COMPARATIVE STUDY OF PRODUCTION AND REPRODUCTIVE PERFORMANCE OF PARENT STOCK AND COMMERCIAL LAYER CHICKENS UNDER DIFFERENT MANAGEMENT CONDITIONS IN ETHIOPIA

PhD Dissertation

By

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PhD Program in Animal Production

May, 2019

Bishoftu, Ethiopia

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A dissertation submitted to the College of Veterinary Medicine and Agriculture of Addis Ababa University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Animal Production.

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As members of the Examining Board of the final PhD open defence, we certify that we have read and evaluated the Dissertation prepared by Dawud Ibrahim titled: comparative study of production and reproductive performance of parent stock and commercial layer chickens under different management conditions in Ethiopia, and recommend that it be accepted as fulfilling the dissertation requirement for the degree of Doctor of Philosophy in Animal Production.

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DEDICATION

I dedicated this PhD dissertation work to my wife Tuba Ahmed and my sons Nasih Dawud and Faruq Dawud for their love, patience, understanding and support throughout my study.

STATEMENT OF AUTHOR

First, I declare that this dissertation is my bonafide work and that all sources of materials used for this dissertation have been duly acknowledged. This dissertation has been submitted in partial fulfillment of the requirements for a PhD degree at the Addis Ababa University, College of Veterinary Medicine and Agriculture and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this dissertation is not submitted to any other academic institution anywhere for the award of any academic degree, diploma or certificate.

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BIOGRAPHICAL SKETCH

The author of this PhD Dissertation was born in September 1977 in Wollo, Ethiopia. He attended his Elementary and Junior Secondary School at Kolfe elementary school in Addis Ababa. He attended his high school education at Medhanialem comprehensive secondary school in Addis Ababa. He successfully passed the Ethiopian School Leaving Certificate Examination and enrolled in Hawassa University in September 1998 where he studied Animal Production and Rangeland management and graduated in July 2001. Up on completion, he was first recruited by Gambella Agricultural Research Institute as researcher and director of livestock research process in 2002. He again joined Mekelle University in 2005 for his Master of Science degree and graduated in July 2007 in Livestock Production and Pastoral Development and then he returned to Gambella Agricultural Research Institute. In 2009, the author was recruited by the Ethiopian Institute of Agricultural Research and assigned to the Debre Zeit Agricultural Research Center where he served as researcher in National Poultry Research Program and then after few years , he assigned as coordinator of this National Poultry Research Program. He published more than 20 research publications (12 journal articles, 7 papers in conference proceedings and one technical manual). He traveled for the professional visits in a few countries of Africa, Asia & Israel, Europe and South America country like Brazil. He then joined the school of graduate studies of College of Veterinary Medicine and Agriculture of Addis Ababa University in 2016 to pursue PhD study in Animal Production. He is married and a father of two sons.

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LIST OF ABBREVIATIONS

ABWG -F/M	Average body weight gain female/male
ADFI-F/M	Average daily feed intake female/male
AFIC	Average Feed Intake Cumulative
ANOVA	Analysis of Variance
BW-F/M	Body weight of females/males
ComL	Commercial Layers
CRBD	Complete Randomized Block Design
CRD	Completely Randomized Design
CSA	Central Statistical Authority
DOC	Day old chicks
DR	Dominant-Red-Barred
DRKK	DR female × KK male
DS	Dominant Sussex D104
DSDR	DS female × DR male
EIAR	Ethiopian Institute of Agricultural Research, Ethiopia
ExpCr	Experimental Crosses
FAO	Food and Agricultural Organization
FCR	Feed Conversion Ratio
GIS	Geographic Information Systems
GIT	Gastro-intestine Tract
HU	Hawassa University
KK	Potchefstroom Koekoek
KKDS	KK female × DS male

LIST OF ABBREVIATIONS (Continued)

LB	Lohmann Brown Classic
LC	letter of credit
LD	Lohmann Dual
NB	Novo Brown
NC	Novo Color
NCD	New castle disease
PS	Parent-stock
SNNPR	Southern Nations, Nationalities, and Peoples' Region, Ethiopia
TFI	Total Feed Intake
~	Sign for approximation (about)

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COMPARATIVE STUDY OF PRODUCTION AND REPRODUCTIVE PERFORMANCE OF PARENT STOCK AND COMMERCIAL LAYER CHICKENS UNDER DIFFERENT MANAGEMENT CONDITIONS IN ETHIOPIA.

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ABSTRACT

A total of 6 parent stocks (PS) bred by European companies, and 1 local PS, females and males of 7 commercial (ComL) and 3 experimental (ExpCr) crossbreeds were evaluated under Ethiopian condition for their production and reproductive performance. The ExpCr obtained by crossing one parental line with another here in referred to as experimental Crosses were compared with progenies of parents ComL and evaluated for their (females' eggs and males' meat) production performances. The study was conducted in two locations; Debre Zeit research center and Hawassa University. The imported PS and ComL were Lohmann-Brown Classic (**LB**), Lohmann-Dual (**LD**), NOVOgen-Brown (**NB**), NOVOgen-Color (**NC**), Dominant-Sussex (**DS**), Dominant-Red-Barred (**DR**); Koekoek (**KK**) was obtained locally. The ExpCr were Dominant red Barred female × Koekoek male (**DR×KK**), Dominant Sussex female × Dominant red Barred male (**DS×DR**) and Koekoek female × Dominant Sussex male (**KK×DS**). Females and males of both the PSs and ComL and ExpCr were evaluated for feed intake, body weight, egg production, fertility and hatchability, males' relative organ weights in percent and their primal cuts and mortality. Additionally, three ExpCr, ♀**DR×**♂**KK**, ♀**DS×**♂**DR**, and ♀**KK×**♂**DS** were evaluated for fertility and hatchability. In total, 1810 females and 261 males parents were arranged in a randomized blocks design in DZARC, whereas a total of 600 females and 75 males parents at HU arranged in a completely randomized design, in females' eggs and males' meat used a total of 621 females and 516 males using a completely randomized design for on-station trials and a total of 4200 females and males using in a completely randomized design for on-farm trials. There were differences among PS in body weight (**BW**), feed intake, age of sexual maturity, egg production, fertility and hatchability in DZARC. Among females, DR and DS had the higher BW, whereas LB, NB and NC had the lower BW. Final mean BW of the meat-type males of NC and LD, were the higher (5027g and 3660g, respectively) whereas other males ranged from 2585g to 2955g. Fertility and hatchability of DR, DS and KK, where females and males have the same genetics, was improved by 6.3% in the crosses of these hens with males from different PS. The LD hens exhibited the higher overall laying rate (64.2%), and with AI, LD hatchability of set eggs (66.6%) was the higher, making it the best chick producer. There were significant ($P<0.05$) effects of PS, age and PS by age interactions at all stages of the laying phases in terms of feed intake, fertility, hatchability, body weight of females and males, and egg production at HU. Significantly highest average female body weight was recorded in DR, followed by DS and KK. Among the average male body weight of LD was significantly higher than other PS, followed by DR, KK and DS, the lower average male body weights were recorded in LB. The average egg production of LB and LD were significantly higher than the rest, followed by KK, DS and DR. DR, DS, KK and LB were higher in egg fertility and hatchability per set eggs, followed by LD. LB exhibited the potential to produce more total number of eggs (about 181.8), followed by KKDS (about 162.3), While others were intermediates; however, the lower total numbers of eggs per hen was recorded in DS and LD under on station condition. Significantly higher BW-M and % dressed was recorded in NC and making NC the best males' meat producer or meatiness, followed by NB. For an on-farm trial, the analysis was done with 50% in females' production and 76.2% in male meat production of the participant farmers due to dropped out circumstances. The NB was the best in egg production, lower in feed intake, higher in egg mass and better in FCR, followed by LB and NC, while DS was the least in egg production, body weight and with other parameters. Significantly higher body weight of males and average body weight gain were recorded DR, KK and NB, followed by NC; while LB and DS was intermediate in these on-farm trials. Thus, despite its high total feed intake (but similar to those PS of DR, DS and KK), LD was the best PS in this study (followed by DR) under floor pen management in Ethiopia. In case of their progeny, LB and KKDS performed well in egg productions, while NC was the best male meat producer or meatiness, followed by NB.

Key words: Parent stock, egg, hatchability, meat, on-station, on-farm, Ethiopia.

1. INTRODUCTION

Animal productions in general and chicken production in particular play important socio-economic roles in developing countries (Clarke, 2004; Kondombo, 2005). Family poultry contributes to good human nutrition by providing food (eggs and meat) with high quality nutrients and micronutrients. The small income and savings provided by the sale of poultry products is especially important for women, enabling them to better cope with urgent needs and reducing economic vulnerability (FAO, 2014).

As in many developing countries, chickens are widely kept in Ethiopia (Halima *et al.* 2006), with total population estimated to be about 60 million of which 90.8%, 4.4% and 4.8% were reported to be indigenous, exotic and hybrid, respectively (CSA, 2017).

Ethiopian chicken population is composed of low producing scavenging chicken. The rural poultry production system of Ethiopia is characterized by an average flock of 6 to 10 mature birds per household laying 30-60 eggs per hen per year and receiving little or no additional inputs except shelter for the night (Alemu & Tadelle, 1997) and generally characterized by poor performance of local chicken in terms of egg production, small egg size, slow growth rate, late maturity and high mortality of chicks (Solomon *et al.,* 2013). Research studies on some of the indigenous breeds have shown that their potential for egg production is very low with average annual egg production was 40 eggs under farmers' management, but under on-station conditions the level of production was increased to 120 eggs per hen per year (Tadelle *et al.,* 2013). These results are extremely low when compared with production levels of exotic breeds. Demands for higher-value and quality foods such as meat, eggs, and milk are also rising, compared with foods of plant origin, such as cereals. These changes in consumption, together with sizeable population growth, have led to large increases in the total demand for animal products in many developing countries (FAO, 2003). Many commercial strains of egg layers have been developed for meeting these demands (Okoro, 2017).

In the past two decades, there has been a shift to commercial production with an increase in small and medium-scale producers that exploit mainly urban markets. But the expansion of the commercial chickens' production in Ethiopia and similar developing countries are limited by the shortage of adequate local supply of high performing chicken stocks. Efforts are currently being made to alleviate this problem by introducing, evaluating and identifying suitable high-performing exotic breeds that can adapt to intensive and extensive management conditions in Ethiopia. Global primary (major) breeding companies tend to promote the breeds that are used under high-level management in developed countries, claiming that they are suitable for all environments (Pym, 2013). Hence, enhancing production and productivity of the chickens in developing countries by testing such stocks along with the associated technologies like husbandry, feeding and health care packages are expected to speed up poultry development activities.

Genetically high-yielding specialized breeds of chickens have been bred exclusively for meat (broilers) or table-egg (layers) production, and they require high-level inputs in terms of nutritional and health management, to fully express their genetic potential (FAO, 2014). Dual- purpose chicken breeds aim at uniting both of these production forms, i.e., hens lay eggs and males produce meat, but it may require a compromise from both sides because laying more eggs is negatively correlated with gaining more meat. Nevertheless, by applying cross-breeding, global breeding companies have attempted to achieve this balance (Lohmann, 2016). Currently, there is an intensive ethical discussion about the practice of culling day-old layer males. One solution to avoid this practice could be using dual-purpose types, where males are reared for meat and females used for egg production (Mueller *et al*., 2018). In the long run increasing the egg and meat production will alleviate animal protein shortage and reduce poverty by increasing the income of poultry farmers.

Past attempts to improve the chicken productivity in Ethiopia through the introduction of high performing commercial breeds were very limited. For years, the Debre Zeit Agricultural Research Center was evaluating only a single imported breed (layers, broilers or dual purpose) at a time, concluding that this single breed is accepted or not, based on the results observed on-station and on-farm conditions, without valid comparisons to alternative breeds. In contrast, the present study is the first one in Ethiopia to evaluate several imported and local breeds in the same trial. This study becomes unique not only in comparing several Parent-Stocks (**PSs**), Commercial Layers (**ComL**)

& Experimental Crosses (**ExpCr**) with all the stocks tested, representing a range from white-creamy or brown-egg layers to specialized layer chickens, were evaluated for fertility, hatchability and production of eggs and meat under different management conditions.

General Objective

The general objective of the study was to compare various Parent Stocks (**PS**), Commercial Layers (**ComL**) & Experimental Crosses (**ExpCr**) for their production and reproduction performance in two sites and also to solve the shortage of high performing chicken stocks in addition to introducing, evaluating and identifying suitable high-performing exotic breeds that can adapt to intensive and extensive management conditions in Ethiopia.

Specific Objectives

- To compare production and reproduction performance of commercial layer parent stock under on- station management conditions of Ethiopia.

- To compare egg and meat production performance of commercial layers and experimental crosses under on-station management conditions of Ethiopia.

- To compare egg and meat production performance of commercial layers under on-farm management conditions in Debre Zeit town in Ethiopia.

2. LITERATURE REVIEW

2.1. Chicken Production in Ethiopia

In Ethiopian context poultry means domestic fowl (‘chicken’) (Wilson, 2010). There is no generally accepted definition of rural poultry production, and various production systems have been described by a number of authors, including Alemu and Tadelle (1995). In Ethiopia, village chickens are an integral component of the farming system of nearly all rural families (Tadelle *et al.*, 2003). Village chicken production fits quite well with the conditions of rural households due to its small feed cost, space requirement and low price of the animals (Solomon, 2003). Chickens are widely kept in Ethiopia (Halima *et al*., 2006), with total population estimated to be about 60 million of which 90.8%, 4.4% and 4.8% were reported to be indigenous, exotic and hybrid, respectively (CSA, 2017). Poultry, especially in the small scale scavenging village context, can make considerable contributions to poverty alleviation and in the supply of high quality protein.

Poultry are kept by all strata of society from the landless rural poor to the well off in the cities. Eggs and poultry meat are more readily available than many other animal products and the small quantities produced under rural settings does not require them to be stored or preserved (Wilson, 2010). Poultry meat and eggs are consumed readily in the highlands, however, in the lowland pastoral areas, eggs are usually left to be brooded by the mother hens and meat is more commonly consumed. Where there are alternatives, the preference is for meat and eggs from local scavenging birds, but higher productivity of improved birds would almost certainly offset any price disparity (Alemu and Tadelle, 2000) consumption level is still very low by world standards. Many of the eggs consumed are in the form of ‘doro wat’ which is a very popular spicy chicken and egg stew (Wilson, 2010).

The production systems are characterized as including small flocks, with nil or minimal inputs, low outputs and periodic devastation of the flocks by disease. Birds are owned by individual households and are maintained under a scavenging system, with little or no inputs for housing, feeding or health care. Typically, the flocks are small in number with each flock containing birds from each age group, with an average of 7-10 mature birds per household, consisting of 2-4 adult hens, a male bird and a number of growers of various ages Gunaratne *et al*. (1992).

Gueye (2005) has defined two forms of the traditional backyard system: Firstly, unimproved backyard system: Use of low-input, low producing native birds, brooding, scavenging, no regular water or feed supply, little or poor night shelter, no vaccination and medication. Secondly, improved backyard system: use of genetically improved birds, scavenging, regular water, supplementary feeding, improved shelter, and care of chicks in the early age, vaccination against prevalent diseases and de-worming. To identify the right type of birds it is essential to evaluate and understand the local production systems, their limitations and opportunities, the circumstances under which such traditional systems came to existence and how they can be gradually improved. 16 Attempts are being made to raise the productivity of family chickens in developing countries, by improving housing, nutrition and health programs.

Poultry production in Ethiopia shows a clear distinction between traditional low-input system on one hand and modern production system using relatively advanced technology on the other hand. There is also a third up-coming “small scale” intensive system with small number of birds (from 50 to 500) as an urban and peri-urban household income source using exotic birds and relatively improved feeding, housing and health care (Alemu and Tadelle, 1997). The leading commercial producer runs a vertically integrated operation at Debre Zeit some 50 km from the capital Addis Ababa. It maintains a modern hatchery to supply its own operations (and to farmers on demand), has efficient broiler and layer facilities, compounds its own feeds and slaughters and dresses birds in its own abattoir whence they are marketed throughout the country and beyond (Wilson, 2010).

2.2. Opportunities and Constraints of Poultry Production in Ethiopia

An important part of raising chickens is feeding. Feed makes up the major cost of production (70 %) and good nutrition is reflected in the bird's performance and its products. Ethiopia produces a wide range of ingredients suitable for poultry feeding. It is a country where practically every crop can be grown in one part or the other posing various alternative feedstuff. Varieties of grain and protein sources are available (Alemu and Tadele, 1997). In Ethiopia, currently there is a high and growing demand for chicken meat and egg due to substantial increase in price of beef and mutton. Therefore, chicken production is likely to play increasing role in supplying animal protein for human consumption in the country (Shapiro *et al.,* 2015). In every aspect, having qualified man powers is paramount to achieve the objective of the business venture. In case of the current time, the required skilled and unskilled human resource is easily available in the market because of a number of universities in the country. Therefore, the poultry production in any aspects will not expect to face lack of labour with required qualification (EIC, 2015). There are so many types of layer, broiler, dual-purpose and local chicken breeds available in the world and so many breeder companies are producing huge amount of day old chicks per day for their customers. This is one of the opportunities to alleviate animal protein shortage and reduce poverty by increasing the income of poultry farmers.

The most striking problem in village chicken production systems is the high mortality rate which could reach as high as 80–90% within the first few weeks after hatching, due to diseases and predation. Among the infectious diseases, NCD, salmonelloses, coccidiosis and fowl pox are considered to be the most important causes of mortality in local chicken while predators are an additional causes of loss (Eshetu *et al.,* 2001). Disease, poor nutrition, poor management, and poor genetic capacity are the major problems of poultry production in Ethiopia (Halima *et al.,* 2006). In addition to the above mentioned constraints; Fisseha *et.al.* (2010) reported that other vital problems affecting the productivity of village chicken including: poor extension services and inadequate credit facilities, availability of few or limited research activities, lack of organized marketing system, seasonal fluctuation of price and lack of processing facilities. Alemu and Tadelle, (1997) reported that the availability and quality of mixed feed for commercial poultry production is generally poor in Ethiopia. In many instances, the cost of mixed feed does not seem to follow reductions in ingredient cost. Prices of mixed feed remains unduly high even at times when the price of the major component of mixed rations (e.g. corn) fall by more than fifty percentage (Haftu, 2016).

Local chickens remain predominant in African villages despite the introduction of exotic and crossbred types, because farmers have not been able to afford the high input requirements of introduced breeds. Although the introduction of high yielding chicken breeds in Africa dates back to the 1920`s, village chicken populations comprise from five to 50 local types (FAO, 1998). A study by Tadelle and Ogle (1996a) in the central highlands of Ethiopia demonstrated that the introduction of exotic breeds to three study villages at various times and in different forms (viz. through the introduction of cockerels, pullets or fertile eggs) has minimal impact in upgrading the genetic status of village stock. Because parallel improvement in feeding, housing and health care were not implemented. The poor meat and egg outputs of indigenous chicken have necessitated the introduction of exotic breeds. The exotic breeds have fast growth rates and better egg production potentials but are susceptible to a number of potential diseases that plague the industry today (Onwurah and Nodu, 2006).

2.3. Environmental Effects on Layer Performance

Poultry plays an important role in human nutrition, employment and income generation. In poultry housing environment may affect the performance of birds as well as its wellbeing. Aerial ammonia in poultry houses is usually found to be the most abundant air contaminant. Ammonia (compound of nitrogen and hydrogen with the formula NH_3) concentration varies depending upon several factors including temperature, humidity, animal density and ventilation rate. Chickens exposed to ammonia showed reduced feed consumption, feed efficiency, live weight gain, carcass condemnation, and egg production (Charles and Payne, 1966). Above 27°C feed consumption gradually decreases. Oarad *et al.* (1981) stated that higher temperature reduce the productive performance of layer hens. At 35°C there is a remarkable decrease of feed consumption.

