyi, F. C., Maiwashe, A., Phitsane, P. M., Halimani, T. E., Chimonyo, M., & Dzama, K. (2009). Characterisation of production systems for indigenous chicken genetic resources of South Africa. *Applied Animal Husbandry & Rural Development*, *2*(1), 18–22.

Mwacharo, J. M., Bjørnstad, G., Han, J. L., & Hanotte, O. (2013). The History of African Village Chickens: An Archaeological and Molecular Perspective. *African*

Archaeological Review, *30*(1), 97–114. https://doi.org/10.1007/s10437-013-9128-1

Mwacharo, J. M., Nomura, K., Hanada, H., Jianlin, H., Hanotte, O., & Amano, T. (2007). Genetic relationships among Kenyan and other East African indigenous chickens. *Animal Genetics*, *38*(5), 485–490. https://doi.org/10.1111/j.1365-2052.2007.01641.x

Mwacharo, Joram M., Bjørnstad, G., Han, J. L., & Hanotte, O. (2013). The history of African village chickens: An archaeological and molecular perspective. *African Archaeological Review*, *30*(1), 97–114.

Ncobela, C. N., & Chimonyo, M. (2016). Nutritional quality and amino acid composition of diets consumed by scavenging hens and cocks across seasons. *Tropical Animal Health and Production*, *48*(4), 769–777.

Ndegwa, J. M. (2013). *Improving Indigenous Chicken Production In Kenya-a Livelihood Strategy: Improving Indigenous Chicken Production In Kenya*. LAP Lambert Academic Publishing.

N'dri, A. L., Mignon-Grasteau, S., Sellier, N., Beaumont, C., & Tixier-Boichard, M. (2007). Interactions between the naked neck gene, sex, and fluctuating ambient temperature on heat tolerance, growth, body composition, meat quality, and sensory analysis of slow growing meat-type broilers. *Livestock Science*, *110*(1), 33–45. https://doi.org/10.1016/j.livsci.2006.09.025

N'dri, Aya Lydie, Sellier, N., Tixier-Boichard, M., Beaumont, C., & Mignon-Grasteau, S. (2007). Genotype by environment interactions in relation to growth traits in slow growing chickens. *Genetics Selection Evolution*, *39*(5), 1–16.

Ng, C. S., Wu, P., Foley, J., Foley, A., McDonald, M.-L., Juan, W.-T., Huang, C.-J., Lai, Y.-T., Lo, W.-S., Chen, C.-F., Leal, S. M., Zhang, H., Widelitz, R. B., Patel, P. I., Li, W.-H., & Chuong, C.-M. (2012). The Chicken Frizzle Feather Is Due to an α-Keratin (KRT75) Mutation That Causes a Defective Rachis. *PLOS Genetics*, *8*(7), e1002748. https://doi.org/10.1371/journal.pgen.1002748

Ngeno, K., Kahi, A., & Bebe, B. (2012). *Indigenous Chicken Ecotypes in Kenya: Genetic Analysis of Growth Patterns of Different Ecotypes of Indigenous Chicken in Kenya*. LAP LAMBERT Academic Publishing.

Ngeno, K., Waaij, E. H. V., & Kahi, A. K. (2014). Indigenous chicken genetic resources in Kenya: Their unique attributes and conservation options for improved use. *World's Poultry Science Journal*, *70*(1), 173–184. https://doi.org/10.1017/S0043933914000154

Nicol, C. (2006). How animals learn from each other. *Applied Animal Behaviour Science*, *100*(1–2), 58–63.