Temperature and humidity are two most significant environmental factors that determine performance of poultry birds (Elijah and Adedapo, 2006). Poultry birds can only tolerate narrow temperature ranges to sustain the peak of their production, for any deviation from the range they need triggers their thermoregulatory mechanisms for survival which have negative consequence on their performance. Ideal temperature range for poultry production is between 12.8 – 23.9°C. At this range the performance is optimum. Temperature between 23.9 – 29.4°C, there is a slight reduction in feed consumption and increase in water intake. The birds cope with it with adequate nutrient intake. Temperatures between 29.4 – 32.2°c, weight gains are lowered, Egg production usually suffers, and cultural measures may be induced to lower temperature inside housing. If condition remains for prolonged period, there may be loss in body weight.

Generally, high temperature results in reduction of poultry live weight, growth rate and high mortality in addition to a decrease on productivity, hatchability and quality of eggs (Ozbey and Ozcelik, 2004). Chronic (prolonged period of high ambient temperature) heat stress is more detrimental. During the heat stress period the increase in body temperature has a negative effect on the fertilization process (Karaca *et al.,* 2002). Also, when the temperature falls below the thermo-neutral zone of 12.8°c, the egg production and efficiency of laying hens are affected. The optimum humidity range was found to be between 50-75%, which may vary with breeds. Also, relative humidity level above 75% causes reduction in egg laying (Elijah and Adedapo, 2006).

2.4. Production Potentials of Local Chickens in Ethiopia

The local chicken breeds in Ethiopia are entirely nondescript breeds showing a great variation in their body size, plumage color and conformation (Tadelle *et al.,* 2000). Ethiopian chicken population is composed of low producing scavenging chicken.

The rural poultry production system of Ethiopia is characterized by an average flock of 6 to 10 mature birds per household laying 30-60 eggs per hen per year and receiving little or no additional inputs except shelter for the night (Alemu & Tadelle, 1997) and generally characterized by poor performance of local chicken in terms of egg production, small egg size, slow growth rate, late maturity, an instinctive inclination to broodiness and high mortality of chicks (Solomon *et al.,* 2013).

Research studies on some of the indigenous breeds have shown that their potential for egg production is very low with average annual egg production of a native chicken was 40 eggs under farmers' management with an average egg weight of 38 grams under scavenging conditions, but under on-station conditions the level of production was increased to 120 eggs per hen per year. These results are extremely low when compared with production levels of exotic egg type breeds which were observed to produce over 300 eggs/hen/year with an average egg weight of 60 grams. Only a few research results are available on the meat production abilities of local stocks and local males may reach

1.5 kg of live weight at 6 months of age under on-station managements (Teketel, 1986). On the other hand, local chickens are known for their ability to resist disease, thermo-tolerance, good egg and meat flavor, hard eggshells, high fertility and hatchability (Solomon *et al.* 2013). Rural chicken in Ethiopia represents a significant part of the national economy in general and the rural economy in particular and contribute to 98.5% and 99.2% of the national egg and chicken meat production, respectively (Tadelle *et al*,. 2003).

2.5. Production Potentials of Koekoek Chicken in Ethiopia

According to the report of Grobbelaar (2010), Potchefstroom Koekoek (**KK**) is a South African registered chicken breed developed in the 1950's at the Potchefstroom Agricultural College in the city of Potchefstroom. It is considered as a composite breed of White leghorn, Black Australorp and Barred Plymouth Rock to obtain specific characteristics of each, making the resulting breed more suitable to Southern African conditions. The breed was intended as a dual purpose, free ranging chicken with laying capabilities as well as a large structure for meat production. The meat of KK chicken as being popular and mostly preferred by local communities over that of commercial broiler breeders. The carcass is attractive with deep yellow colored skin. The breed has characteristic black and white speckled colour patterns, also described as barred, which is present in about nine poultry breeds hence why the chicks are sexable soon after hatching.

The KK PS was introduced and used in Ethiopia for more than 10 years. KK breed was selected based on good advantages of seen in DZARC farm, KK was developed with the specific production traits of brown shell eggs, 200 eggs per hen per year, 55.5gm weight of eggs, deep yellow attractive carcasses colored skin, heavy weight of male (2.653kg) and female (1.873kg) at the end of productions, the culled male and female since becoming popular in their meat test at festival and other occasions, the breed is sex-linked gene that very useful for color sexing. This breed can be used for cross breeding for layers types or dual-purpose breed, the breed is known by ability of hatch their own offspring's.

2.6. Production Potentials of Commercial Layer Chickens

During the last few decades commercial layer flocks have shown significant improvements in terms of egg production and egg quality. The final goal of all breeding companies is to maximize the number of saleable eggs per hens housed taking into account other aspects like feed, health, management in general and welfare (ISA, 2016). According to Lohmann Breeder's Company (2016), egg production performance of Lohmann Brown classic commercial layers was 370- 375 per hen per 60 weeks of egg production periods with 65 grams of egg weight and 115 – 125 grams of feed consumptions per day per hen. At the end of egg production periods the Lohmann brown classic commercial layer's body weight was ranging 1.9 – 2.1kg and male will weigh around 3kg. From the same company egg production performance of Lohmann Dual was 370 – 375 per hen per 60 weeks of egg production periods with 65 grams of egg weight and 115 – 125 grams of feed consumptions per day per hen. At the end of egg production periods the female layer was 1.8 – 2.1kg and that of male was 4.2 – 4.4kg.

According to Novogen Breeder Company (2016), egg production performance of Novo brown commercial layer was 295 – 300 per hen per 60 weeks of egg production periods with average egg weigh of 65.2grams and 115 – 125grams of feed consumption per day per hen. At the end of production periods Novo brown commercial layer's body weigh was 1.9kg and that of male was 2.9kg. From the same company the Novo color dual purpose breed's egg production was 295 – 300 per hen per 60 egg production periods with average egg weigh of 65.2grams and 115 – 125grams of feed consumption per day per hen. At the end of egg production periods Novo brown commercial layer's body weigh was 1.9kg and that of male was 4kg.

According to Dominant Breeder's Company (2016), egg production performance of the Dominant Sussex D104 layer was 299 per hen per 60 weeks of egg production periods with average egg weight of 62 grams and 122 grams of feed consumption during the production periods of 60 weeks. At the end of egg production periods Dominant Sussex D104 commercial layer's body weight was 2.15kg and that of male was 2.6kg. From the same Breeder Company of Dominant CZ (2016), egg production performance of Dominant Red Barred D922 dual-purpose breed was 257 per hen per 60 weeks of egg production periods with average egg weight of 61.5 grams and 122 grams of feed consumption per day per hen. At the end of egg production periods Dominant Red Barred D922 dual-purpose breed's body weight was 2.3kg and that of male was 2.9kg.

2.7. Poultry Breeding in Ethiopia

Disease, poor nutrition, poor management, and poor genetic capacity are the major problems of poultry production in Ethiopia (Halima *et al.,* 2006). Past attempts to improve the poultry productivity in Ethiopia through the introduction of high performing commercial chickens was not successful. The contribution of commercial chickens in improving the productivity was less than 2% (Tadelle *et al.,* 2000). Various interventions enhancing indigenous chicken productivity have been attempted in the past including breed substitution, crossbreeding/upgrading, and selection within population. The objective of substituting indigenous chicken with exotic breeds was to have chickens with faster growth and higher egg production. However, adaptability of the introduced exotic chickens was a problem under the prevailing conditions of production. Furthermore, substitution of local breeds with exotic breeds is opposed by the global move on conservation of indigenous genetic resources because it leads to the disappearance and displacement of the indigenous breeds. The only way to prevent breed substitution from happening would be to make the indigenous chicken more valuable to farmers. This can be realized by genetic improvement of indigenous chicken through within breed selection (Kiplangat *et al.,* 2015).

Crossbreeding or upgrading of indigenous chicken with commercial exotic chickens through cockerels or pullets exchange was another genetic intervention implemented in the past in several African countries. The intervention started in 1950s in Nigeria where indigenous chickens were crossed with Rhode Island Red (RIR), Light Sussex and Black Australorp chicken (Oluyemi *et al.,* 1979). Crossbreds demonstrated superiority in performance but their survival rates were low and the intervention was categorized as unsuccessful (Fayeye *et al.*, 2005).

Within breed selection was used in some African countries such as Egypt, Nigeria, and recently Ethiopia, to genetically improve indigenous chicken. This strategy was successful in Egypt as it resulted in creation of Fayoumi breed which has a 60% higher egg production as compared to the indigenous chicken (Hossary *et al.,* 1995). Two pure lines of the Fayoumi breed were developed by selecting one for growth, and another one for egg production (Kiplangat *et al.*, 2015).

In Ethiopia, selection within Horro indigenous chicken was started in 2000 at the Debre Zeit Agricultural Research Centre and has been successful in increasing egg production and body weight (Wondmeneh *et al.,* 2015). Egg production in Horro chicken increased by 123.5% to 75 eggs at week 45, and age at first egg reduced to 148 from 203 days by generation five (Tadelle *et al.*, 2013). The breeding program using chickens from the Horro region was initiated to improve the productivity of village chickens through selective breeding. The Horro chickens and the breeding objectives (egg number and live weight) for this program were identified using a participatory approach (Nigussie *et al.*, 2010). The performance of the current generation of the improved breed does not yet meet the expectations of farmers, but considering the rate of improvement, it is anticipated that future generations will fulfill the needs of the farmers (Wondmeneh *et al.*, 2015).

2.8. Synthetic Breeding

Genetic improvement of indigenous chickens may be achieved through either selection or cross breeding using improved breeds or through employment of both approaches. Selection captures the benefits associated with additive gene action. However, a large indigenous chicken ecotype would require between three to six years of selection to attain 1.3kg body weight at 16 weeks of age under intensive management system. This implies that a lot of time and resources would be needed to arrive at intended genetic improvement of indigenous chickens when selection within breed is chosen (Munisi *et al.*, 2015).

On the other hand cross breeding between indigenous stock and exotic commercial chickens, would take advantage of productive merits which have already been accumulated through selection in the exotic chickens as well as merits for hardiness which have been endowed in indigenous chickens through decades of natural selection (Rajkumar *et al.,* 2011). However, the major setback in the crossbreeding program has been the need for repeated provision of exotic birds for crossing. This has been hampered by unreliable supply and high costs of acquiring and maintaining exotic breeding cocks (Munisi *et al.*, 2015).

An alternative improvement approach would be to carry out crossing between two or more populations to create a single population of chickens followed by selection within the crossbred population, a method which is popularly known as synthetic breeding (Munisi *et al*., 2015). With synthetic breeding, only one population with all desirable traits has to be maintained instead of two or more parental populations needed in regular crossing programs. Depending on the genetic diversity between the parental breeds, various levels of heterosis would be expected. However, before adopting any breeding strategy, adequate information on qualities and capabilities of different breeds of chickens is required to select the right type of breeds/genetic stocks (Munisi *et al*. 2015). There for the synthetic breeding to produce heavy types of layers for intensive and extensive production systems in Ethiopian is key to solve the shortage of high performing chicken stocks in addition to introducing, evaluating and identifying suitable high-performing exotic breeds that can adapt and to intensive and extensive management conditions in Ethiopia.

2.9. Hatchery and Hatchability Problems in Ethiopia

In general, the knowledge on hatching processes is low and management standards at most of the hatcheries are poor. This leads to low hatching percentages on several of the hatcheries in Ethiopia. Hatching results are influenced both by parent stock management as well as the management of the hatchery itself. Managing parent stock is more difficult than managing layers or broilers. The parent stock farms observed clearly lacked good management: animals were not always uniform, cocks often too fat, dry hens are not culled and many birds suffer from diseases and external parasites (Boere *et al.*, 2015).

On most of the parent stock farms, there is no candling equipment available to test fertility of the eggs. Furthermore, hatching of both layer and broiler parent stock are often put together in the same batch, which is far from ideal, as layer hatching eggs are more sensitive to disturbances in the hatching process. A structural problem with all the hatcheries in Ethiopia is the altitude on which they are built. All are on higher altitudes

(1500 meters or above), where the oxygen concentrations are lower. This leads to higher mortalities between days 15 and 20 of the hatching process, when chicks gradually need more oxygen. The total output of the hatcheries currently is too low to meet the demand. This leads to long waiting lists for poultry keepers and empty, unoccupied houses for periods sometimes up to 7 months or longer. This makes poultry production a risky venture and as a result, many people drop out of poultry keeping and turn to other ways of income (Boere *et al.*, 2015).

It is believed that fertility rate of breeder hens is a very important measure of their reproductive performance. Fertility refers to the percentage of incubated eggs that are fertile while hatchability is the percentage of fertile eggs that hatch. According to (Cyril Hrncar *et al.*, 2015) mean fertility was 59.81%, 57.36% and 58.82% for Brahma, Cochin and Orpington respectively. There was no significant difference in fertility among the different chicken breeds. Mean hatchability from fertilized eggs was 80.08%, 82.54% and 89.86% for Brahma, Cochin and Orpington respectively. Comparisons between heavy breeds revealed significant differences in hatchability among the breeds. Significant effect of genotypes on hatchability was also observed by Jayarajan (1992). They found that hatchability of total eggs set as 91.28, 86.08, 79.57 and 84.95% for Barred Plymouth Rock, White Leghorn, Rhode Island Red and White Rock, respectively. Studies have shown that fertility can highly vary even within the same breed mainly due to poor management and improper proportion of males or poor ability of males in the flock to produce viable sperms (Islam *et al*., 2002; Murad *et al*., 2001). Variations in hatchability on the other hand can be accounted for by various factors. Several researchers have reported that hatchability decreases with increasing egg storage period as percentage early and late embryonic mortality increases (Elibol and Brake, 2008; Hrncar and Bujko, 2012).

2.10. Poultry Feeds and Availabilities

Poultry feed and nutrition is one of the most critical constraints to poultry production under both the rural small holder and large -scale systems in Ethiopia. The problem is mainly associated with lack of processing facilities, inconsistent availability and distribution and sub-standard quality of processed feeds, when available. Regular availability of good quality ingredients and a fully balanced complete feed are essential for efficient poultry production. Grains, cereal by-products, oil seed cakes and meat and bone meal are obtained locally. The shortage in the supply of grains especially corn is improving due to the increase in the production of corn in recent years. The most serious problems arise from the unavailability of suitable micro-nutrient sources: vitamins and minerals (Haftu, 2016).

Even though, Ethiopia has high figures of poultry population, it is characterized by low production and productivity due to mainly non availability of cheap but high quality feed ingredients and under exploitation of available local feed resources. Provision of protein sources is a major problem facing improved poultry production. Soya bean cake and full fat soya bean are a major oil seed plant protein sources used for poultry in commercial poultry production, but the high cost of this vital feed ingredient calls for an alternative (Aklilu, 2007). The difficulty in the provision of nutritionally adequate feed ingredients is likely to be the most limiting factor in increasing livestock production in the developing countries. Feed formulation for Monogastric compared with ruminants is much more economically demanding especially on a commercial scale (Younas and Yaqoob, 2005).

Different poultry feeds give different results in terms of growth and egg production. To attain the exact quantities of nutrients, it is important to balance the ration of diets (Mohammad *et al.*, 2014). Poultry diets are made primarily from a mixture of several feedstuffs such as cereal grains, soya bean meal, and animal by-product meals, fats and vitamin and mineral premixes (Alimon and Hair-Bejo, 1995). A poultry diet is expected to contain three essential nutrients of protein, vitamins, and minerals as well as provides adequate metabolizable energy (ME). The most easily available sources of energy are the carbohydrates contained in common grains, grain by-products and plants generally (Dateh, 2013). The important and basic components of a laying hen diet include energy, carbohydrates, protein and amino acids, fat, and vitamins and minerals. Not only must all of these nutrient sources be present in the diet, but they must also be present in certain amounts (Depersio, 2011). Certain mineral elements such as iron, manganese, copper and zinc are essential dietary nutrients for poultry and livestock. However, all mineral elements, whether considered to be essential or potentially toxic, can have an adverse effect upon the humans and animals if it is present in the diet at excessively high concentrations. Zinc is an essential element needed by our body in small amount. Without enough zinc in the diet, there could be loss of appetite, decreased immune function, slow wound healing, and skin sores (Mohammad *et al.,* 2014).

Minerals are needed for formation of the skeletal system, for general health, as components of general metabolic activity, and for maintenance of the body's acid-base balance. Calcium and phosphorus are the most abundant mineral elements in the body, and are classified as macro-minerals, along with sodium, potassium, chloride, sulphur and magnesium. Calcium and phosphorus are necessary for the formation and maintenance of the skeletal structure and for good egg-shell quality (Velmurugu, 2017).

The quality of mixed feed for commercial poultry production is generally poor in Ethiopia. Most formulations available do not have vitamin/mineral premixes. Ingredients and processed feeds vary in nutritive value and there is no regular quality control mechanism in the country. Unavailability of feed quality legislation and laboratory facilities for chemical analysis also contributes greatly to the poor quality of processed feeds (Tadelle *et al.,* 2003). In addition to lack of Government control and analytical services has further provoked the situation. There is insufficient data as to the nutritive content of feeds consumed by chickens in the country and possible contamination of the feeds by the nutritive elements. So far no systematic work has been carried out to give a clear idea about the heavy metals, proximate content in feeds available in the country.

The price of raw materials varies according to source of supply and region. Little attention is given to the least cost formulation of rations. It is believed that considerable scope exists to reduce the price of feed in some areas without reducing its nutritive value. Transport costs add significantly to the cost of feed in areas distant from the source of supply. The lack of feed mills and dependence on supplies of some ingredients from large cities and its surroundings add to the overall cost of feed in many parts of the country. The absence of bulk deliveries and storage has increased feed costs. In some cases, a lot of wastage occurs due to weevil infestation. The shortage in the supply of protein supplements of animal origin has made the price of abattoir by-products extremely high. In many instances, the cost of mixed feed does not seem to follow reductions in ingredient cost. Prices of mixed feed remains unduly high even at times when the price of the major component of mixed rations (e.g. corn) fall by more than fifty percentage (Tadelle *et al.*, 2003).

2.11. Poultry Disease

Chicken production under backyard system has long been an important component of rural economy in Ethiopia. Village chickens have been widely used for cheap source of protein through their main output, egg and meat production. However, unlike the intensive one, traditional poultry production system is characterized by low input, low output and periodic destruction of a large portion of the flock due to outbreak of disease. In the village poultry production systems, disease was cited as the most important stumbling block for production problem in Ethiopia (Alemu & Tadelle, 1997; Tadelle *et al.*, 2003). Nowadays as part of the intensification of poultry production strategies, introduction of diseases of various types into several poultry farms simultaneous with importation of exotic breeds to backyard chickens is becoming a growing concern. In line with distribution of exotic breeds to farmers, it is creating a great treat to the indigenous backyard chickens. Among others, Newcastle diseases, Marek's disease, and infectious bursal disease (IBD) are the most important viral diseases inflicting heavy losses (Alamargot, 1987; Duguma *et al.*, 2005).

Infectious and non-infectious diseases is one of the major constrains in poultry rearing. Farmers face a wide range of diseases, which reduced the production of the birds. During last few years several emerging diseases like infectious bursal disease, aflatoxicosis, avian influenza, chicken anemia virus and egg drop syndrome and some unknown cause threatened the industry and cause huge damage to the farmers. Viruses, which affect the mucus membranes of the respiratory and reproductive tract, such as Newcastle disease and infectious bronchitis, not only cause a decrease in egg production, but also cause the shell to become abnormally thin and pale (Beyer, 2005 and Butcher and Miles, 2003).

Infectious Bursal Disease (Gumboro Disease): Infectious bursal disease is an acute and highly contagious disease of young chicken which is caused by infectious bursal disease virus (IBDV). The causal agent was first isolated in Gumboro, Delawer in United States of America (USA), and the disease was originally known as Gumboro disease (Quinn *et al.*, 2002).

Infectious bursal disease is the major health and production constrain of young chicken. IBD is acute highly contagious globally occurring viral poultry disease. High pathogenic strain of IBDV is known to cause 100% morbidity and mortality of 20-30% IBDV is present in two clinical forms. Acute on set high mortality in chicken up to 20%, usually in bird around 3-4 weeks old. Immune- suppression disease as the result of infection at early age, predisposing bird to secondary infection. Old birds show the subclinical form of IBD depending on the strain and amount of virus, age and breed of bird. A previous study in Ethiopia indicating that mortality rate of IBD range from 45-50%. The overall prevalence of IBD antibody recorded in different part of country and poultry production system reached up to 93.3% (Giambron *et al.,* 1999; Saif *et al.,* 2008).