Njenga, S. K. (2005). *Network for Smallholder Poultry Development, The Royal Veterinary And Agricultural* [Master's Thesis, The Royal Veterinary And Agricultural University, Dyrlaegevej]. Retrieved on 19th October, 2020 from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.506.5263&rep=rep1&type=pdf

Njuguna, J. N., Gicheru, M. M., Kamau, L. M., & Mbatha, P. M. (2017). Incidence and knowledge of bovine brucellosis in Kahuro district, Murang'a County, Kenya. *Tropical Animal Health and Production*, *49*(5), 1035–1040. https://doi.org/10.1007/s11250-017-1296-6

Nonga, H. E., Kajuna, F. F., Ngowi, H. A., & Karimuribo, E. D. (2010). Physical egg quality characteristics of free-range local chickens in Morogoro municipality, Tanzania. *Livestock Research for Rural Development*, *22*(12). Retrieved on 19th October, 2020 from http://lrrd.cipav.org.co/lrrd22/12/nong22218.htm

Nord, A., & Williams, J. B. (2015). The energetic cost of incubation. In D. C. Deeming & S. J. Reynolds (Eds.), *Nests, eggs, and incubation: New ideas about avian reproduction* (pp. 152–170). Oxford University Press.

Nyaga, P. (2007). The structure, marketing and importance of the commercial and village poultry industry: An analysis of the poultry sector in Kenya. *Rome, Food and Agriculture Organization (FAO) of the United Nations*.

Obasi, P. C., Henri-Ukoha, A., Ukewuihe, I. S., & Chidiebere-Mark, N. M. (2013). Factors Affecting Agricultural Productivity among Arable Crop Farmers in Imo State, Nigeria. *Journal of Experimental Agriculture International*, *3*(2), 443–454. https://doi.org/10.9734/AJEA/2013/2030

Ochieng, J., Owuor, G., & Bebe, B. O. (2013). Management practices and challenges in smallholder indigenous chicken production in Western Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *114*(1), 51–58.

OECD. (2011). *Fostering Productivity and Competitiveness in Agriculture*. Organisation for Economic Co-operation and Development. Retrieved on 19th October, 2020 from https://www.oecd.org/publications/fostering-productivity-and-competitiveness-in-agriculture-9789264166820-en.htm

Ojango, J. M. K., & Pollott, G. E. (2002). The relationship between Holstein bull breeding values for milk yield derived in both the UK and Kenya. *Livestock Production Science*, *74*(1), 1–12.

Okello, J. J., Gitonga, Z., Mutune, J., Okello, R. M., Afande, M., & Rich, K. M. (2010). *Value chain analysis of the Kenyan poultry industry: The case of Kiambu, Kilifi, Vihiga, and Nakuru Districts*.

Okeno, T. O., Kahi, A. K., & Peters, J. K. (2010). Characterization of indigenous chicken production systems in Kenya: Household flock structure, dynamics and breeding practices. *Biennial Conference Paper*, 877–884.

Okeno, Tobias O., Kahi, A. K., & Peters, K. J. (2011). Breed selection practices and traits of economic importance for indigenous chicken in Kenya. *Growth*, *2*(3.01), 1–44.

Okeno, Tobias O., Kahi, A. K., & Peters, K. J. (2012). Characterization of indigenous chicken production systems in Kenya. *Tropical Animal Health and Production*, *44*(3), 601–608.

Okoh, E., Sathyamoorthy, S., Olaniyan, E., & Ezeokeke, O. (2010). Application of Integrated Production System Modelling in Effective Well and Reservoir Management of the Bonga Field. *Nigeria Annual International Conference and Exhibition*. Nigeria Annual International Conference and Exhibition, Tinapa - Calabar, Nigeria. https://doi.org/10.2118/140632-MS

Okonkwo, W. I., & Akubuo, C. O. (2007). Trombe wall system for poultry brooding. *International Journal of Poultry Science*, *6*(2), 125–130.

Olwande, J., Smale, M., Mathenge, M. K., Place, F., & Mithöfer, D. (2015). Agricultural marketing by smallholders in Kenya: A comparison of maize, kale and dairy. *Food Policy*, *52*, 22–32. https://doi.org/10.1016/j.foodpol.2015.02.002

Olwande, P. O., Ogara, W. O., Okuthe, S. O., Muchemi, G., Okoth, E., Odindo, M. O., & Adhiambo, R. F. (2010). Assessing the productivity of indigenous chickens in an extensive management system in southern Nyanza, Kenya. *Tropical Animal Health and Production*, *42*(2), 283–288.

Onagbesan, O., Bruggeman, V., Smit, L. D., Debonne, M., Witters, A., Tona, K., Everaert, N., & Decuypere, E. (2007). Gas exchange during storage and incubation of Avian eggs: Effects on embryogenesis, hatchability, chick quality and post-hatch growth. *World's Poultry Science Journal*, *63*(4), 557–573. https://doi.org/10.1017/S0043933907001614

Ondwasy, H., Wesonga, H., & Okitoi, L. (2006). *Indigenous chicken production manual* (KARI Technical Note No. 18; Technical Note Series). Kenya Agricultural Research Institute. https://betuco.be/dieren/Indigenius%20chicken%20production%20kenya.pdf

Pedersen, C. V. (2002). *Production of semi-scavenging chickens in Zimbabwe* [PhD Thesis]. Royal Veterinary and Agricultural University, Department of Animal Science and Animal Health, Division of Tropical Animal Husbandry.

Pereira, L. (2017). Climate Change Impacts on Agriculture across Africa. In *Oxford Research Encyclopedia of Environmental Science*. Oxford University Press. https://openaccess.city.ac.uk/id/eprint/21175/12/

Petrosyan, A., Papazyan, T., & Nollet, L. (2006). Administration of Se as Sel-Plex on top of sodiumselenite still improves fertility of hatchability of a broiler breeder flock. *EPC 2006-12th European Poultry Conference, Verona, Italy, 10-14 September, 2006*.

Preez, J. H. (2007). *The effect of different incubation temperatures on chick quality. Master of philosophy in livestock industry management* [Master of Philosphy, University of Stellenbosch]. https://core.ac.uk/download/pdf/37318899.pdf

Pym, R. A., & Alders, R. G. (2012). Introduction to village and backyard poultry production. In V. Sandilands & P. M. Hocking (Eds.), *Alternative Systems for Poultry: Health, Welfare and Productivity* (Vol. 30, pp. 97–109). CAB International.

Raphulu, T., Van Rensburg, C. J., & Van Ryssen, J. B. J. (2015). Assessing nutrient adequacy from the crop contents of free-ranging indigenous chickens in rural villages of the Venda region of South Africa. *South African Journal of Animal Science*, *45*(2), 143–152.

Reardon, T., Barrett, C. B., Berdegué, J. A., & Swinnen, J. F. (2009). Agrifood industry transformation and small farmers in developing countries. *World Development*, *37*(11), 1717–1727.

Reijrink, I. A. M. (2010). *Storage of hatching eggs – Effects of storage and early incubation conditions on egg characteristics, embryonic development, hatchability, and chick quality* [Ph.D Thesis, Wageningen University]. Retrieved on 19th October, 2020 from https://library.wur.nl/WebQuery/wurpubs/fulltext/139676

Rewe, T. (2004). *Development of breeding objectives for production systems utilising the Boran Breed in Kenya* [PhD Thesis]. Egerton University Nakuru Kenya.

Riise, J. C., Kryger, K. N., Seeberg, D. S., & Christensen, P. F. (2005). Impact of smallholder poultry production in Bangladesh–12 years experience with Danida supported livestock projects in Bangladesh. *Danida, Ministry of Foreign Affairs,* *Copenhagen, Denmark*. Retrieved on 19th October, 2020 from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.553.5501&rep=rep1&type=pdf

Rolls, E. T. (2005). *Emotion Explained.* Oxford University Press. http://dx.doi.org/10.1093/acprof:oso/9780198570035.001.0001

Rolls, E. T. (2014). *Emotion and decision-making explained.* Oxford University Press.

Romanov, M. N., Talbot, R. T., Wilson, P. W., & Sharp, P. J. (2002). Genetic control of incubation behavior in the domestic hen. *Poultry Science, 81*(7), 928–931.