The sector is growing more quickly than any of the other major agricultural sectors in Ethiopia. Therefore, this sector will be expected to satisfy the future demands for protein in the country. In spite of the existence large population of chicken and potential future expansion of the poultry industry in the country, the production system has been adversely affected by a variety of constraints such as management problem (like nutrition, housing), predators and poultry diseases. Among these, the diseases are the major factors that hinder poultry development and poultry mortalities due to disease are estimated to range from 20% to 50% but they can rise as high as 80% during epidemics (OIE, 2004; Safari *et al.,* 2004).

The breeder flock must be managed in such a way so as to optimize the production of clean fertile hatching eggs in an economic fashion. Management program must ensure that the chicks or poultry produced will be viable from both an immunologic and nutritional perspective when they are placed in the production setting. Disease prevention measures must also be in place to prevent diseases that will result in morbidity and mortality in the breeder flock itself. The building and equipment in which the fertile egg is converted to a day-old chick, poultry, or other fowl and the equipment used to process and deliver it to the farm must be clean and sanitary. An individual hatched from a pathogen-free egg will remain pathogen-free only if it hatches in a clean hatcher, is put in a clean box and held in a clean room where it can breathe clean air, and then is hauled to the farm in a clean delivery van (Saif *et al.*, 2008).

Small and large-scale chicken farms are rapidly growing in Ethiopia. The chicken strains imported are temperate breeds that are less adapted to the heat stress and disease challenges in the country. Accompanying intensification of poultry farming, there is occurrence of epidemics of newly introduced diseases and/or epidemics of endemic diseases. One of the diseases that is of growing concern in poultry is Infectious Bursal disease (Gumboro disease). As in this report a large-scale occurrence of Infectious Bursal disease in the central part of Ethiopia with intensive and high-density juvenile farms (Saif *et al.*, 2008).

2.12. Poultry Products Marketing and Utilization

Poultry products in most developing countries, especially in Africa, are still expensive. The marketing system is generally informal and poorly developed. Unlike eggs and meat from commercial hybrid birds (derived from imported stock), local consumers generally prefer those from indigenous stocks. As most consumers with greater purchasing power live in and around cities, intensification of poultry production should be initiated in peri-urban areas or, at least, in areas having a good road network (Branckaert *et al.*, 2000). In North West Ethiopia, the price, demand and supply of chicken are highly related to religious festivals, mainly Christian festivals. The egg marketing channel is more or less similar to that of chicken. Eggs are sold at the farm gate to egg collectors, in the open markets to middlemen and consumers and to retail shops, hotels and supermarkets in towns. Eggs pass through a relatively longer chain to reach the consumers than chicken. The main actors in egg marketing are producers, collectors, traders or (wholesalers), local kiosk, shops and supermarkets. Urban markets followed by nearest local market and farm gate are, in order of importance, the preferred outlets for egg marketing by producers (Fisseha *et al.*, 2010).

The demand of protein food is progressively growing with the improvements of society's income and population growth that affects trends of chicken production. With an annual human population growth rate of 2.4%, the present 77.4 million Ethiopia's human population will increase to about 149.3 million by the year 2040 (FAO., 2005). With the increasing population of the country, there is an increasing demand for the supply of food. Thus, the demand for animal products is expected to increase substantially. To meet the ever-increasing demand for meat and eggs, introduction of superior/exotic breed has been proposed as one of the plausible option. Under the prevailing management situations, it may be difficult to fulfill these demands in short time. Therefore, intensification and upgrading of the potential of birds will be inevitable to provide surplus products (Haftu, 2016).

3. MATERIALS AND METHODS

3.1. Study Sites

The study was carried out under on-station in Debre Zeit Agricultural Research Center (DZARC) and Hawassa University (HU) in Ethiopia. Two sites were used to increase reliability of the study. In addition, the study was carried out under on-farm management conditions of the villages of Debre Zeit district in Ethiopia.

DZARC is situated in Debre Zeit town under the Ethiopian Institute of Agricultural Research (EIAR). The research center is located 45km south-east of Ethiopia's capital Addis Ababa, at an latitude of 8°44' N and longitude of 38° 38’E with average altitude of about 1900 meters above sea level, and it is at the center of a poultry production area (CSA, 2013). Average high temperatures are between 24°C to 29°C during the day and average low temperatures are between 9°C to 14°C during the night, and humidity ranges from minimum of 48% to maximum of 68% (Center GIS information). Ideal temperature range for poultry production is between 12.8 – 23.9°C. At this range the performance is optimum.

HU is situated in Hawassa city in South Nations, Nationalities, and People Regional State (SNNPR). Hawassa is located 273km south of Ethiopia’s capital city Addis Ababa, is geographically situated at latitude and longitude of 7°3′N 38°28′E with average altitude of about 1708 meters above sea level. Hawassa area is known for its poultry production (CSA, 2013). Temperature of the area ranges from maximum of 29°C to minimum of 12°C and humidity ranges 70% to 80% (Agro-Meteorology Department data).

3.2. Study Animals

3.2.1. Parent stocks

Day old chicks (DOC) of six commercial **PS** bred by European companies and one locally available PS from three well-known European breeding companies were imported. The PSs were Dominant Sussex D104 (DS) and Dominant Red Barred D922 (DR) from Dominant CZ (Czech Republic), NOVOgen-Brown (NB) and Novogen-Color (NC) from Novogen (France), Lohmann Brown Classic (LB) and Lohmann-Dual (LD) from Lohmann Tierzucht (German company). The NB and NC had females from the same maternal line, selected for egg production, but they differ in the genetics of their males. Those of NB were from a brown egg-type paternal line, whereas in NC, the males were obtained from a medium-size meat-type paternal line. The LD was also with the females coming from a medium-size egg type maternal line, and dwarf meat-types males were used as the paternal line.

The Potchefstroom Koekoek (KK) PS was used as a local reference as it has been used for intensive and extensive management conditions in Ethiopia, South Africa and other African countries. KK was used in Ethiopia for more than 10 years. The KK was selected based on good advantages as seen in DZARC farm, with 200 eggs per hen per year, 55.5g egg weight, deep yellow skin, relatively high body weight (BW) of male (2.65kg) and female (1.87kg) at the end of production, and it carries sex-linked gene for color sexing of DOC (Grobbelaar *et al.,* 2010; Wondmeneh *et al.,* 2011). In addition to the PS of these seven commercial layers, the study included the PS of three experimental crosses: DR females mated to KK males (♀DR×♂KK), DS females mated to DR males (♀DS×♂DR), and KK females mated to DS males (♀KK×♂DS). The three Experimental Crosses were evaluated for fertility and hatchability between genetically similar vs remote parents as shown Figure 1. Among the seven commercial PS in this study, in three of them - DR, DS and KK - the females and males shared the same genetic background and differ only in a single sex-linked gene that allows sexing of day-old chicks. The fertility and hatchability of eggs from these three 'Pure" (similar-parents) PS were compared to those of the three Experimental Crosses of the PS consisted of crosses between hens from one PS and males from a genetically different PS.

3.2.2 Commercial layers and experimental crosses females and males

Day old chicks (DOC) of seven Commercial Layers (ComL) & three Experimental Crosses (ExpCr) females and six ComL & three ExpCr males were collected from Debre Zeit Agricultural Research Center (DZARC). The ComL & ExpCr were Dominant red Barred D922 (DR), Dominant Sussex D104 (DS), Potchefstroom Koekoek (KK), Lohmann Brown Classic (LB) and Lohmann Dual (LD) (only in females' eggs trail), Novo-Brown (NB), Novo-Color (NC).

The Koekoek (KK) was used as a local reference as it has been used for intensive and extensive management conditions in Ethiopia, South Africa and other African countries for more than 10 years.

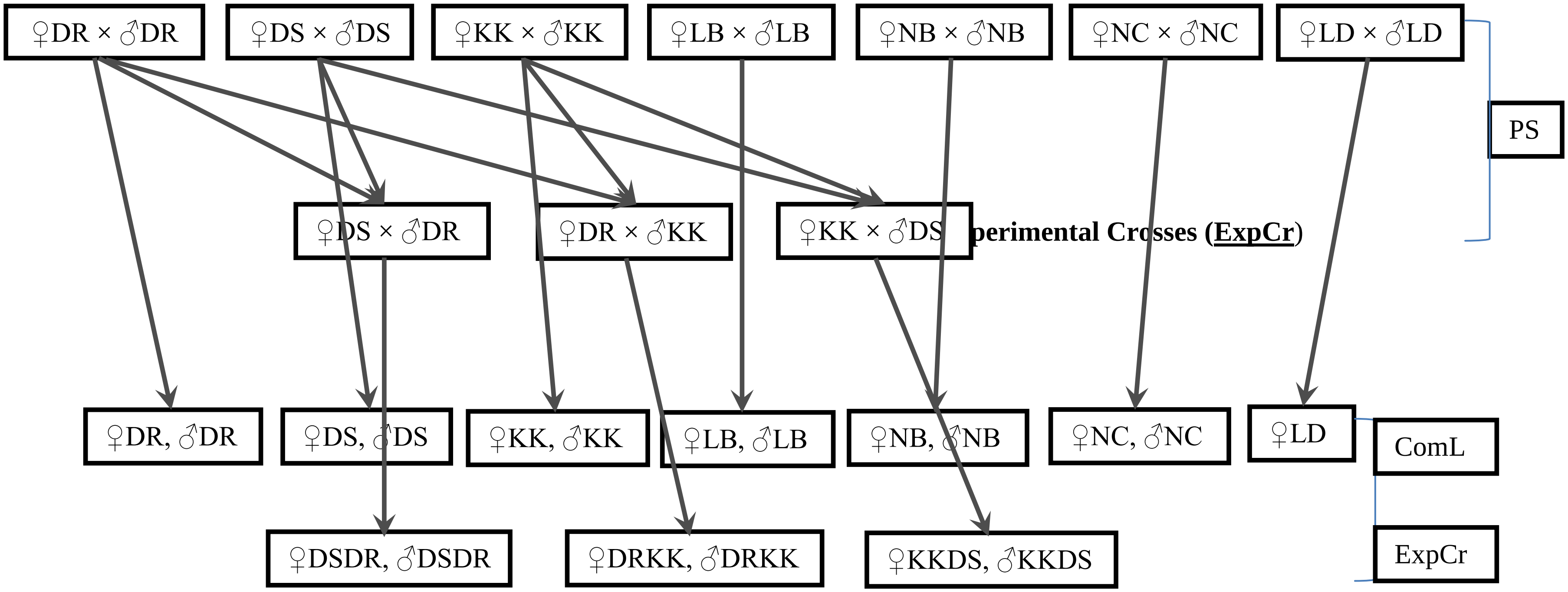

Figure 1. Mating scheme of the study.

DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown; NB = Novogen Brown; NC = Novogen Color; LD = Lohmann Dual, DSDR = Dominant Sussex hens × Dominant Red Barred males; DRKK = Dominant Red Barred hens × Koekoek males; KKDS = Koekoek hens × Dominant Sussex males.

3.2.2. *Sex differentiation methods*

The three Commercial Layers (ComL) females and males (LB, NC and NB) were color sexed; the female DOCs progeny are brown (“gold”) and the male DOCs are white (“silver”) when hatched. The DOCs of DS were sexed by the slow/fast feather development. In case of DR, the female DOCs are completely red and the male DOCs show white spot on the head, wings and back. The DOC of KK have white spot on the head of male and full black color of female. In LD, autosexing is not possible because all DOCs are entirely white.

In case of the Experimental crosses of Dominant Sussex D104 female × Dominant red Barred D922 male (♀DS×♂DR), the female DOCs are completely red and the male DOCs shows red spot on head and wings but the rest of their body is completely white. The Potchefstroom Koekoek female × Dominant Sussex D104 male (♀KK×♂DS), the female DOCs are completely black and the male DOCs have white spot on the head. The Dominant red Barred D922 female × Potchefstroom Koekoek male (♀DR×♂KK) autosexing was not possible due to mixture of different color in both sexes and also as a new cross.

3.3. Health management

The birds were vaccinated against common diseases indicated in the vaccination programs, like Marek’s, New castle disease (NCD), Gumboro, Fowl Typhoid, and Fowl Pox at the appropriate age as recommended by veterinarians as shown in Table 1. In addition, the Ox tetracycline plus (OTC plus) was given when necessary. Standard vaccination and medication were strictly adhered to and strict sanitary measures followed during the experimental period (Dawud *et al.,* 2011; Wondmeneh *et al.,* 2015).

Table 1. Vaccination schedules for all experimental breeds

Date	Week	Name and type of vaccination	Route of administration
Day 1	1	Marek's	Sub-cuntanious
Day 3	1	NCDV(HB1)	Ocular(eye droplet)
Day 7 or 9	1	Gumboro(IBDV)	Drinking water
Day 21	3	Gumboro(IBDV)	Drinking water
Day 27	3	NCDV(Lasota strain vaccine)	Drinking water
Day 45	6	Fowl typhoid	Sub-cuntanious
Day 63	8	NCDV(Lasota strain vaccine)	Drinking water
Day 90	12	Fowl typhoid	Sub-cuntanious
Day 70-105	10-14	Fowl pox	Wing web
Day 112-120	16	NCDV (inactivated)	Ocular(eye droplet)
	Every 16 week	NCDV(Lasota strain vaccine)	Drinking water

3.4. Housing and Management

3.4.1. Parent stock management at Debre Zeit Agricultural Research Center

The females and males of each PS were reared in a separate pen under standard management conditions up to 16 weeks of age, then a total of 1810 females and 261 males from the seven PSs were assigned to the on-station trial. At the beginning of the trial (16 wks), all PS chickens were weighted and randomly allocated to deep litter pens in four experimental layer houses in a randomized blocks design. Each of three small houses had seven pens of $8m^2$, one pen for each breed; 50 hens and 7 males were housed in each of these pens. The 4th house had 31 pens of $7m^2$, each with 40 hens and 6 males per pen. In this big (4th) house, hens and males from DR, DS, LB, and LD were assigned randomly to 4 pens per PS, whereas NB, NC and KK, due to shortage of DOCs, were assigned each to 1 pen. The three experimental PS combinations (♀DR×♂KK, ♀DS×♂DR & ♀KK×♂DS) were assigned randomly to 4 pens each. The experimental houses were open-sided with deep litter of 15cm of teff (*Erogrostis teff*) straw on concrete floor. Standard lighting program based on the age of the birds, stocking density of seven birds per m^2 were applied based on the recommendation of the breeding companies.

3.4.2. Parent stock management at Hawassa University

The females and males of each Parent Stock (PS) were raised in a separate pen under station conditions till 16 weeks of age at Debre Zeit Agricultural Research Center (DZARC). A total of 600 female and 75 male from the five parents were transferred to the poultry research farm at Hawassa University's (HU) poultry farm. The house was partitioned into fifteen (15) pens to accommodate 3 replicates per strain (40 females and 5 males per pen). At the beginning of week 16, all chickens were weighted and randomly allocated to pens filled with deep litter in a completely randomized design (CRD). The experimental house was open-sided with deep litter of 15cm of teff straw on concrete floor. Standard lighting program based on the age of the birds, stocking density of 7 birds per m^2 were applied based on the recommendation of the breeder's companies.

3.4.3. Management of commercial layers (on-station trials)

Two houses were prepared for seven Commercial Layers (ComL) & three Experimental Crosses (ExpCr) for egg production (females) and six ComL & three ExpCr for meat productions (males). These houses were partitioned from 27 to 30 pens ((7 ComL & 3 ExpCr) x 3 replicates) for each females and males. For each ComL & ExpCr of female and males, 20 birds per pen were used except 40 birds per pen for Lohmann Dual female trials due to sexing problems at day old chickens, 12 birds per pen for Dominant Sussex D104 female × Dominant red Barred D922 male (DSDR) in females trial and 15 birds per pen for Dominant Sussex D104 female × Dominant red Barred D922 male (DSDR) in male line trials due to shortage of birds at day old chickens. A total of 621 females and 516 males were used for on-station progenies trial. The ten lines of the female and nine lines of males in a separate house was weighted and randomly allocated to the pens using Completely Randomized Design (CRD). The experimental houses were open-sided with deep litter of 15cm of *teff* (*Erogrostis teff*) straw on concrete floor.

Standard lighting program based on the age of the birds, stocking density of seven birds per m^2 were applied based on the recommendation of the breeding companies. Each of the pens size was $3m^2$ (1.2m x 2.5m). When the female growers are about to start laying (at the age of week 16 to 18), individual nest was provided to them at a ratio of 1 nest to 7 layers.

3.4.4. Commercial layers (on-farm trials)

A methodology of farmer selection was as follow, a large difference was expected between such farms, and therefore in order to have sufficient statistical power, at least 7 replicated farmers per breed per sexes were planned first. Farmers were given a five days training on how to manage the chickens and keep records. Each farmer was received a 100 day-old chickens per breeds per sexes. If the participant farmer would like to keep both females and males, the farmers should divide his/her chicken house in to two pens for each female and male breed in one house, otherwise the farmer should have one pen for either sexes to allocated one breed in one farmers house. The types of the farmers' house would be either mud house or mud with cement plastered in each experimental site; the trial would follow the recommendations of DZARC packages of 100 birds for egg production (females) and meat production (males). The same rearing and vaccination program as on-station was followed for chickens in the on-farm study.

The six lines of the female and male in each participant house was weighted and randomly allocated using Completely Randomized Design (CRD). When the trial was started, a total of 4200 ComL for egg production (females) and 4200 ComL for meat productions (males) that means (100 birds per sexes × seven farmers × six ComL) was given first. The main challenges for this on-farm experiments were getting farmers who keep the ComL until end of the trials in egg production (females) to keep up to 60 weeks, meat productions (males) to keep up to 12–16 weeks of birds age, so that, the trials were with negotiation of farmers based on their interest and then the farmers were getting the following benefits:- farmers were provided ComL with free of cost, researcher would cover all cost of vaccinations and treatment, any chicken products like eggs, meat and others were belongs to the farmers, farmers were assisted in marketing their products and in addition to this benefits. In these on-farm trials, 50% (21 out of 42) of the participant farmers in egg production (females) were dropped out at different times either due to Gumboro outbreak, high chicken mortality, economic problems for purchasing feeds, getting high price for the pullet or reduced motivation of the farmer.

In meat production (males) 23.8% (10 out of 42) of the participant farmers were dropped out due to economic problems for purchasing feeds and reduced motivation of the farmer.

The analysis was done with 50% in egg production (females) (from 16 to 48 weeks of ages only) and 76.2% in meat production (males) (from 0 to 12 weeks of age) of the participant farmers due to dropped out circumstances.

3.5. Feeds

3.5.1. Feeds for parent stock layers

Feed for Parent Stock layers chicken was formulated at DZARC using Feed Win software® according to the recommendations of each breeder's manual but for HU Parent Stock trials the standard layer ration was fed with a diet purchased from local feed mill containing 17.9% CP, 2784.8 kcal/kg ME). The following ingredients in DZARC trials were used: white maize, bone and meat meal, noug seed cake, soya bean meal, wheat middling, limestone, DL-methionine, L-lysine, vitamin-premix and salt were used. Feeders and waterer were placed in the house per pen according to the recommendations of each breeder's manual. Water was given ad-libitum to all chickens in the experiments without recording the amount consumed. Each of the experimental breeds' requirements is shown in Table 2.

Table 2. Crude protein (CP) and energy content in the feed, by Parent Stock[1] and age.

PS	Age (wks)	CP (%)	Energy (kcal/kg ME)	Source
DR and DS	16 to 40	17	2750	Dominant CZ, 2016.
	> 40	15.5	2700	
LB, LD and KK	16 to 46	18.7	2800	Lohmann, 2016;
	> 46	17.95	2725	Wondmeneh *et al*. 2011.
NB and NC	16 to 46	18	2800	Novogen, 2016.
	> 46	17	2750	

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown; LD = Lohmann Dual; NB = Novo Brown; NC = Novo Color.

3.5.2. Feeds for commercial layers and experimental crosses females & males

Feed for the ComL & ExpCr chicken reared on-station was formulated at DZARC using Feed Win software® according to the recommendations of each breeder's manual and the following ingredients were used: white maize, bone and meat meal, noug seed cake, soya bean meal, wheat middling, limestone, DL-methionine, L-lysine, vitamin-premix and salt were used. Feeders and waterer were placed in the house per pen according to the recommendations of each breeder's manual. Water was given adlibitum to all chickens in the experiments without recording the amount consumed. Crude protein (CP) and energy content in the diets fed to the females of seven commercial layers (ComL) and three experimental crosses (ExpCr), by age is shown in Table 3. Crude protein percent (%CP) and energy content in the feed for each of the commercial and experimental crosses males was formulated as follow: 0 to 4, 5 to 8 and 9 to 16 week of age, the %CP was 22, 20 & 20% respectively and energy content in the feed was 3000, 3100 & 3200 energy kcal/kg ME respectively to weeks of age.

Feeds for on-farm Commercial layers Females & Males the standard layer ration was fed with a diet purchased from local feed mill containing 15 to 20% CP, 2700 to 2900 kcal/kg ME based on the birds weeks of age. Each of the ComL's requirements is shown in Table 3. Feeders and waterer was placed in the house/per participant house according to the recommendations of each breeder's manual. Water was given ad-libitum to all chickens without recording the amount consumed. Crude protein percent (%CP) and energy content in the feed for each of the ComL males at 0 to 4, 5 to 8 and 9 to 16 week of age, were 22, 20 & 20% CP respectively and 3000, 3100 & 3200 kcal/kg ME respectively.

Table 3. Crude protein (CP) and energy content in the diets fed to the females of seven Commercial layers (ComL)[1] and three Experimental crosses (ExpH)[2], by age

Layers and Crosses	Age	%CP	Energy kcal/kg ME	Source
DR and DS	0 to 8	19.5	2875	Dominant CZ, 2016.
	9 to 16	15	2750	
	17 to 39	17	2750	
	> 40	15.5	2700	
LB, LD, DRKK, DSDR, KKDS and KK	0 to 8	19.5	2800	Lohmann, 2016; Wondmeneh *et al.* (2011).
	9 to 16	17.5	2750	
	17 to 45	18.5	2800	
	> 46	17	2750	
NB and NC	0 to 8	20	2900	Novogen, 2016.
	9 to 16	17	2750	
	17 to 45	20	2750	
	> 46	19	2750	

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown; NB = Novo Brown; NC = Novo Color; LD = Lohmann Dual.
[2]RxK = Dominant Red Barred hens x Koekoek males; SxR = Dominant Sussex hens x Dominant Red Barred males; KxS = Koekoek hens x Dominant Sussex males.

3.6. Data Collection

3.6.1. Common data collection to all trials

Routine data recording for DZARC and HU during the trial from each pen/participant house pen included weekly body weight (average of 10% of the females and all of males in each pen/ participant house pen), weekly number of all collected eggs, and number of dead birds per sex per pen. Data on feed intake was recorded every day, and for parent stock trials in both locations of DZARC and HU a daily average feed intake (g/bird/day) of female and male together per pen due to unavailability of sophisticated materials to record the daily average feed intakes of females and males separately and also female and male cannot be kept separately since they are parent stocks.

3.6.2. Egg size and quality measurement

Egg quality parameters were measured five times at 26, 30, 36, 40 and 44 weeks of age in DZARC and at 27, 31, 35, 39 and 45 weeks of age in HU parent stock trials. The temperature and humidity in the egg storage room were kept at an optimum level 12°C to 14°C and 75% to slow down the loss in quality. Data were taken from the stored eggs on the second day after collection. Either 12 or 21 normal eggs per DZARC PS (three eggs per pen) were randomly selected from the egg laying nest at one time and used for analysis. Fifteen normal eggs per treatment in HU (3 eggs per pen) were randomly selected from the egg laying nest at one time and used for analysis.

Egg weight, albumen weight, yolk weight and shell weight measurement were determined by electric balance. Egg shape (width and length), albumen height measured at the height of the chalazae at midway point between thinner and outer circumference of the white with a spherometer. The external and internal egg quality measurements were obtained by carefully making an opening around the sharp end of the egg, large enough to allow passage of both the albumen and the yolk through it without mixing their contents together. The yolk was carefully separated from the albumen and placed in a petri dish for weighting. Simultaneously, the associated albumen was placed on another petri dish and weighted. After each weighing, the petri dishes were washed in clean water and wiped with dry cloth before next weighing (Veena *et al.*, 2015). Yolk height was measured at its top point by a spherometer. Shell thickness was measured by digital caliper at the sharp-end, equatorial, and blunt-end regions after shell membrane was removed, and the mean of these three points was recorded.

Yolk color was determined by DSM Yolk Color Fan (formerly Roche Yolk Color Fan) with 15-color index. Eggshell color was determined visually to either white, brown, light brown or white-creamy egg shell color.

3.6.3. Fertility and hatchability measurement

To determine fertility and hatchability in DZARC, 36 eggs per pen were collected three times, each for five consecutive days, when the hens were 28, 34 and 44 weeks of age. The temperature and humidity in the egg storage room were kept at an optimum level 12°C to 14°C and 75% respectively. The eggs were incubated in Victoria (Italy) incubator with capacity of 10368 set eggs and 3452 hatching eggs. The total number of set eggs per PS per age, combined over pens and three incubations, was 252 (36x7) in DR, DS, LB, LD, and 144 (36x4) in KK, NB, and NC (Table 5). The total number of set eggs from each experimental PS (♀DR×♂KK, ♀DS×♂DR, and ♀KK×♂DS), combined over pens and three incubations (ages), was 144 (36x4).

For the Parent Stock trials in HU, 27 eggs per pen were collected three times, each for five consecutive days, when the hens were at 30, 36 and 45 weeks of age, and incubated in a petersime (Belgium) Incubator with capacity of 4400 set eggs and 1466 hatching eggs. The total number of set eggs per strain per age, combined over pens and 3 incubations, was 81 (27x3) in 5 strains (DR, DS, KK, LB, KD) (Table 11). For both locations, at the end of 18th days of incubation, all eggs were candled three times and the infertile ones were counted and removed, and all remaining eggs were transferred to hatching baskets.

The Percent fertility from set eggs per pen was calculated as number of set egg minus (the number of infertile eggs at candling per pen plus number of infertile eggs at hatch), divided by the number of set eggs per pen times 100. Upon hatch, each day-old-chick (DOC) was weighted and counted. The mean percent hatchability of set eggs was calculated from the number of DOC divided by the number of set eggs times 100. The mean percent hatchability of fertile eggs was calculated from the number of DOC divided by the difference between the number of eggs set and the number of eggs found to be infertile at candling and non-hatched eggs without embryo, times 100.

3.6.4. Sampling and measurements of carcass analysis

At the end of the experimental period (16 weeks of age), the males were starved of feed for 10 hours but given water. Nine males (three average body weight males) from each pen and treatment were randomly selected and slaughtered for carcass characteristics. After bleeding, the males were scalded in boiling water (60°C for 45 seconds before de-feathering and eviscerating) and then the feathers were removed. The carcass weight was calculated by removing the feathers and blood. Each organ were separated from the carcass and individually weighted.

The following primal cuts and organs were obtained; thighs, drumsticks, backs, breast, wings, neck, heart, liver, gizzard, spleen, abdominal fat, gastrointestinal track weight (GIT weight), shank and length of GIT. The cut parts were weighed, recorded and expressed as percentage of live body weight.

3.6.5. Additionally derived data were generated through calculation as follows.

- Weekly % lay (hen-day) = (100 x eggs per week divided by actual number of hens per pen) × 7).
- Overall % lay (hen-day) = average of weekly % lay from all the trial's 44 weeks (16 to 60 for all on-station) but for Dz on-farm trials it was 30 weeks (16 to 48).
- Total number of eggs per hen per 44wks = overall % lay × 308 (the number of days in 44 weeks for all on-station trials).
- Total number of eggs/hens over 30wks = overall %lay × 210 (the number of days in 30 weeks for on-farm trials).
- Average daily feed intake (ADFI) = pen's daily feed intake divided by number of birds (females+males) in the pen.
- Average daily feed intake (ADFI) = pen's daily feed intake divided by number of birds in each separated house for on-station trials in each pen.
- Average daily feed intake (ADFI) = pen's daily feed intake divided by number of birds in each participant houses for on-farm trials.
- Weekly % mortality = 100 x number of dead birds per sex divided by initial number of birds per sex.
- Age at first egg = when the first egg was found in the pen (Wondmeneh *et al*., 2015).
- Age at 5% Lay = when the pen reached 5% lay (Wondmeneh *et al.*, 2015).
- Age at peak of lay = when the pen reached maximal weekly % lay.
- Average % lay at peak of lay = the pen's maximal weekly %lay.
- Weekly % lay of open hens = weekly number of collected eggs per pen divided by number of open hens per pen × 100 only for the ComL & ExpCr.
- Weekly % closed hens = weekly number of closed hens per pen divided by number of

hens per pen x 100 only for the ComL & ExpCr.

▪ Yolk weight ratio (%) = 100 x yolk weight divided by egg weight.

▪ Albumen weight ratio (%) = 100 × albumen weight divided by egg weight.

▪ Shell weight ratio (%) = 100 × shell weight divided by egg weight.

▪ Egg shape index = 100 x egg width divided by egg length.

▪ Egg Mass (kg/hen) = the total number of eggs per hen per pen over the entire trials multiplied by average egg weight per hen per pen divided by 1000.

▪ The female FCR = the total AFI is divided by the sum of total egg mass + BWF-F 16-60 for on-station but it was 16-48 on-farm trials.

▪ Males Average Feed Intake cumulative (AFI cumulative) = AFI weekly × 7 + AFI cumulative...

▪ The male FCR Cumulative = the AFI cumulative/male body weight gain -35 (DOC weight).

▪ Thighs % = weight of thighs/ live birds × 100 and in similar way additionally data were generated for percent of drumsticks, backs, breast, wings, neck, heart, liver, gizzard, spleen, abdominal fat, gastro-intestinal track weight (GIT weight), shank and length of GIT.

▪ % dressed data were generated by sum of the percentile of (thighs, drumsticks, backs, breast, wings, neck, heart, liver, gizzard and spleen) edible parts in Ethiopia or dressed weight/live body weight x 100.

▪ Dressed weights were sum of the weights of (thighs, drumsticks, backs, breast, wings, neck, heart, liver, gizzard and spleen).

▪ % Rear parts were sum of the percentile of thighs, drumsticks and back.

3.7. Statistical Models and Data Analysis

Although the data of average daily feed intake (ADFI), body weight of females (BW-F) and males (BW-M) and egg production (% Lay) were calculated weekly, weeks are too short periods for reliable data. Therefore, the overall trial duration of 44 weeks (from 16 to 60 weeks of age) was split to five age periods (16-24, 25-32, 33-40, 41-48, and 49-60), each of eight weeks (except the last period, with 12 weeks). These age groups represent early egg production, pre-peak, peak, post peak and decline in egg productions, respectively.

For the ComL & ExpCr trials, the overall females trial duration of 44 weeks (from the beginning of week 16 to the end of week 60) was split to seven age periods (0-8,9-16, 17-24, 25-32, 33-40, 41-48, and 49-60), each of 8 weeks (except the last period, with 12 weeks). These age groups represent growth stages, pullet stages, early egg production, pre-peak, peak, post peak and decline in egg productions respectively. The overall males trial duration of 16 weeks (from the beginning of week 0 to the end of week 16) was split in to three age periods (0-4, 5-8, and 9-16), each of 4 weeks (except the last period, with 8 weeks).

For the on-farm trials, the overall females trial duration of 30 weeks (from the beginning of week 16 to the end of week 48) was split to four age periods (16-24, 25-32, 33-40 and 41-48) except AFI (as it was split to six age periods), each of 8 weeks and the overall males trial duration of 12 weeks (from the beginning of week 0 to the end of week 12) was split in to three age periods (0-4, 5-8, and 9-12), each of 4 weeks. These age groups represent early egg production, pre-peak, peak, post peak and decline in egg productions respectively.

The ANOVA model for DZARC included PS and Age period as main effects, their interaction (PS x Age) and Houses as blocks. Thus, the ANOVA was conducted according to the following model:

$$Y_{ijklm} = \mu + PS_i + A_j + X_k + (PSA)_{ij} + H_l + e_{ijklm}$$

Where: Y_{ijklm} = the y^{th} Observed response,

μ = overall mean,

PS_i = PS breed effect,

A_j = age effect,

X_k = covariate of initial body weight,

$(PSA)_{ij}$ = PS ×Age interaction effect,

H_l = House (block) effect,

e_{ijklm} = random error.

The Analysis of Variance (**ANOVA)** model for HU included PS and age in weeks as main effects and their interaction (PS by age). Thus, the ANOVA was conducted according to the following model: - $Y_{ijkl} = \mu + PS_i + A_j + X_k + (PSA)_{ij} + e_{ijkl}$

Where: Y_{ijkl} = the y^{th} observed response,

μ = overall mean,

PS_i = PS breed effect,

A_j = age effect,

X_k = covariate of initial body weight,

$(PSA)_{ij}$ = PS × age interaction effect,

e_{ijkl} = random error.

The ANOVA model for DZARC on-station trials for females and males were included as ComL & ExpCr and age in weeks as main effects and their interaction (ComL & ExpCr x Age). Thus, the ANOVA was conducted according to the following model:

$y_{ijkl} = \mu + B_i + A_j + X_k + (BA)_{ij} + e_{ijkl}$

Where: Y_{ijkl} = the yth observed response,

μ = overall mean,

B_i = ComL & ExpCr breed effect,

A_j = age effect,

X_k = covariate of initial body weight

$(BA)_{ij}$ = (ComL & ExpCr) x Age interaction effect,

e_{ijkl} = random error.

The ANOVA model for Debre Zeit town on-farm trials for females and males were included as ComL and age in weeks as main effects and their interaction (ComL x age). Thus, the ANOVA was conducted according to the following model:-

$$Y_{ijkl} = \mu + B_i + A_j + X_k + (BA)_{ij} + e_{ijkl}$$

Where: Y_{ijkl} = the yth observed response,

μ = overall mean,

B_i = ComL breed effect,

A_j = Age effect,

X_k = covariate of initial body weight

$(BA)_{ij}$ = ComL x Age interaction effect,

e_{ijkl} = random error.

Mean separation was determined using Tukey test with 5% probability. The JMP software Version 12 (SAS Institute Inc., 2014) was used to analyze the data.

4. RESULTS

This section is divided into four sub-sections. In the first and second sub-section of (4.1) and (4.2), results from evaluation of the production and reproduction performances of commercial layer parent stock in Debre Zeit and Hawassa University on- station management conditions, were respectively presented. In the third sub-section of (4.3), results from evaluation of egg and meat production performances of commercial layers and experimental crosses on-station management conditions and in the fourth sub-section of (4.4), results from evaluation Egg and meat Production performances of commercial layers under on-farm management conditions in Debre zeit town in Ethiopia are presented.

4.1. Parent Stock (DZARC Trials)

4.1.1. Feed intake

Means of average daily feed intake (ADFI, g/bird per day) of females and males (together) of the seven PSs in each of five age in weeks are presented in Figure 2, whereas feed intake over the entire trial age in weeks, expressed as ADFI averaged from 16 to 60 wks and also total feed intake (TFI) per bird during the trial's 308 days, are presented in Table 4. During the trial's first eight weeks (16-24), NB hens (and few males) exhibited the lower mean ADFI (about 85 g/hen per day), followed by NC and LB (slightly more than 90 g/hen per day) with mean ADFI of the other four PSs (DR, DS, KK and LD) reaching almost 100 g/hen per day from 16 to 24 weeks (Figure 2). These four PSs continued to exhibit the higher ADFI, with LB joining them during the 33-40 wks, and from 33 to 60 weeks, mean ADFI of these five PSs ranged between 125 to 130 g/h/d. From the 25-32 age in weeks and onward, the chickens – mostly females – of NC and NB (actually from the same maternal line) exhibited the lower ADFI means, rising from 100 g/hen per day during 25-32 wks, through ~120 g/hen per day during 33-40 and 41-48 wks, up to around 125 g/hen per day, only slightly lower than the other five PSs (Figure 2).

The overall feed intake was significantly higher ($P<0.05$) in DR, DS and LD, with mean ADFI over the entire trial (16-60 wks) ranging 121-122 g/hen per day, accumulating to mean TFI around 37.5 kg/hen over the trial's 308 days. Significantly lower ($P<0.05$)

overall feed intake was exhibited by NB and NC, with mean ADFI (16-60 wks) ranging 110-112 g/hen per day, accumulating to 34.0 and 34.5 kg/hen. The other two PS, KK and LB, were intermediate, with mean ADFI of about 118 g/hen per day and mean TFI of 36 and 36.7 kg/hen (Table 4).

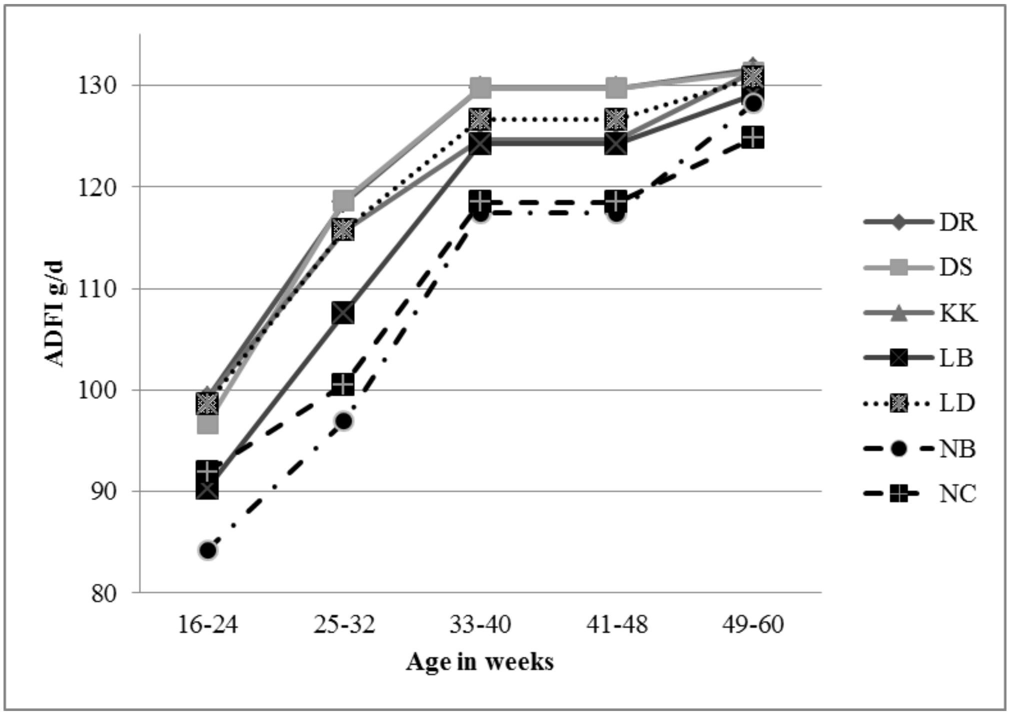

Figure 2. Average daily feed intake (ADFI) per chicken from the 7 Parent Stocks at 5 age periods of the trial.

(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novogen Brown; NC = Novogen Color).

4.1.2. Body weight

The body weight (BW) curves (females and males) during the trial's 44 weeks of the seven PSs are presented in Figure 3. Means by PS and sex of the initial (16 wks) and final (60 wks) BW are presented in Table 4. At 16 wks of age, the PSs did not differ significantly ($P>0.05$) in BW of females, with their means ranging from approximately 1200 to 1330 g. In contrast, the meat-type males of the two specialized PS (LD and NC) were significantly the heaviest ($P<0.05$) (about 1650 g) already at 16 wks, followed by the males of DR, DS and KK (means ranging from 1662 to 1995 g), and the males of the two egg-type PS (LB and NB) exhibiting the lowest BW (about 1200 g).