Roothaert, R. L., Ssalongo, S., & Fulgensio, J. (2011). The Rakai chicken model: An approach that has improved fortunes for Ugandan farmers. *International Journal of Agricultural Sustainability*, *9*(1), 222–231.

Roovert-Reijrink, V. (2018). *The influence of incubation conditions on chick quality*.

Rota, A., Thieme, O., De' Besi, G., & Gilchrist, P. (2014). Designing successful projects. In FAO, IFAD, & KF (Eds.), *Decision tools for family poultry development* (p. 106). Food and Agriculture Organization of the United Nations (FAO); International Fund for Agricultural Development (IFAD); Kyeema Foundation (KF). Retrieved on 29th March, 2020 from http://www.fao.org/3/a-i3542e.pdf

Safalaoh, A. C. L. (2001). Village chicken upgrading programme in Malawi. *World's Poultry Science Journal*, *57*(2), 179–188.

Santos, Z. A. de S., Freitas, R. T. F. de, Fialho, E. T., Rodrigues, P. B., Lima, J. A. de F., Carellos, D. de C., Branco, P. A. C., & Cantarelli, V. de S. (2005). Nutritional value of feedstuffs for pigs determined at the University of Lavras. *Ciência e Agrotecnologia*, *29*(1), 232–237. https://doi.org/10.1590/S1413-70542005000100029

Sapp, R. L., Rekaya, R., Misztal, I., & Wing, T. (2004). Male and female fertility and hatchability in chickens: A longitudinal mixed model approach. *Poultry Science*, *83*(8), 1253–1259. https://doi.org/10.1093/ps/83.8.1253

Schou, T., Permin, A., Juul-Madsen, H., Sørensen, P., Labouriau, R., Nguyên, T., Fink, M., & Pham, S. (2007). Gastrointestinal helminths in indigenous and exotic chickens in Vietnam: Association of the intensity of infection with the Major Histocompatibility Complex. *Parasitology*, *134*, 561–573. https://doi.org/10.1017/S0031182006002046

Sears, A., Baker, M. G., Wilson, N., Marshall, J., Muellner, P., Campbell, D. M., Lake, R. J., & French, N. P. (2011). Marked campylobacteriosis decline after interventions aimed at poultry, New Zealand. *Emerging Infectious Diseases*, *17*(6), 1007.

Seo, S. N., & Mendelsohn, R. (2008). Animal husbandry in Africa: Climate change impacts and adaptations. *African Journal of Agricultural and Resource Economics*, *2*(1), 65–82. https://doi.org/10.22004/ag.econ.56968

Slenning, B. D. (2010). One health and climate change: Linking environmental and animal health to human health. *North Carolina Medical Journal*, *71*(5), 434–437.

Smith, C. L., & Evans, C. S. (2008). Multimodal signaling in fowl, Gallus gallus. *Journal of Experimental Biology*, *211*(13), 2052–2057.

Smith, C. L., & Evans, C. S. (2009). Silent tidbitting in male fowl, Gallus gallus: A referential visual signal with multiple functions. *Journal of Experimental Biology*, *212*(6), 835–842.

Smith, T. W. (2000). Care and incubation of hatching eggs. *Mississippi State University*. https://www.thepoultrysite.com/articles/care-and-incubation-of-hatching-eggs

Sockman, K. W., Sharp, P. J., & Schwabl, H. (2006). Orchestration of avian reproductive effort: An integration of the ultimate and proximate bases for flexibility in clutch size, incubation behaviour, and yolk androgen deposition. *Biological Reviews*, *81*(4), 629–666. https://doi.org/10.1017/S1464793106007147

Sørensen, P. (2010). *Chicken genetic resources used in smallholder production systems and opportunities for their development* (Paper No. 5; Smallholder Poultry Production). Food and Agriculture Organization of the United Nations. Retrieved on 19th October, 2020 from http://www.fao.org/3/al675e/al675e00.pdf

Ssalongo, S. B. (2003). Integrated Programmed Hatching of Day Old Chicks on One Particular Day of the Week in Rakai District. *Working Document, INCORET, Kampala*.