There were highly significant (P<0.05) PS*Age interactions in body weight, as evident from the growth curves (Figure 3). Among the females, the interaction was mainly due to DR, where the mean BW increased up to 1850 g at 32 wks up to nearly 2000g at 60 wks, significantly higher (P<0.05) than all other PS (Table 4). The DS females, also bred by Dominant CZ, exhibited the second heaviest BW mean (about 1750 g) at wks, but their mean only slightly increased after that age, to 1798.3g at 60 weeks (Table 4), not significantly higher (P>0.05) than the other five PSs that exhibited similar BW curves over age, with relatively rapid elevation from 16 to 32 wks (period of entering sexual maturity), followed by a plateau up to 48 wks, and further elevation to 60 wks (Figure 3).

Table 4. Least square means of body weight of females and males, average daily feed intake per chicken (ADFI), and total feed intake per chicken during the entire trial, of seven Parent Stocks[1].

Parameters	Age (wks)	DR	DS	KK	LB	LD	NB	NC
Ave. daily feed intake (ADFI, (g/bird/day)	16-60	122.5^{a}	121.9^{a}	119.4^{b}	116.9^{b}	120.9^{a}	110.3^{c}	112.0^{c}
Total feed intake (TFI, kg/bird/308 days)	16-60	37.7^{a}	37.5^{a}	36.8^{b}	36.0^{b}	37.2^{a}	34.0^{c}	34.5^{c}
Body weight of females (BW-F, g)	16	1336.7	1286.3	1233.5	1244.1	1242.0	1196.7	1196.0
	60	1994.1^{a}	1798.3^{b}	1753.8^{b}	1620.0^{b}	1671.7^{b}	1599.0^{b}	1642.5^{b}
Body weight of males (BW-M, g)	16	1995.1^{b}	1662.7^{c}	1777.5^{bc}	1220.3^{d}	2988.0^{a}	1190.5^{d}	3139.8^{a}
	60	2955.4^{c}	2704.0^{cd}	2734.5^{cd}	2574.3^{d}	3659.3^{b}	2585.5^{d}	5027.5^{a}
Source of variation								
PS		****	****	****	****	****	****	****
Weeks		****	****	****	****	****	****	****
PS ×Ages		****	****	****	****	****	****	****

$^{a–d}$Means with different letters within rows differ significantly by Tukey test at P<0.05.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novogen Brown; NC = Novogen Color.

Among the males, the PS*Age interaction was mainly due to the NC males that reach mean BW of about 4700g at 32 wks, about 1500g higher than LD males, 2000g higher than DR, DS and KK males, and almost 3000g higher than the males of LB and NB, the two egg-type PS (Figure 3). The mean BW of the two later PS continues to increase up to ~2580g at 60 wks, similar to the means of DS and KK (~2720g). The 60-wks mean BW of DR males was somewhat higher (2955g), whereas the final mean BW of LD males was significantly higher ($P<0.05$) (3659g) and the NC males exhibited the highest mean BW (5027g) at the end of the trial (Table 4, Figure 3).

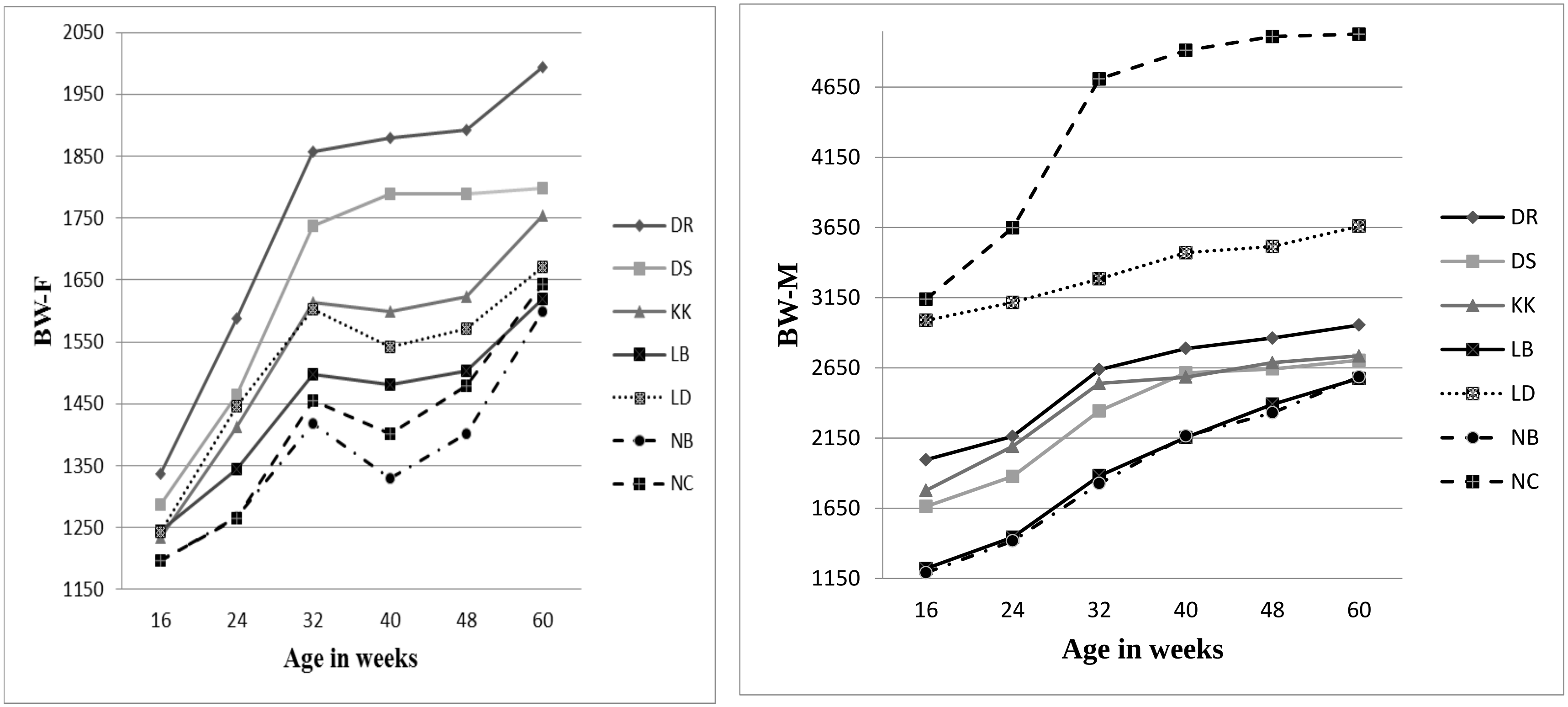

Figure 3. Average body weight (BW) of females (F) and males (M) from the 7 Parent Stocks at 6 ages of the trial.
(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novogen Brown; NC = Novogen Color).

4.1.3. Egg production

Egg production parameters, all hen-day (i.e., per live hens), are presented for the seven PSs in Table 5 and in Figure 4. The earliest sexual maturity - first egg at ~132 days and 5% lay at ~140 days - was exhibited by LB and LD, followed by NB, DS and DR, with NC and KK being the last to lay 1st egg (about 150 days) and to reach 5% lay (almost 160 days). The PSs differed also in % lay, especially during the 25-32 weeks, with LD leading with an average of 70% whereas NC and NB trailing with an average of 30% lay during the 25-32 weeks (Figure 4). The laying rate of all PS continues to increase during the 33-40 weeks, ranging from over 80% (LB and LD) to 65% (NB) and 60% (NC). The later's % lay continued to slightly increase during the 41-48 weeks, and already started to decline in all other PS (Figure 4). Accordingly, NC hens were the last to reach peak of lay, at 316 days of age, whereas all other six PS were statistically similar, with age at peak ranging from 232 to 247 days of age (Table 4). The % lay at peak was the higher in LB and LD, averaging 92%, and lowest in NB (68%) with the other PS in between (Table 5).

The age at onset of lay and the rate and persistency of lay thereafter, were all combined into the average % lay during all 44 weeks of the trial. These overall laying percentages were multiplied by 308 (number of days in 44 weeks) to calculate the mean total number of eggs per hen. The higher egg production, 64.2% (197.6 eggs) was exhibited by LD, followed (but significantly lower ($P<0.05$)) by LB with 56.3 % and 173.5 eggs (Table 5). In spite of similarities in age at onset of lay and at peak, and % lay at peak, LD hens produced more eggs because their % lay elevated faster and was significantly higher ($P<0.05$) than that of LB (and all other PS) during the 25-32 period (Figure 4).

Table 5. Least square means of age at first egg and at 5% Lay[1], age at peak of lay[1], peak % Lay[1], average %Lay (hen-day) over all 44 weeks, and the calculated total number of eggs/hen-day, of seven Parent Stocks[2].

Parameters	DR	DS	KK	LB	LD	NB	NC
Age at first egg in pen (days)	140.0[b]	138.2[b]	152.3[a]	131.4[c]	133.3[c]	138.3[b]	148.8[a]
Age at 5% Lay (days)	154.8[a]	156.8[a]	158.2[a]	139.8[b]	144.8[b]	147.6[ab]	159.9[a]
Age at peak of lay (days)	240.6[b]	247.9[b]	244.3[b]	247.6[b]	243.3[b]	232.5[b]	316.1[a]
%Lay at peak of lay	79.5[b]	72.7[bc]	75.0[b]	91.0[a]	92.7[a]	68.1[c]	81.0[b]
%Lay, Weeks 16-60 (hen-day)	52.8[bc]	44.1[d]	48.7[cd]	56.3[b]	64.2[a]	47.0[cd]	45.8[d]
Number of eggs/hen/44wks	162.5[bc]	135.8[d]	149.9[cd]	173.5[b]	197.6[a]	144.9[cd]	140.9[d]

[a–d] Means with different letters within rows differ significantly by Tukey test at $P<0.05$.
[1]All egg production data are per live hens ("hen-day").
[2]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novogen Brown; NC = Novogen Color.

The lower total egg production was exhibited by the DS hens (135.8 eggs, Table 5), due to poor laying consistency, with the lower egg production (~50 % lay) during the 49-60 age in weeks (Figure 4).

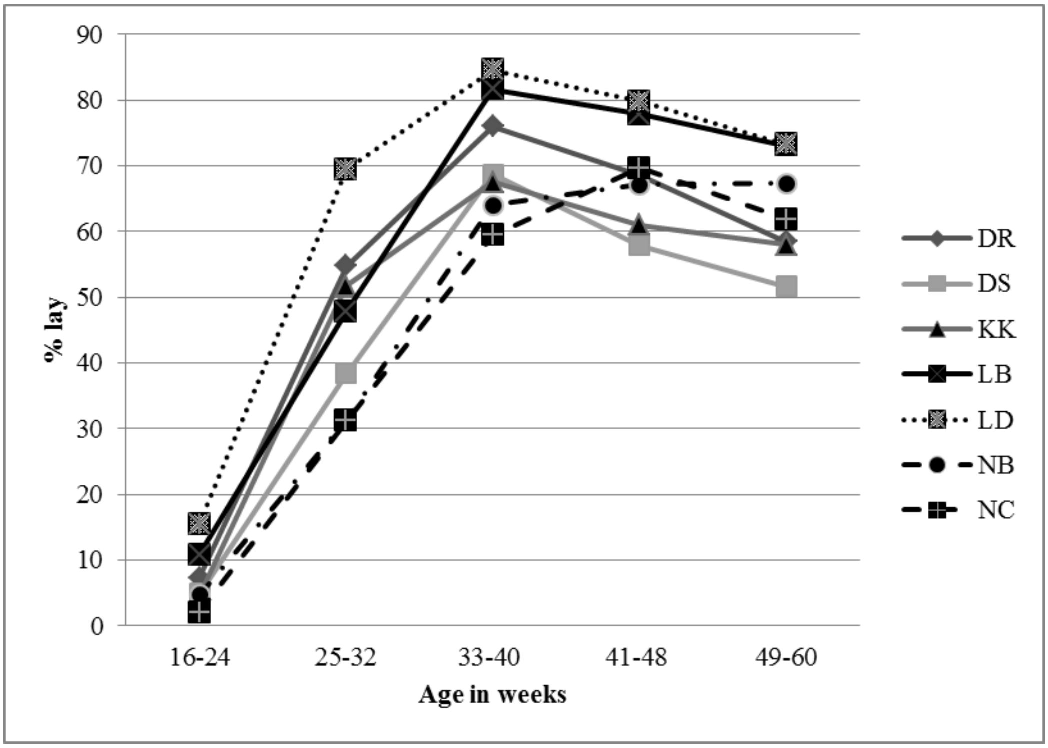

Figure 4. Average % Lay (hen-day) of hens from the 7 Parent Stocks at 5 age periods of the trial.
(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novogen Brown; NC = Novogen Color).

4.1.4. Fertility and hatchability

Eggs were collected for incubation at three ages, when the hens were 28, 34 and 44 weeks old. At each age, 12 eggs were randomly sampled from each pen, hence from the PS with seven replicated pens (DR, DS, LB and LD), 84 eggs were incubated at each age, and 252 eggs over the three ages. In the PS with only 4 replicated pens (KK, NB and NC), 48 eggs were incubated at each age, and 144 eggs over three ages. The results -- % fertility, % hatchability of fertile eggs, and % hatchability of set eggs – are presented for each age, graphically (Figure 5) and numerically (Table 6).

At 28 weeks, the percentage of fertile eggs (% fertility) varied considerably among the PS. It was quite high (around 80%) in DR, DS and KK, lower (62%) in LB, further lower in NB (46%) and very low in LD and NC (32% and 22%, respectively, Table 6). Six weeks later (34 weeks), % fertility of the top three PS remained at 80-88% and it increased to all other PS – to a reasonable level in LB (~75%) and in NB (63%). It also increased in LD and NC, but only to 40%, a non-acceptable level (Figure 5a). Because

LD and NC were bred to produce heavy types of layer chickens, the males in these two PS were much heavier than their female partners (Table 4). To test the possibility that the low fertility was due to difficulty in natural mating's, the hens of LD and NC were artificial inseminated with semen collected from their male pen mates, starting from 40 weeks of age. The AI elevated the % fertility of LD and NC to almost 80%, the same level as all other PS (Table 6, Figure 5a).

The percentage of fertile eggs that hatched (% hatch/fertile) at 28 weeks was very similar (around 79%) in all PSs except KK with significantly higher ($P<0.05$) mean (92.3%). At 34 weeks, the % hatch/fertile of NC dropped to 35%, whereas the percentages of all other PS were quite similar to those of 28 weeks (Figure 5b, Table 6). At 44 weeks, the % hatch/fertile of NC was 83.3%, suggesting that the 35% at 34 weeks was accidental rather than real reduction in hatchability. All seven PS exhibited quite similar % hatch/fertile at 44 weeks, ranging from 75 to 88%.

The percentage of all set eggs that hatched (% hatch/set) combines % fertility and % hatch/fertile. At 28 and 34 weeks, the PS means of % hatch/set were spread over a very wide range, from KK (76 and 85%), followed by DR and DS (62 to 66%), LB (46 and 56%) and NB (37 and 46%). The % hatch/set means of the two PS with heavy males under natural mating's were very low – 24 and 29% in LD, 17 and 8% in NC (Table 6, Figure 5c). In contrast to the two early ages, at 44 weeks all seven PS exhibited similar % hatch/set, ranging from 66 and 63% (DR and KK) to ~57 and 54% (DS, LB and NB). With AI, the two heavy-males PSs (LD and NC), reached ~66% hatch/set, similar or superior to the other PS (Table 6, Figure 5c).

Table 6. Number of eggs set at each of 3 ages[1], and least square means of % fertility, % hatchability of fertile eggs and of set eggs, weight of set eggs, body weight of day-old chicks of seven Parent Stocks[2].

	Age (wks)	DR	DS	KK	LB	LD	NB	NC
Total eggs set/PS/age[1]		252	252	144	252	252	144	144
Fertility from set eggs (%)	28	83.0[a]	77.1[ab]	82.6[a]	62.0[b]	31.8[c]	46.1[bc]	22.2[c]
	34	81.3[a]	79.4[ab]	88.5[a]	79.8[ab]	35.9[c]	63.2[b]	40.0[c]
	44[3]	80.6	76.2	75.1	75.8	75.0	69.5	78.5
Hatchability from fertile eggs (%)	28	78.6	79.2	92.6	77.7	76.3	89.4	79.1
	34	79.6[ab]	79.5[ab]	96.3[a]	77.8[ab]	68.6[b]	76.1[ab]	23.1[c]
	44[3]	81.8[ab]	75.2[b]	84.1 [ab]	74.8[b]	88.8[a]	78.9 [ab]	83.3 [ab]
Hatchability from set eggs (%)	28	65.5[ab]	62.3[ab]	76.4[a]	46.5[bc]	24.7[c]	37.4[bc]	17.6[c]
	34	66.3[b]	63.3[b]	85.0[a]	56.5[bc]	29.0[d]	46.5[c]	8.2[e]
	44[3]	65.8[a]	57.2[b]	63.1[a]	56.3[b]	66.6[a]	54.1[b]	65.2[a]
Calculated expected chicks/hen/ 44wks (based on % hatchability averaged over the 3 ages)		106.2[a]	82.3[b]	113.0[a]	91.9[ab]	79.1[b]	66.6[bc]	46.7[c]
Calculated expected chicks/hen/44 weeks (based on % hatchability at 44 weeks of age)		106.6[b]	77.8[c]	94.9[bc]	97.6[b]	131.5[a]	77.9[c]	91.7[bc]
Weight of eggs set (g), averaged over 3 ages[4]		60.3[a]	58.5[a]	49.8[c]	54.7[b]	54.3 [b]	54.2 [b]	55.2 [b]
Weight of day old chicks (g), averaged over 3 ages[4]		34.3[a]	34.1[a]	28.7[d]	31.8[bc]	32.6[b]	30.7[c]	32.0[bc]

[a–e]Means with different letters within rows differ significantly by Tukey test at P<0.05.
[1]Eggs were collected for incubation 3 times, when the hens were 28, 34 and 44.weeks of age;
[2]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novogen Brown; NC = Novogen Color.
[3]During this period, artificial insemination (AI) was used in the pens of LD and NC, where the males were much heavier than the hens.
[4]PS*Age interaction was not significant.

The expected number of chicks per hen in each pen was calculated by multiplying the total number of eggs per hen (Table 6) by the % hatch/set averaged over the three ages, and also by the % hatch/set at 44 weeks only, and both are presented in Table 6. The results of % hatch/set suggest that only at the 3rd incubation test (at 44 weeks), the seven PS exhibited their true potential of fertility and hatchability, realizing that heavy-males PS require AI in order to reach acceptable level of fertility. Accordingly, LD lead with the mean of 131.5 expected chicks, followed by DR, LB, KK and NC with means ranging from ~106 to ~92 chicks, and finally DS and NB with ~78 chicks (Table 6).

This Table 6 also shows the mean weight of set eggs and hatched chicks of each PS, averaged over the three ages of incubation. The eggs of DR and DS were the heaviest (60.3 and 58.5 g) and their chicks were the heaviest (34.3 and 34.1 g). The KK had the smallest eggs (49.8 g) and chicks (28.7 g), and mean egg and chick weights of the other four PS were about 54-55 g and 31-32 g.

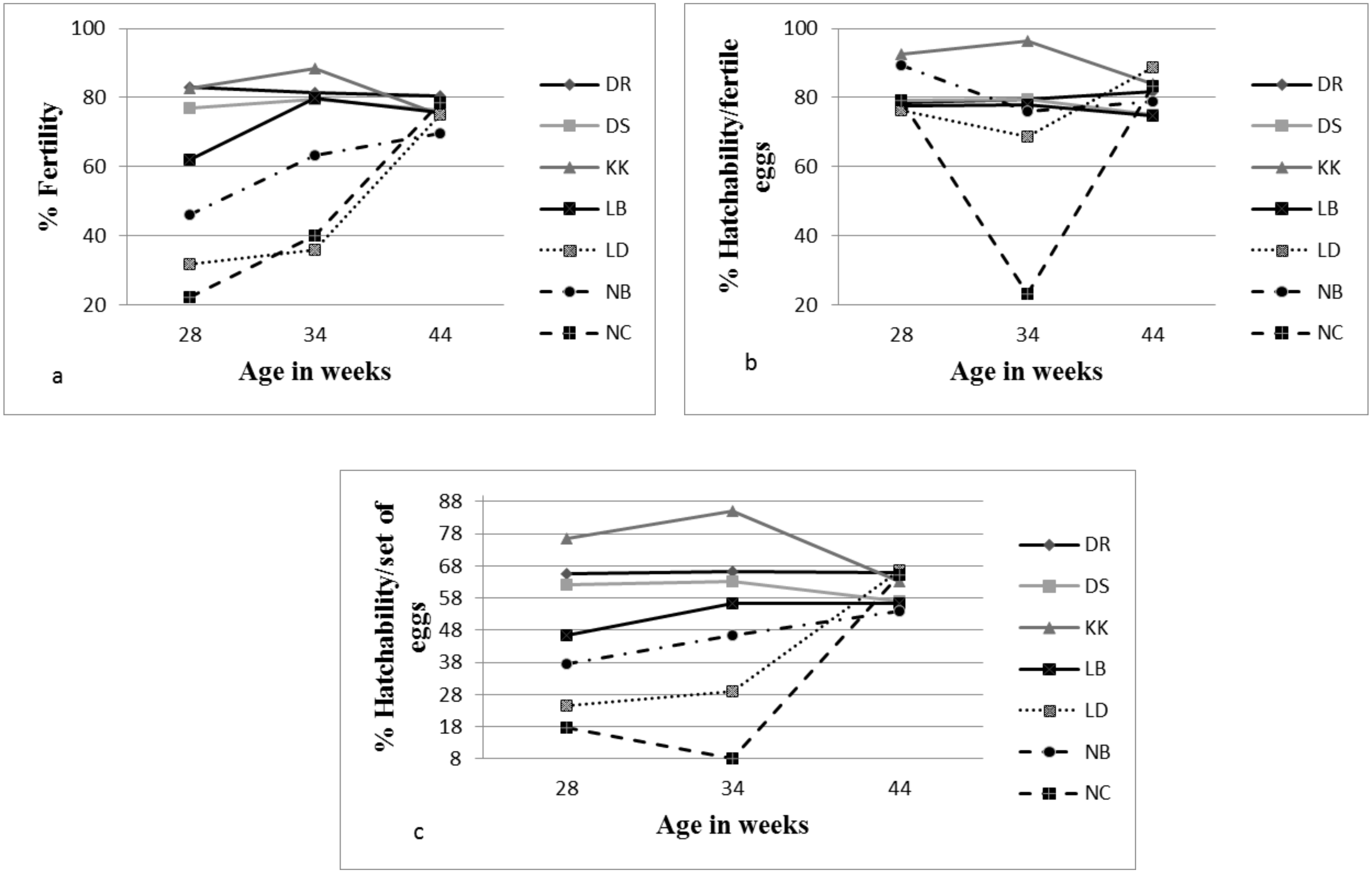

Figure 5. Fertility of the parent stocks at three weeks of age periods. A. Average % fertility, B. % hatchability from fertile eggs, and C. % hatchability from all set eggs.

(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novogen Brown; NC = Novogen Color).

4.1.5. Fertility and hatchability of crosses between genetically similar vs remote parents

Among the seven commercial PS in this study, in three of them - DR, DS and KK - the females and males shared the same genetic background and differ only in a single sex-linked gene that allows sexing of day-old chicks. The fertility and hatchability of eggs from these three 'Pure" (similar-parents) PS were compared to those of the three experimental PS consisted of crosses between hens from one PS and males from a genetically different PS. Thus, as part of this study's testing of seven commercial PSs, DR hens were mated with DR males (♀DR×♂DR 'Pure' PS) in seven pens and also with KK males (♀DR×♂KK 'Cross' PS) in four other pens. Similarly, DS hens were mated with DS males (♀DS×♂DS 'Pure' PS) in seven pens and also with DR males (♂DS×♀DR 'Cross' PS) in four other pens, and KK hens were mated with KK males (♀KK×♂KK 'Pure' PS) in four pens and also with DS males (♀KK×♂DS 'Cross' PS) in four other pens. The data of % fertility, % hatch/fertile and % hatch/set eggs obtained at the three ages (28, 34 and 43 weeks) from these six PSs were analyzed by a two-way model with hens genetics (DR, DS, KK) being one factor with three levels, and parents' similarity within the PS ('Pure' versus 'Cross') being the second factor with two levels, and the results are presented in Table 7.

The eggs from DR, DS and KK hens exhibited similar means of % fertility within the 'Pure' mating's and within the 'Cross' mating, hence the hens' main effect was not significant. But within each hen PS, % fertility of the 'Cross' eggs was significantly higher than in the 'Pure' eggs and averaged over the three hens' PS, fertility was 86% in 'Cross' eggs and only 81.3% in 'Pure' eggs, a highly significant (P=0.006) difference (Table 7). For % hatch/fertile, there was highly significant effect (P<0.001) of hens' PS, with KK exhibiting about 92% compare to DR and DS with similar means of hatch/fertile, ranging from ~80 to ~83%. There was also a significant (P=0.036) advantage of 'Cross' over 'Pure', averaging 85.9% vs. 83% (Table 7). Also for % hatch/set eggs, the main effect of hens' PS was highly significant (P<0.001), with KK exhibiting higher means than DR and DS within 'Pure' and within 'Cross'. There was also highly significant advantage (P=0.003) of mating between genetically remote parents, with 74% hatch/set eggs from 'Cross' mating's compare to 67.7% hatch/set eggs from 'Pure' mating (Table 7).

Table 7. Least Square means averaged over 3 incubations[1], of % fertility and hatchability of eggs laid by DR[2], DS[2], and KK[2] hens either mated with males from the same PS (similar parents, 'Pure') or crossed with males from another PS (remote parents, Cross).

PS	DR hens		DS hens		KK hens		'Pure' vs. 'Cross' means, averaged over the 3 PS			Significance (P value)		
Parameters	♀DR×♂DR	♀DR×♂KK	♀DS×♂DS	♀DS×♂DR	♀KK×♂KK	♀KK×♂DS	'Pure'	'Cross'	Re-Si	Hens PS main effect	'P' vs. 'C' main effect	Hens by 'P' vs 'C' interaction
%Fertile/set eggs	82.5	87.7	80.1	84.7	81.5	85.6	81.3	86.0	4.7**	0.368	0.006	0.969
%Hatch/fertile eggs	79.7[b]	81.6[y]	78.1[b]	83.2[y]	91.4[a]	92.9[x]	83.0	85.9	2.9*	< 0.001	0.036	0.459
%Hatch/set eggs	65.7[b]	71.5[y]	62.9[b]	70.6[y]	74.8[a]	79.9[x]	67.7	74.0	6.3**	< 0.001	0.003	0.839

[1]Eggs were collected for incubation 3 times, when the hens were 28, 34 and 44 weeks of age;

[2]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek

*, **The remote-crossing effect (difference between the means of 'Remote' and 'Similar' over the 3 PSs) was significant at 0.05 and 0.01 levels, respectively.

[a, b]Means of 'Pure' Parent Stock with different letters within rows differ significantly by the Tukey test at P<0.05.

[x, y]Means of 'Crosses' with different letters within rows differ significantly by the Tukey test at P<0.05.

4.1.6. *Egg size and quality*

Egg parameters were measured five times during the trial, when the hens were 26, 30, 36, 40 and 44 weeks old. There was no substantial PS*Age interactions, and therefore PS means averaged over all five ages are presented in Table 8. There were significant differences ($P<0.05$) among the PS in egg weight, with DR and DS laying the largest eggs (almost 60 g), KK hens laying the smallest eggs (51.8g), and the other four PS (LB, LD, NB and NC) forming an intermediate group; their mean egg weight ranged from 54.5 to 56.6g (Table 8). As expected, the PSs were ranked similarly for all egg-size-related measurements: yolk weight, albumen weight and egg width and length. There was only one exception: shell weight was similar in DR and DS (largest eggs) and KK (smallest eggs). Accordingly, KK eggs exhibited the highest % shell weight and consequently the lowest % albumen. The seven PS did not differ significantly ($P>0.05$) in % yolk weight and in egg shape index (Table 8). There were no significant differences ($P>0.05$) among PS in shell thickness (around 0.33 mm), yolk height (17.3-18.2 mm) and albumen height (7-7.4 mm) and therefore these means are not presented. In addition, floor systems are the environmentally controlled enclosures which enable greater uniformity in shell thickness, shell color and yolk color. Egg shell color was also noted - the eggs of DR, DS and KK were white-creamy and those of LB, LD, NB and NC had brown shells.

Table 8. Least square means of egg weight, yolk weight, albumen weight, shell weight, egg width and length, shell thickness, yolk color, yolk height, albumen height of seven Parent Stock[1].

Parameters	DR	DS	KK	LB	LD	NB	NC
Egg weight (g)	59.9^{a}	59.3^{a}	51.8^{c}	54.9^{b}	54.5^{b}	55.7^{b}	56.6^{b}
Yolk weight (g)	16.4^{a}	16.2^{a}	14.4^{c}	14.7^{c}	14.9^{c}	15.6^{b}	15.6^{b}
Albumen weight (g)	35.6^{a}	35.3^{a}	29.4^{c}	32.5^{b}	31.8^{b}	33.6^{b}	33.2^{b}
Shell weight (g)	7.87	7.81	7.94	7.70	7.76	6.48	7.78
Yolk weight ratio (%)	27.4	27.3	27.8	26.7	27.3	27.9	27.5
Albumen weight ratio (%)	59.4^{a}	59.5^{a}	56.4^{b}	59.1^{a}	58.4^{a}	60.4^{a}	58.8^{a}
Shell weight ratio (%)	13.2^{b}	13.2^{b}	15.3^{a}	14.1^{ab}	14.3^{ab}	11.7^{c}	13.7^{b}
Egg width (mm)	43.9^{a}	43.2^{a}	40.7^{d}	42.1^{b}	41.4^{c}	42.2^{b}	43.1^{a}
Egg length (mm)	56.2^{a}	55.7^{a}	53.4^{b}	53.4^{b}	53.7^{b}	53.7^{b}	54.3^{b}
Egg shape index	78.2	77.5	76.5	78.8	77.9	78.8	78.6

[a–d] Means with different letters within rows differ significantly by Tukey test at $P<0.05$.
[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novogen Brown; NC = Novogen Color.

4.1.7. Mortality

The Least square means of average female and male mortality over the entire trial (Week 16 to 60) of seven Parent Stocks are presented in Table 9. In this mortality of PS trials were mostly accidental but also disease outbreaks that occurred in all PS at growing stages due to vaccine failure. The female and male mortality of NC were significantly higher ($P<0.05$) than all other PSs due to high mortality between 25 and 32 weeks (males) and 33 to 40 weeks (females) of age. The females of DS and LD exhibited the lowest mortality (0.24%), with the other PS exhibiting intermediate mortality (Table 9).

Among males, there was very low mortality (0.05%) in DS, with similar mortality, between 0.66 and 0.99%, among the males of all other 5 PS (DR, LD, KK, NB and LB). There were significant difference ($P<0.05$) among PS in average PS mortality rate during the laying stages. The study also showed that there were significant differences ($P<0.05$) on average PS mortality at the different ages in week and the interaction (PS x Ages) among PS at all stages of the laying phases in average female and male mortality.

Table 9. Least square means of female and male mortality of seven Parent Stock[1].

Parameters		DB	DS	KK	LB	LD	NB	NC
Mortality (% over 44 weeks)	F	0.60[b]	0.28[b]	0.46[b]	0.41[b]	0.21[b]	0.70[ab]	1.26[a]
	M	0.66[bc]	0.05[c]	0.77[abc]	0.99[ab]	0.70[bc]	0.79[abc]	1.86[a]
Source of variation								
PS		****	****	****	****	****	****	****
Weeks		****	****	****	****	****	****	****
PS × Ages		****	****	****	****	****	****	****

[a–c]Means with different letters within rows differ significantly by the Tukey test at P<0.05.
[1]DB = Dominant Red Barred; DS = Dominant Sussex; KK = Potchefstroom Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown, NC = Novogen Color.

4.2. Parent Stock (HU Trials)

4.2.1. Feed intake

Average feed intake (g/bird/day) of female and male together at different periods for all the five PS layers were presented in Table 10 and Figure 6. Significantly higher (P<0.05) average daily feed intakes were recorded in DR and DS than other PS in week 16 to 24 and 25 to 32, followed by the KK, while the lower average feed intakes were recorded in LB and LD. This superiority in PS, DR and DS may be due to heavy body weight of the PS layers. There were significant difference (P<0.05) among the test PS in average feed intakes (g/bird/day) of female and male together during the laying stages (16 to 32 weeks of age). The average feed intake (between 33 to 60 weeks of age) was not significantly different (P>0.05) among PS across all the ages.

In general, there were no significant difference (P>0.05) in average feed intakes (g/bird/day) for both sexes during the laying stages (16 to 60 weeks of age). There were significant difference (P>0.05) among PS within age in week but no significant difference (P>0.05) for the PS by age interaction at all stages of the laying phases.

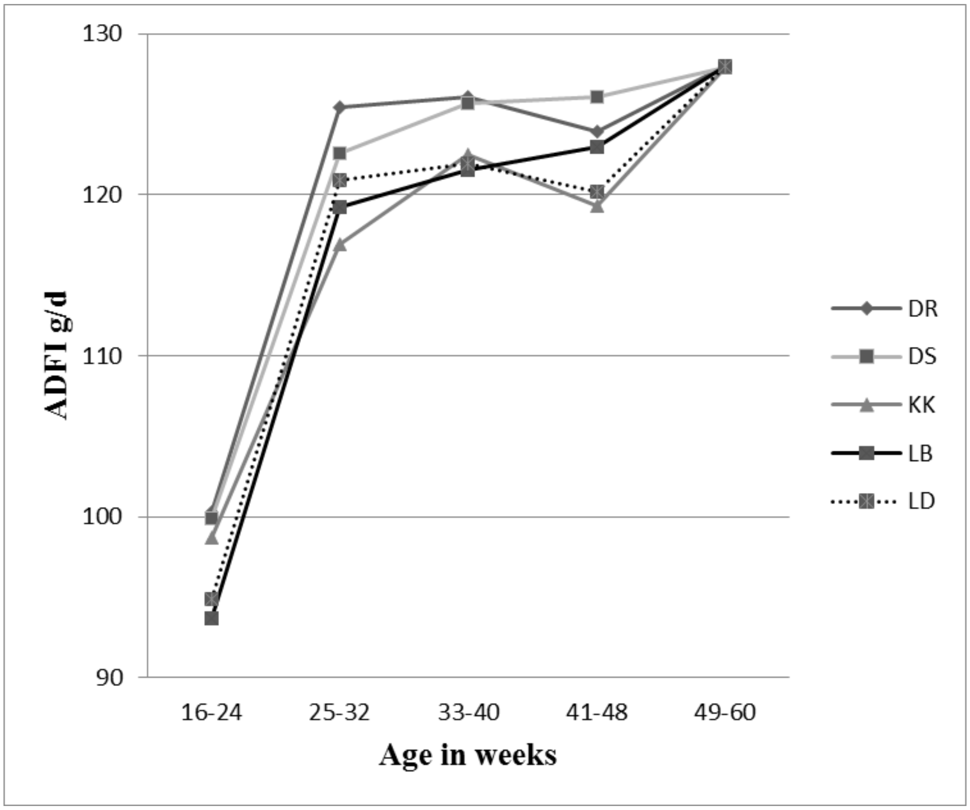

Figure 6. Average daily feed intake (ADFI) per chicken from the 5 Parent Stocks at 5 age periods of the trial.

(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual).

4.2.2. Body weight

Body weights (LSM) (g/bird/wk) of female and male chickens of each Parent Stock (PS) at different periods were shown in Table 10 and Figure 7. There were significant differences (P<0.05) among PS layers in average body weight (g/bird/wk) of female during the laying stages (16 to 60 weeks of age). The result also shows significant difference (P<0.05) within age but the PS by age interactions effect on the average female body weight at all stages of the laying phases was not significant (P>0.05). Significantly highest (P<0.05) average female body weight was recorded in DR, followed by DS and KK. The lowest average female body weights were recorded in LD and LB at all ages of the laying phases.

There were significant differences ($P<0.05$) among all PS in average body weight (g/bird/wk) of male between (16 to 60 weeks of age). The analysis of the result also showed that there were significant effect ($P<0.05$) among PS layers within age in week but not significantly different ($P>0.05$) among PS and PS by age interaction on the average male body weight at all stages of the laying phases.

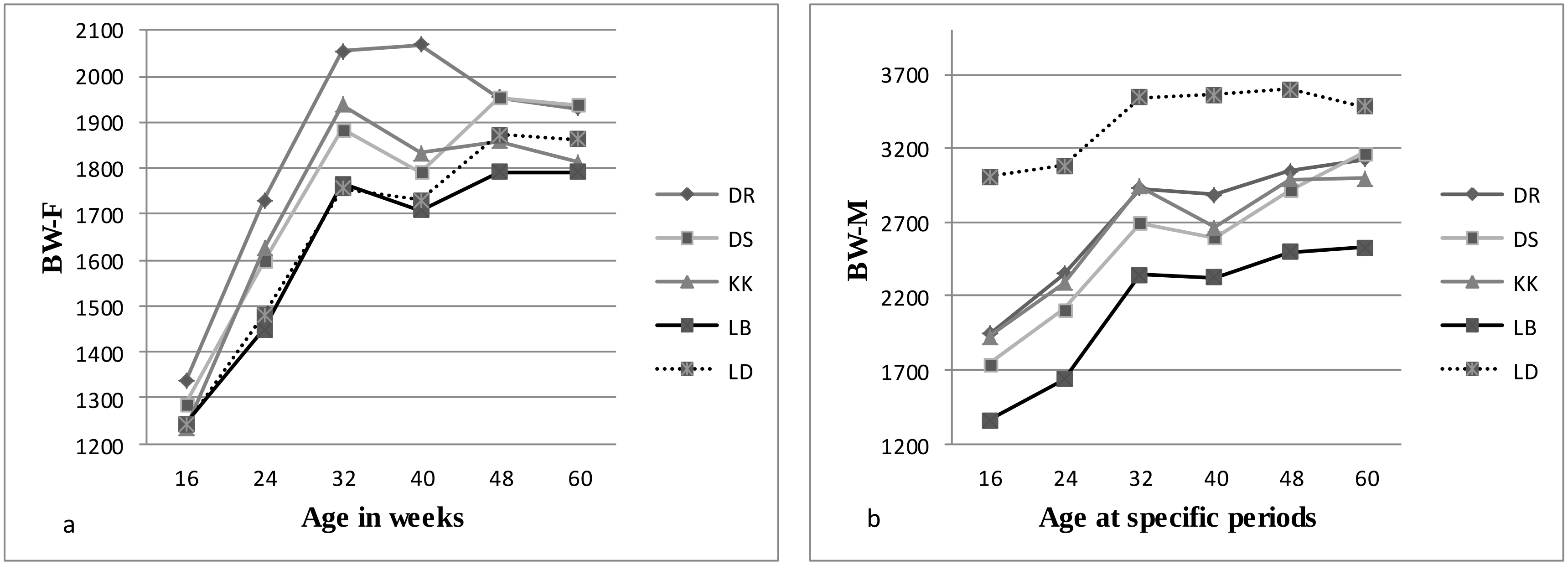

Figure 7. Average body weight (BW) of females (F) (a) and males (M) (b) from the 5 Parent Stocks at 6 ages of the trial.
(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual).

The average male body weight (g/bird/wk) of LD was significantly higher than other PS, followed by DR, KK and DS, the lowest average male body weights were recorded in LB during studies. This (LD) superiority was from the dwarf (homozygous dw/dw) meat-type line of LD. The other males were from the layer-types and hence lowest in body weight during the laying stages compared to that of LD male.

Table 10. Least square means of body weight of females and males, average daily feed intake per chicken (ADFI) and total feed intake per chicken during the entire trial, of five Parent Stocks[1].