Ssewannyana, E., Ssali, A., Kasadha, T., Dhikusooka, M., Kasoma, P., Kalema, J., Kwatotyo, B. A., & Aziku, L. (2008). On-farm characterization of indigenous chickens in Uganda. *J. Anim. Plant Sci*, *1*(2), 33–37.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., & de Haan, C. (2006). *Livestock's long shadow*. FAO of the UN. Retrieved on 20th February, 2020 from http://www.fao.org/3/a0701e/a0701e00.htm

Sumy, M. C., Khokon, M. S. I., Islam, M. M., & Talukder, S. (2010). Study on the socio-economic condition and productive performances of backyard chicken in some selected areas of Pabna district. *Journal of the Bangladesh Agricultural University, 8*(1), 45–50.

Suthar, M., Mughal, S. A. K., & Azam, M. (2012). The influence of female:male ratio of Fayoumi layers on fertility, hatchability of eggs and chicks livability. *Revista Científica UDO Agrícola, 12*(3), 644–648.

Szyszka, O., & Kyriazakis, I. (2013). What is the relationship between level of infection and ‘sickness behaviour’ in cattle? *Applied Animal Behaviour Science*, *147*(1), 1–10. https://doi.org/10.1016/j.applanim.2013.05.007

Thiele, G., Devaux, A., Velasco, C., & Horton, D. (2007). Horizontal evaluation: Fostering knowledge sharing and program improvement within a network. *American Journal of Evaluation*, *28*(4), 493–508.

Thieme, O., Sonaiya, F., Rota, A., Guèye, F., Dolberg, F., & Alders, R. (2014). Defining family poultry production systems and their contribution to livelihoods. *Decision Tools for Family Poultry Development. FAO Animal Production and Health Guidelines*, *16*, 3–8.

Thomann, A., Devaux, A., Ordinola, M., Cuentas, M., Urday, P., Sevilla, M., & Andrade-Piedra, J. (2011). Native potato market chain and poverty reduction: Innovation around corporate social responsibility. In A. Devaux, M. Ordinola, & D. Horton (Eds.), *Innovation for Development: The Papa Andina Experience* (pp. 263–275). International Potato Center.

Thornton, P., Herrero, M., Freeman, A., Mwai, O., Rege, E., Jones, P., & McDermott, J. (2007). Vulnerability, Climate change and Livestock – Research Opportunities and Challenges for Poverty Alleviation. *ICRISAT*, *4*(1), 1–23.

Tona, K., Onagbesan, O., Bruggeman, V., De Smit, L., Figueiredo, D., & Decuypere, E. (2007). Non-ventilation during early incubation in combination with dexamethasone administration during late incubation: 1. Effects on physiological hormone levels, incubation duration and hatching events. *Domestic Animal Endocrinology*, *33*(1), 32–46.

Tona, Kokou, Onagbesan, O., Bruggeman, V., Mertens, K., & Decuypere, E. (2005). Effects of turning duration during incubation on embryo growth, utilization of albumen, and stress regulation. *Poultry Science*, *84*(2), 315–320.

Tona, Kokou, Onagbesan, O., De Ketelaere, B., Decuypere, E., & Bruggeman, V. (2003). Effects of turning duration during incubation on corticosterone and thyroid hormone levels, gas pressures in air cell, chick quality, and juvenile growth. *Poultry Science, 82*(12), 1974–1979.

Turblin, V. (2008). Disinfection of hatching eggs importance and practical aspects. *Hatchery Expertise Online. Ceva Animal Health Asia Pasific. Ceva. Asiapasific@ Ceva. Com. Diunduh Juli*, *21*, 2017. Retrieved on 28th January, 2020 from https://silo.tips/download/d-i-s-i-n-f-e-c-t-i-o-n-o-f-h-a-t-c-h-i-n-g-e-g-g-s

Turk, J. M. (2013). Poverty, livestock and food security in developing countries. *CAB Reviews*, *8*(033), 1–8.