Parameters	Age (wks)	DR	DS	KK	LB	LD
Ave. daily feed intake (ADFI, (g/bird/day)	16-60	120.7	120.4	117.1	117.1	117.2
Total feed intake (TFI, kg/bird/308 days)	16-60	37.1	37.1	36.2	36.1	36.1
Body weight of females (BW-F, g)	16	1336.7	1286.3	1233.5	1244.1	1242.0
	60	1930	1938.7	1813.3	1793.3	1863.3
Body weight of males (BW-M, g)	16	1943.3^{b}	1740.0^{bc}	1924.0^{b}	1361.0^{c}	3006.7^{a}
	60	3126.7^{b}	3176.7^{ab}	3000.0^{b}	2526.7^{c}	3483.3^{a}

$^{a\text{–}c}$ Means with different letters within rows differ significantly by Tukey test at P<0.05.
[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual.

4.2.3. Egg production

Average egg production performances (% in wks) during laying phase (16 to 60 weeks of age) for the five PS are shown in Table 11 and Figure 8. The average egg production of LB and LD were significantly higher (P<0.05) than the rest, followed by KK, DS and DR. There was significant difference (P<0.05) among PS in average weekly egg production (% in wks) during the laying phase (16 to 60 weeks of age).

Table 11. Least square means of age at first egg and at 5% Lay[1], age at peak of lay[1], peak % Lay[1], average %Lay (hen-day) over all 44 weeks, and the calculated total number of eggs/hen-day, of five Parent Stocks[2].

Parameters	DR	DS	KK	LB	LD
Age at first egg in pen (days)	140.0	137.7	140.0	135.3	137.7
Age at 5% Lay (days)	147.0	144.7	147.0	142.3	147.0
Age at peak of lay (days)	263.7	296.3	256.7	298.7	280.0
%Lay at peak of lay	79.0[b]	77.8[b]	77.6[b]	93.3[a]	95.5[a]
%Lay, Weeks 16-60 (hen-day)	54.4[b]	55.3[b]	55.5[b]	72.2[a]	70.9[a]
Number of eggs/hen/44wks	166.1[b]	169.6[b]	170.8[b]	221.8[a]	217.8[a]

[a–b] Means with different letters within rows differ significantly by Tukey test at P<0.05.
[1]All egg production data are per live hens ("hen-day").
[2]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual.

The result also shows significant effect (P<0.05) of PS within age in week but not significant difference (P>0.05) in PS x age interaction on average egg production performances (% in wks) at all stages of the laying phases.

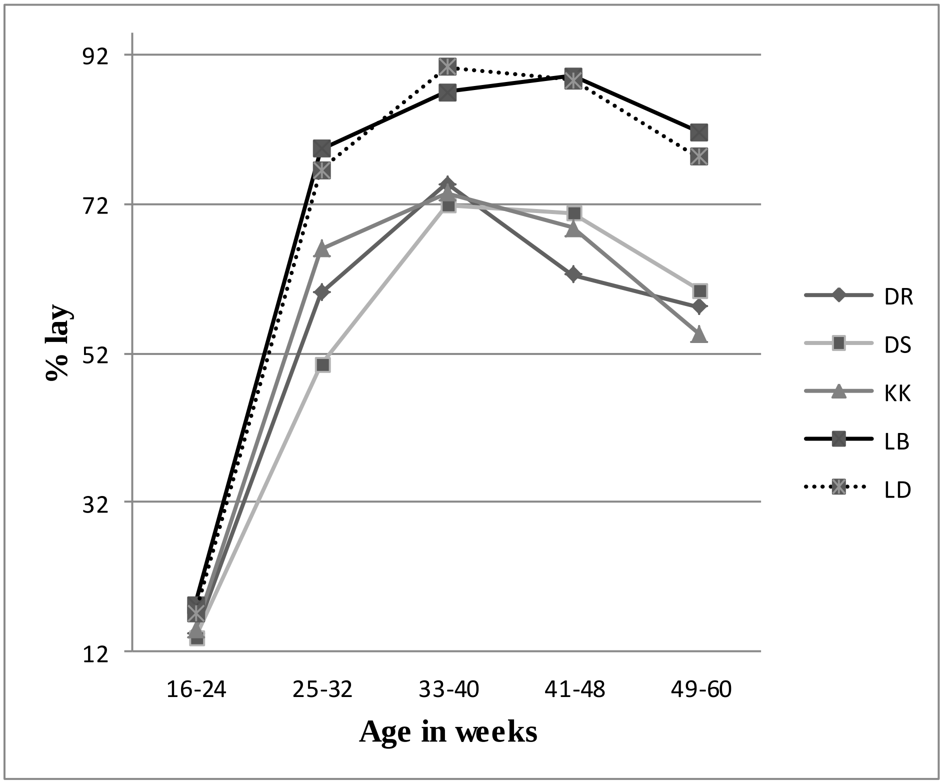

Figure 8. Average % Lay (hen-day) of hens from the 5 Parent Stocks at 5 age periods of the trial.
(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual).

4.2.4. Fertility and hatchability

The reproductive performance of the PS is presented in Figure 9 and 12. There was a significant difference ($P<0.05$) among parent layers in all reproductive traits except in average age at first eggs drop (days), age at 5% eggs, and average age at peak lay (days). DR, DS, KK and LB were higher in egg fertility and hatchability per set eggs, followed by LD. The present result clearly indicated that the LD was poor in fertility (%) and hatchability (%) per set eggs at all stages of the laying phases. These lowest records were from the meat-type male line of LD. KK had the highest and PS LD was the lowest, while other PS layers (DR, DS and LB) were intermediate in hatchability per fertile egg during the evaluation periods.

Table 12. Number of eggs set at each of 3 ages[1], and least square means of % fertility, % hatchability of fertile eggs and of set eggs, weight of set eggs, body weight of day-old chicks of five Parent Stocks[2].

Parameters	Age (wks)	DR	DS	KK	LB	LD
Total eggs set/PS/age[1] (No)		81	81	81	81	81
Fertility from set eggs (%)	30	83.3^{a}	83.3^{a}	84.4^{a}	70.0^{b}	30.0^{c}
	36	87.0^{a}	77.8^{ab}	85.2^{a}	76.9^{ab}	38.0^{c}
	45	70.0^{a}	63.3^{ab}	71.1^{a}	77.8^{a}	17.8^{c}
Hatchability from fertile eggs (%)	30	85.0^{ab}	81.2^{b}	92.1^{a}	76.1^{c}	53.8^{d}
	36	92.5	82.0	85.8	78.6	80.4
	45	45.1^{b}	38.6^{c}	57.9^{ab}	68.5^{a}	8.33^{d}
Hatchability from set eggs (%)	30	71.1^{a}	67.8^{ab}	77.8^{a}	55.6^{b}	23.3^{d}
	36	80.6^{a}	63.9^{bc}	73.1^{ab}	62.0^{bc}	32.4^{d}
	45	35.5^{bc}	12.2^{c}	44.4^{ab}	55.5^{a}	2.2^{d}
Calculated expected chicks/hen/44wks (based on % hatchability averaged over the 3 ages)		99.4^{ab}	76.9^{ab}	107.3^{ab}	127.3^{a}	34.6^{b}
Weight of eggs set (g), averaged over 3 ages[3]		62.7^{a}	58.4^{ab}	53.0^{c}	56.3^{bc}	55.0^{bc}
Weight of day old chicks (g), averaged over 3 ages[3]		38.1	34.4	32.3	35.3	31.9

[a–d]Means with different letters within rows differ significantly by Tukey test at $p<0.05$.

[1] Eggs were collected for incubation 3 times, when the hens were 28, 34 and 44.weeks of age;

[2] DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual.

[3] PS*Age interaction was not significant.

There was no significant difference ($P>0.05$) in DOC weight (g/bird) among PS but there were significant difference ($P<0.05$) among PS layers in weight of set eggs (g) for average of the three incubations (Table 12).

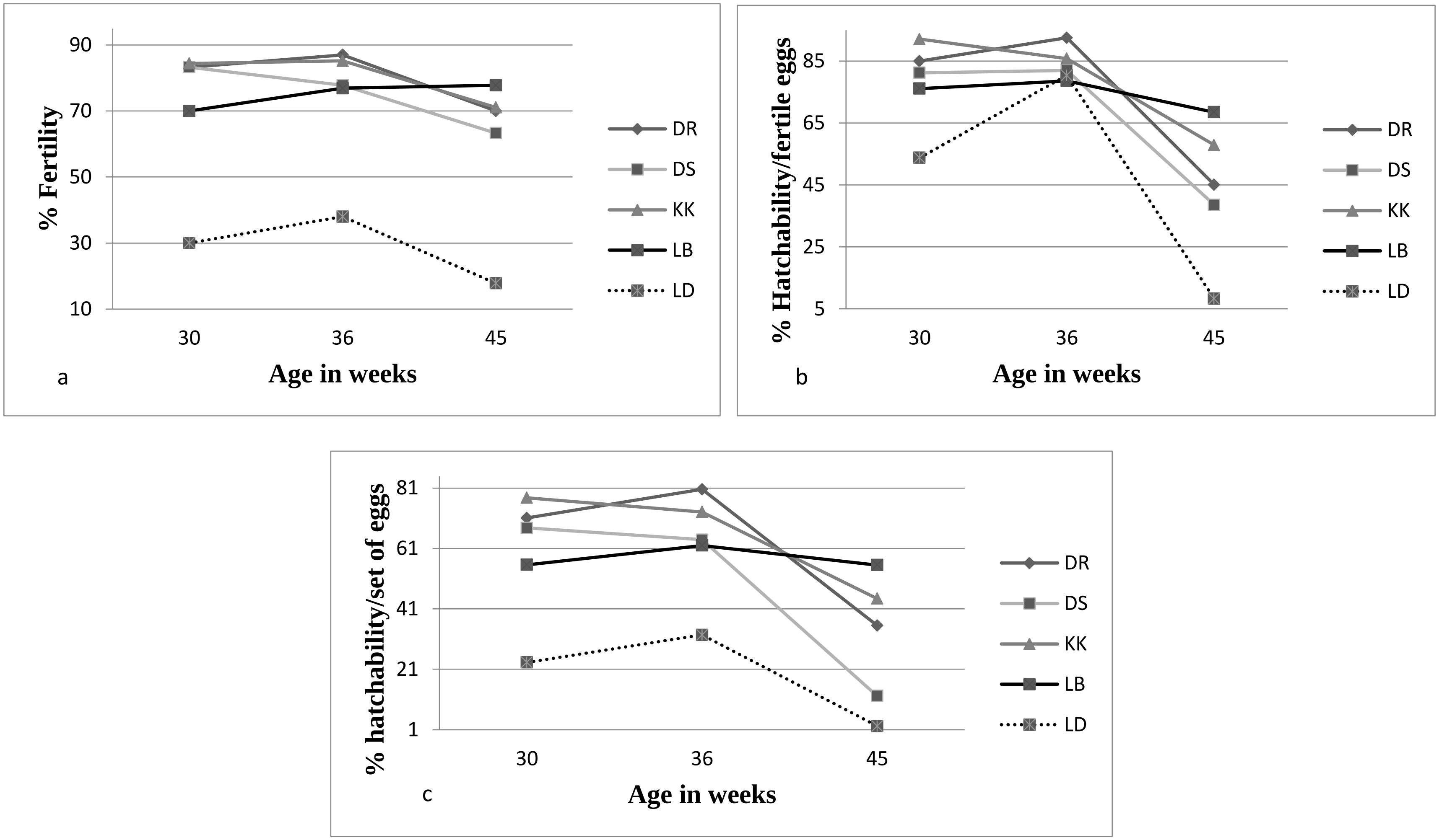

Figure 9. Average % Fertility (a), % Hatchability of fertile eggs (b), and % Hatchability of all set eggs (c), of eggs laid by hens from the 5 Parent Stocks at three weeks of age periods.

(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual).

4.2.5. Egg size and quality

DS, DR and KK had white-creamy egg shell color, while LB and LD had brown egg shell color. There was significant difference (P<0.05) among the test PS in terms of egg weight (g), albumen weight (g), egg shape (width in cm & length in cm). However, there were no significant differences (P>0.05) among layers in average yolk weight (g), shell weight (g), yolk weight ratio (%), albumen weight ratio (%), shell weight ratio (%), egg shape index, average shell thickness (mm), yolk color (color fun), yolk height (mm), albumen height (mm) at 27, 31, 35, 39 and 45 weeks of age (Table 13). It was found out that DR had the highest egg weight (g) while KK had the lowest weight. The PS layers of DS, LB and LD had intermediate in egg weight (g). Eggs from PS DR had significantly the highest albumen weight (g) while eggs from PS KK had the lowest albumen weight.

Table 13. Least square means egg weight, yolk weight, albumen weight, shell weight, egg width and length, shell thickness, yolk color, yolk height, albumen height of five Parent Stock[1].

Parameters	DR	DS	KK	LB	LD
Egg weight (g)	62.7[a]	58.4[ab]	53.0[c]	56.3[bc]	55.0[bc]
Yolk weight (g)	18.2	18.0	16.3	16.5	16.8
Albumen weight (g)	36.2[a]	32.2[ab]	29.7[b]	32.4[ab]	31.7[ab]
Shell weight (g)	8.33	8.13	7.01	7.47	6.55
Yolk weight ratio (%)	29.1	31.0	30.0	29.4	30.6
Albumen weight ratio (%)	57.7	54.9	56.2	57.4	57.7
Shell weight ratio (%)	13.2	14.4	13.3	13.3	11.8
Egg width (mm)	43.9[a]	42.3[ab]	41.3[b]	42.0[b]	41.7[b]
Egg length (mm)	57.3[a]	55.8[a]	52.9[b]	53.8[b]	53.5[b]
Egg shape index	76.7	75.8	78.1	78.2	78.0
Av. shell thickness (mm)	0.33	0.34	0.34	0.36	0.37
Yolk color (color fun)	10.7	9.2	9.6	10.0	9.2
Yolk height (mm)	18.0	17.8	17.9	17.7	17.9
Albumen height (mm)	7.99	7.49	7.18	7.69	8.30

[a–c]Means with different letters within rows differ significantly by Tukey test at P<0.05.
[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novo Brown; NC = Novo Color.

4.2.6. Mortality

The average female and male mortality (% in wks) of the layers during laying period (16 to 60 weeks) is presented in Table 14. The highest average female mortality was recorded in DR, followed by KK, DS and LD, while the lowest average female mortality was recorded in LB, PS layers. Lower average male mortality was recorded in all the five PS layers. There was significant difference (P<0.05) among PS in average female mortality rate during the laying stages. The study also showed that there were significant differences (P<0.05) on average female mortality at the different ages in week but not significantly different (P>0.05) among PS layers in PS by age interaction. For male mortality (% in wks) significant difference (P<0.05) was shown only for the age in week in all stages of the laying phases.

Table 14. Least square means of mortality female and male of five Parent Stock[1].

Parameters		DR	DS	KK	LB	LD
Mortality (% over 44 weeks)	F	0.14^{a}	0.05^{ab}	0.08^{ab}	0.03^{b}	0.05^{ab}
	M	0.03	0.01	0.01	0.05	0.03

[a–b]Means with different letters within the rows differ significantly by the Tukey test at P<0.05.
[1]DR = Dominant Red Barred D922; DS = Dominant Sussex D104; KK = Potchefstroom Koekoek; LB = Lohmann Brown Classic and LD = Lohmann Dual.

4.3. Females' Eggs and Males' Meat Productions (On-Station Trials) of ComL and ExpCr

4.3.1. Female feed intake

The average daily feed intake (ADFI g/bird per day) during the 0-16, 0-60 weeks and from the onset of laying to the end of laying age in weeks, ADFI g/bird per day between age in weeks (16 or 60 weeks), total average feed intake (AFI kg/hen in 44weeks) during the trial's 308 days and FCR are presented in Table 15 and Figure 10. The daily average feed intake (ADFI) during the study age in weeks (16 to 60 wks) were less than 100g/bird per day in all ComL & ExpCr, Except NC (114.4), DRKK (103.5) and KKDS (107.1). Significantly higher (P<0.05) ADFI difference was recorded after 16 weeks of age in all ComL & ExpCr.

During the study periods (0-8 to 49-60 weeks) NC and KKDS showed the highest but LD & DSDR showed the lowest ADFI than others ComL & ExpCr (Figure 9). These five ComL and one ExpCr of (DRKK, LB, KK, NB, DR, and DS) continued to exhibit the highest ADFI ranged between 94.4 to 120 g/h per day, with DS and DRKK are joining them during from 41 to 60 weeks. There was high difference ($P<0.05$) among ComL & ExpCr, within age and (ComL & ExpCr x Age interactions) in ADFI (g/bird/day) and total average feed intakes (Total AFI Kg/bird/308 days) of female due to the highest ADFI and total AFI in NC during the laying stages.

The overall feed intake was significantly higher ($P<0.05$) in NC, with mean ADFI over the entire trial (16-60 weeks) ranging 99.5-120 g/h per day, accumulating to mean TFI around 35.3 kg/hen over the trial's 308 days. Significantly lower ($P<0.05$) overall feed intake was exhibited by LD and DSDR, with mean ADFI (16-60 weeks) ranging 68.9-104.2 g/h per day, accumulating to 25.7 and 26.5 kg/hen. KKDS ranked second in overall feed intakes, with mean of ADFI (16-60weeks) ranging 99.5-117.1g/h/d, accumulating to 33.0kg.hen. The other ComL & ExpCr, DRKK, DR, LB, KK, NB and DS, were intermediate, with mean ADFI of about 95.9 g/h per day and mean TFI of 27.1 and 31.5 kg/h (Table 15).

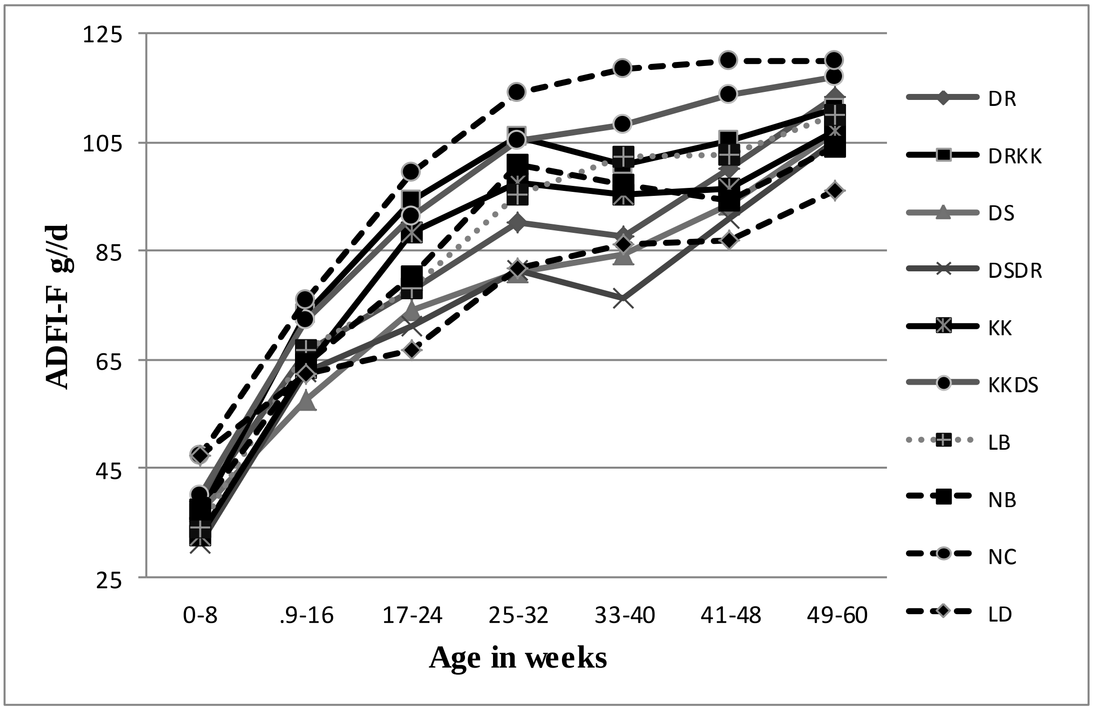

Figure 10. Average daily feed intake (ADFI) per chicken from the seven Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2] females at 7 age periods of the trial.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color; LD = Lohmann Dual.
[2]DRKK = Dominant Red Barred hens x Koekoek males; DSDR = Dominant Sussex hens x Dominant Red Barred males; KKDS = Koekoek hens x Dominant Sussex males.