Umaya, R. S. (2014). The uniqueness of immunocompetence and meat quality of native chickens: A specialized review. *World Journal of Pharmacy and Pharmaceutical Sciences*, *3*, 2576-2588.

USAID. (2010). *Partnership for Safe Poultry in Kenya (PSPK) Program—Value Chain Analysis of Poultry in Uganda*. The United States Agency for International Development (USAID). Retrieved on 28th January, 2020 from http://www.fao.org/sustainable-food-value-chains/library/details/en/c/270862/

USDA. (2013). *Climate Change and Agriculture in the United States: Effects and Adaptation*. USDA Technical Bulletin 1935. Retrieved on 28th January, 2020 from https://www.usda.gov/sites/default/files/documents/CC%20and%20Agriculture%20Report%20(02-04-2013)b.pdf

Van der Pol, C. W., Van Roovert-Reijrink, I. A. M., Maatjens, C. M., Van den Brand, H., & Molenaar, R. (2013). Effect of relative humidity during incubation at a set eggshell temperature and brooding temperature posthatch on embryonic mortality and chick quality. *Poultry Science*, *92*(8), 2145–2155.

Wachira, M. A., Mail, S. K., Munyasi, J. W., Nzioka, M., Mwangi, D. M., Kaguthi, P., & Kithome, J. (2010). Uptake of improved technologies through dissemination by indigenous chicken service providers in Southern Rangeland of Kenya. *Proceedings at the 12 Th KARI Biannual Scientific Conference in November*, 1376–1382.

Wang, Q., Ma, M., Zhu, Z., Zhu, T., & Li, M. (2012). Non-destructive detection of hatching egg's survival based on machine vision. *Journal of Food, Agriculture & Environment*, *10*(1 part 1), 578–581.

Weyuma, H., Singh, H., & Megersa, M. (2015). Studies on management practices and constraints of back yard chicken production in selected rural areas of Bishoftu. *British Journal of Poultry Sciences*, *4*(1), 01–11.

Wineland, M., & Carmen, C. (2007). *Spray sanitizing hatching eggs*. North Carolina State University. http;//www.ces.ncsu.edu/depts/poulsci/

Wollie, G., Zemedu, L., & Tegegn, B. (2018). Economic efficiency of smallholder farmers in barley production in Meket district, Ethiopia. *Journal of Development and Agricultural Economics*, *10*(10), 328–338. https://doi.org/10.5897/JDAE2018.0960

WSPA. (2012). *Livestock production and climate change*. World Society for the Protection of Animals. https://unfccc.int/resource/docs/2012/smsn/ngo/194.pdf

XiuLian, M., & ShuJuan, Y. (2011). Unfertilized eggs verification system before hatching based on embedded system and machine vision. *Nongye Jixie Xuebao = Transactions of the Chinese Society for Agricultural Machinery*, *42*(5), 187–192.

Yemane, N., Tamir, B., & Belihu, K. (2013). Characterization of village chicken production performance under scavenging system in Halaba district of southern Ethiopia. *Ethiopian Veterinary Journal*, *17*(1), 68–80.

Yoshizaki, N., & Saito, H. (2002). Changes in shell membranes during the development of quail embryos. *Poultry Science*, *81*(2), 246–251.

Yusuf, S. F. G., Lategan, F. S., & Masika, P. J. (2014). Characterization of indigenous poultry production systems in the Nkonkobe Municipality, Eastern Cape Province South Africa. *Journal of Agricultural Sciences*, *5*(1–2), 31–44.

Zhang, W., Pan, L., Tu, K., Zhang, Q., & Liu, M. (2014). Comparison of spectral and image morphological analysis for egg early hatching property detection based on hyperspectral imaging. *PLoS One*, *9*(2), e88659.