4.3.2. Female body weight

The females' body weight (BW-F) at 7 ages, from the start 8 weeks (growing stage), 16 weeks (before onset of lay) and 60 weeks (end of trial), body weight gain (BWG-F) between age in weeks (16 or 60 weeks) are presented in Table 15 and Figure 11.

The body weight (BW-F) curves of females from the seven Commercial layers (ComL) & three Experimental crosses (ExpCr) exhibited differences ($P<0.05$) among ComL & ExpCr, within age and (ComL & ExpCr x Age interactions) in body weight and therefore ComL & ExpCr differences were analyzed in each age in weeks separately.

Among the females, the interaction was mainly due to NC at all ages, where BW of NC means was significantly highest ($P<0.05$) (about 1378g from the lowest of NB and 851.3g from the higher DRKK) BW at 60 weeks of age. The DRKK female ranked second heavier BW (about 2160g at 60 weeks of ages). DR females ranked third and LD female ranked last at all ages. KK, KKDS, DS, LB, DSDR and NB female ranked forth to ninth, with exact order varying between ages; however, by the end of the trial, at 60 weeks of age, BW of NC female was 3011.3g, due to the genetic background during their male parents stocks combinations study but this ideas did not works in the case of LD and the result was the lowest body weight even than other ComL & ExpCr. Except NC, all ComL & ExpCr exhibited similar BW curves over age, with relatively rapid elevation from 16 to 32 weeks (age in weeks of entering sexual maturity), followed by a plateau up to 48 weeks, and further elevation to 60 wks (Figure 11).

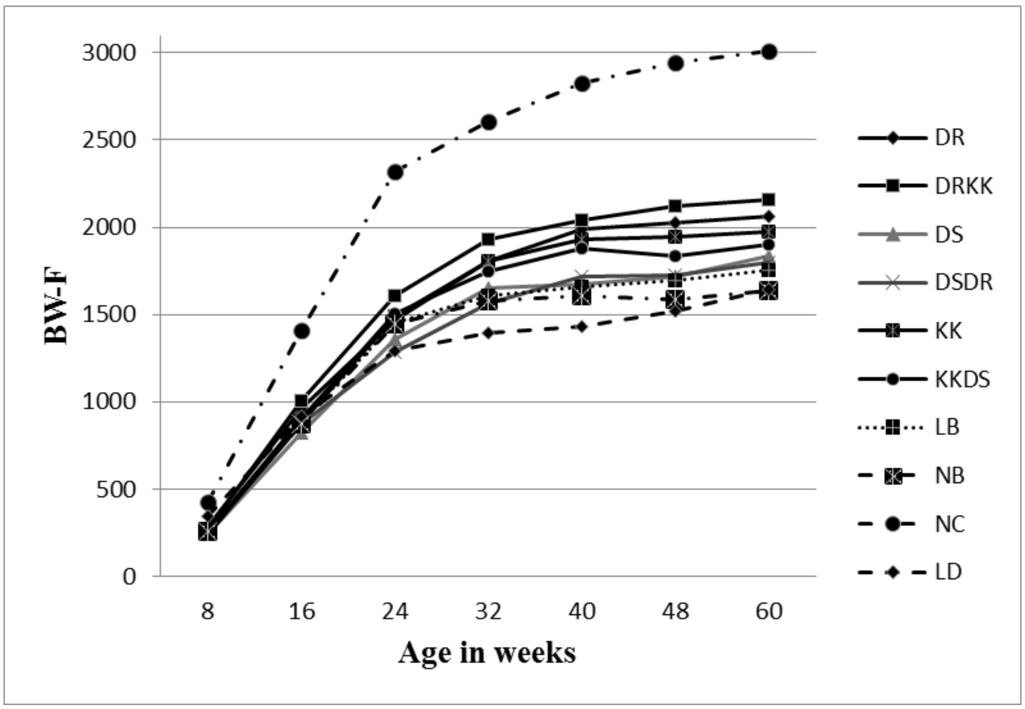

Figure 11. Average body weight of females from the seven Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2] at 7 ages of the trial.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color; LD = Lohmann Dual.
[2]DRKK = Dominant Red Barred hens x Koekoek males; DSDR = Dominant Sussex hens x Dominant Red Barred males; KKDS = Koekoek hens x Dominant Sussex males.

Significantly higher ($P<0.05$) average body weight gain (BWG-F) was recorded in NC females than other ComL & ExpCr, followed by DRKK, DR and KK. The lowest BWG-F was recorded in LD, while DS, KKDS, DSDR, and LB were intermediates (Table 15).

Table 15. Means body weight, body weight gain, and daily feed intake, egg weight, total numbers of eggs, egg mass, total AFI and FCR of females from seven Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2].

	Age (wks)	DR	DRKK	DS	DSDR	KK	KKDS	LB	NB	NC	LD
ADFI (g/bird/day)	0-16	52.5^{bc}	54.9^{b}	47.3^{c}	46.9^{c}	47.9^{c}	56.2^{ab}	50.3^{bc}	53.0^{bc}	61.6^{a}	54.8^{b}
	0-60	82.1^{bcd}	89.6^{abc}	76.4^{cd}	74.2^{d}	82.9^{bcd}	92.6^{ab}	84.2^{bcd}	83.8^{bcd}	99.4^{a}	75.3^{cd}
	16-60	93.9^{bcd}	103.5^{abc}	88.0^{bcd}	85.1^{cd}	96.9^{abcd}	107.1^{ab}	97.7^{abcd}	95.4^{abcd}	114.4^{a}	83.6^{d}
Total AFI (kg/hen/44wks)	16-60	30.085^{abc}	31.538^{abc}	27.100^{bc}	26.532^{c}	29.842^{abc}	33.000^{ab}	30.098^{abc}	29.376^{abc}	35.247^{a}	25.741^{c}
Feed Conversion ratio (FCR)	16-60	3.18^{ab}	3.43^{ab}	3.39^{ab}	3.06^{ab}	3.77^{a}	3.45^{ab}	2.74^{b}	3.08^{ab}	3.26^{ab}	3.45^{ab}
BW-F (g)	8	289.5^{c}	272.5^{cd}	245.0^{d}	251.0^{cd}	245.1^{d}	260.6^{cd}	245.5^{d}	257.0^{cd}	425.9^{a}	347.4^{b}
	16	964.3^{bc}	1007.9^{b}	819.6^{d}	875.8^{cd}	883.0^{cd}	902.5^{bcd}	888.7^{cd}	871.1^{cd}	1409.0^{a}	921.2^{bcd}
	60	2063.3^{bc}	2160.0^{b}	1831.3^{bcd}	1795.6^{cd}	1971.1^{bcd}	1902.2^{bcd}	1757.8^{cd}	1633.3^{d}	3011.3^{a}	1646.6^{d}
BWG-F (g)	16-60	1099.0^{b}	1152.1^{b}	1011.8^{bc}	919.7^{bc}	1088.1^{b}	999.7^{bc}	869.1^{bc}	693.8^{c}	1602.3^{a}	725.4^{c}
Average egg weight(g)	16-60	58.6^{b}	55.6^{bc}	58.2^{b}	58.4^{b}	51.7^{d}	55.0^{c}	57.5^{bc}	57.7^{bc}	62.3^{a}	56.7^{bc}
Total number of eggs/hen/44wks	16-60	150.6^{abcd}	151.1^{abcd}	126.8^{cd}	131.9^{bcd}	139.0^{bcd}	162.3^{ab}	181.8^{a}	158.3^{abc}	157.0^{abcd}	123.4^{d}
Egg Mass (Kg/hen)	16-60	8.82^{abcde}	8.39^{bcde}	7.37^{cde}	7.70^{cde}	7.19^{de}	8.92^{abcd}	10.4^{a}	9.12^{abc}	9.78^{ab}	6.99^{e}

[a–e]Means with different letters within rows differ significantly by the Tukey test at $p<0.05$.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color; LD = Lohmann Dual.

[2]DRKK = Dominant Red Barred hens x Koekoek males; DSDR = Dominant Sussex hens x Dominant Red Barred males; KKDS = Koekoek hens x Dominant Sussex males.

4.3.3. Egg production

Average means of age at first egg and 5% lay, at peak of lay (days), % lay at peak of lay, % lay (hen-day) over the entire trial (from 16 to 60 weeks of age), % Lay of open hens, % closed hens and average % Lay (hen-day) of hens at 5 age periods are presented in Table 16 and Figure 12 a & b. There was significant effects ($P<0.05$) in all egg production performance traits during the laying stages (16 to 60 weeks of age) except for age at peak of lay (days).

The earliest sexual maturity - first egg at ~119 days (NC), at ~123.7 days (NB), at ~128.3 days (LB) & at ~135.3 days (LD) and 5% lay at ~130.7 days (NC), at ~133 days (LB), at ~135.3 days (NB) & at ~137.7 days (LD) - was exhibited than other ComL & ExpCr, followed by, DR, KK, KKDS, DRKK and DSDR, while the DS reached sexual maturity at older age during the study age in weeks. The ComL & ExpCr differed in % lay, especially during the 41-48 age in weeks, with LB and KKDS are leading with an average of 80.6 %(LB) and 61.1% (KKDS) respectively whereas DS, LD and DSDR trailing with an average of DS 44% lay during the 41-48 age in weeks (Figure 12). Except one of the ExpCr (DSDR) and two of the ComL (LD & DR), the laying rate of others ComL & ExpCr continues to increase up to 33-40 weeks period, but LB was continues to increase up to 41-48 weeks period, ranging over 80.6% (LB).

One of the notable performances observed in KKDS (64.5%) was also continues to increase up to end of the trials at lower rate of LB, while others already started to decline after 40 weeks of age as presented in Figure 11. LB (87.8%) was top in average % Lay at peak of lay and LD (59.6%) was the lowest, while KKDS, KK, DSDR, NB, NC, DRKK, DS and DB were intermediates.

The average egg production-hen-day (%) of LB (62%) and KKDS (58.5%) were significantly higher than other of the seven ComL and three ExpCr layers, followed by DRKK, NB, NC and KK, while DS and DR were intermediates; however, the lowest egg production hen-day was recorded in LD and DSDR over the entire trials, not only in egg productions but also in body weight (LD & DSDR) were the least during the study periods.

Table 16. Means of age at first egg and at 5% Lay, age at peak of lay and peak % Lay, %Lay (hen-day), (%Lay from open and % closed hens of seven Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2].

Parameters	DR	DRKK	DS	DSDR	KK	KKDS	LB	NB	NC	LD
Age at first egg (days)	140.0^{ab}	154.0^{a}	157.5^{a}	156.3^{a}	143.5^{ab}	151.7^{a}	128.3^{b}	123.7^{b}	119.0^{b}	135.3^{ab}
Age at 5% Lay (days)	147.0^{ab}	161.0^{a}	161.0^{a}	161.0^{a}	150.5^{ab}	158.7^{a}	133.0^{b}	135.3^{b}	130.7^{b}	137.7^{b}
Age at peak of lay (days)	234.5	226.3	242.7	269.5	259.0	249.7	290.5	193.7	217.0	221.7
% Lay at peak of lay	64.5^{ab}	72.7^{ab}	68.3^{ab}	74.6^{ab}	75.6^{ab}	77.7^{ab}	87.8^{a}	73.9^{ab}	73.0^{ab}	59.6^{b}
% Lay, 16-60 wks (hen-day)	44.1^{de}	55.0^{bc}	45.7^{de}	40.1^{e}	49.5^{cd}	58.5^{ab}	62.0^{a}	53.0^{bc}	51.3^{bc}	42.2^{e}
% Lay of open hens, 16-60 wks	58.7^{abc}	62.8^{abc}	52.5^{cd}	55.7^{abcd}	55.3^{bcd}	62.2^{abc}	68.0^{a}	65.9^{ab}	56.4^{abc}	45.0^{d}
% closed hens, 16-60 wks	18.4^{abcd}	20.8^{abc}	29.2^{a}	22.2^{ab}	20.5^{abc}	18.1^{bcd}	10.6^{cd}	21.3^{abc}	9.10^{d}	17.2^{bcd}

[a–e]Means with different letters within rows differ significantly by the Tukey test at P<0.05.
[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color; LD = Lohmann Dual.
[2]DRKK = Dominant Red Barred hens ×Koekoek males; DSDR = Dominant Sussex hens × Dominant Red Barred males; KKDS = Koekoek hens × Dominant Sussex males.

The average % lay of open hens or the highest probability for egg production, over the entire trial was recorded in LB (68%) and NB (65.9%), followed by DRKK (62.8%), KKDS (62.2%), DR (58.7%) and NC (56.4%). DSDR and KK were ranked third and DS & LD were ranked last at all ages. The average % closed hens or the least probability for egg production, over the entire trial were recorded in DS and DSDR, followed by NB, DRKK, KK and LD, while DR and KKDS were intermediates; however, LB and NC were the lowest % closed hens at all ages. There was difference (P<0.05) among ComL and ExpCr, age in periods and (ComL &

ExpCr x age interactions) in average egg production performances over the entire trial, egg production-hen-day (%), % lay of open hens and % closed hens during the laying stages.

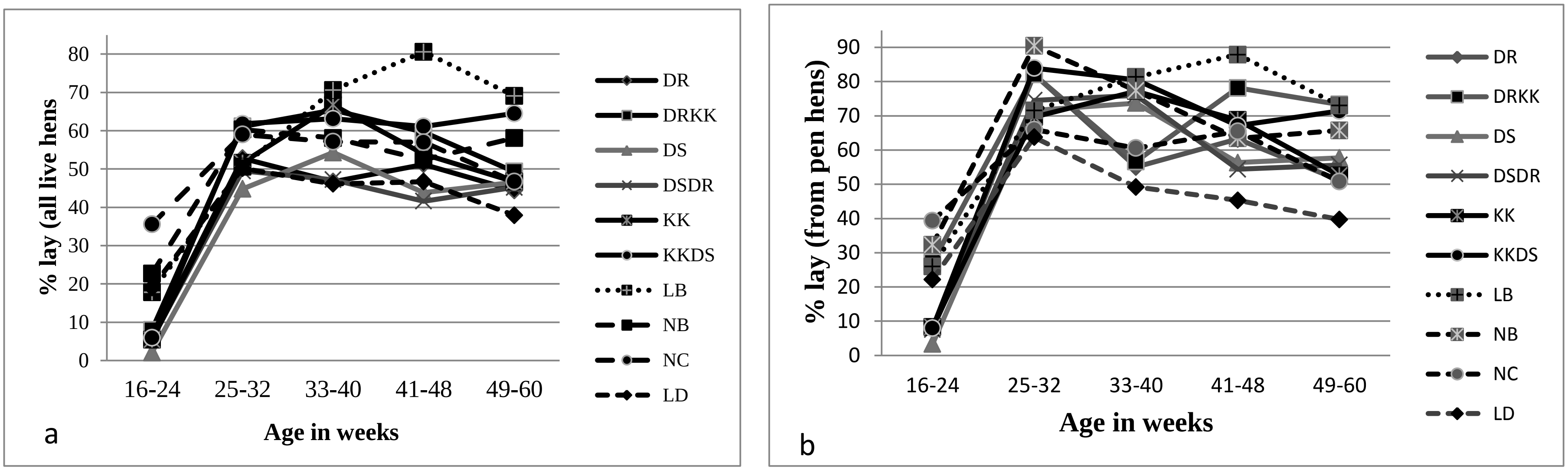

Figure 12. Average % Lay (hen-day) and % lay of open hens from the seven Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2] at 5 age periods of the trial.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown; NB = Novogen Brown Classic; NC = Novogen Color; LD = Lohmann Dual.

[2]DRKK = Dominant Red Barred hens × Koekoek males; DSDR = Dominant Sussex hens × Dominant Red Barred males; KKDS = Koekoek hens × Dominant Sussex males.

4.3.4. Egg size and quality

The average egg weight (g), total numbers of eggs/hen in 44weeks, and Egg Mass (kg/hen) are presented in Table 15. The age at onset of lay and the rate and persistency of lay thereafter, were all combined into the average % lay during this trial. These overall laying percentages were multiplied by 308 (number of days in 44 weeks) to calculate the mean total number of eggs per hen. Significantly the highest total number of eggs/hen was recorded in LB (about 181.8 eggs/hen), followed by KKDS (about 162.3 eggs/hen), While NB, NC, DRKK, DR, KK and DSDR ranked third to eighth respectively; however, the lowest total numbers of eggs/hen over the entire trial was recorded in DS (126.7 eggs/hen) and LD (123.4 eggs/hen) as presented in Table 14, due to poor laying consistency, with the lowest egg production (~44 % lay) staring from 40 weeks to the end of the 60 weeks period (Figure 9). The main parameters related to ComH and ExpH performance are egg production on the income side, feed intake on the costs side and their combination (FCR) were considered to compare the female' as egg productions, so that, the LB was the best in higher egg production, in lowest feed intake, higher egg mass and best in FCR, followed by NB during this trial.

As it was expressed in Parent Stock papers, egg weight is more relevant in layers but it might not be a good trait when eggs are not sold on weight basis in developing countries like Ethiopia. There were high effects ($P<0.05$) among ComL & ExpCr and age in weeks in egg weight (g) during the laying stages (16 to 60 weeks of age). The highest average weight was recorded in NC (about 62.3g), followed by DR (about 58.6g), DSDR (about 58.4g) and DS (about 58.2g). NB, LB, LD and DRKK ranked fifth to eight respectively; however, the lowest average egg weight was recorded in KKDS and KK during the laying stages. Based on the relation to total numbers of egg/hen and the mean egg weight, the highest egg mass (Kg/hen) was recorded in LB (about 10.4), NC (about 9.78) and NB (about 9.12). KKDS, DR and DRKK ranked fourth to sixth respectively; however, the lowest egg mass was recorded in DS, DSDR, KK and LD over the entire trials.

The female bird's ability to convert nutrients to an important aspect of overall performance is expressed in feed conversion ratio (FCR). The FCR of the hens in the 16-

60 weeks laying trial was calculated for each pen by dividing total feed intake by the sum of body weight gain and egg mass production during the entire trial (Table 14). The best FCR was exhibited by LB (2.74), combining the highest egg mass (10.4 kg) and intermediate feed intake (30.1 kg). It was followed by NB (3.08) with quite high egg mass (9.12 kg) and intermediate feed intake (29.4 kg) and DSDR (3.07) with lower egg mass (7.7 kg) but also lower feed intake (26.5 kg). It should be noted that NC hybrid, bred specifically for dual-purpose production, ranked only fifth in FCR (3.26), despite being second in egg mass (9.78 kg) and highest in BWG-F (1602g), but also highest in feed intake (35.2 kg) and in BW-F (3011 g at 6 weeks). The lowest FCR was exhibited by KK (3.77), because of very low egg mass (7.19 kg) due to the lowest egg weight (51.7g), intermediate feed intake (29.8 kg), and relatively high BW-F (1971g) at 60 weeks (Table 15).

4.3.5. Female mortality

The Least Square means of average % mortality over the entire trial (Week 16 to 60) of females from seven Commercial layers (ComH) and three Experimental crosses (ExpCr) are presented in Table 16. The female average % mortality of DSDR, NB and LD were significantly higher than other ComL and ExpCr due to disease outbreak. The females of KK, DRKK, LB and NC exhibited the lowest mortality (~0.8%), with the other ComL and ExpCr exhibiting intermediate mortality (Table 18). There were significant difference ($P<0.05$) among ComL and ExpCr on average % mortality during the laying stages but there were no significant differences ($P>0.05$) on average % mortality at the different ages in week and the interaction (ComL and ExpCr x ages) at all stages of the laying phases.

Table 17. Least square means of average % mortality of females from seven Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2].

Parameters	DR	DRKK	DS	DSDR	KK	KKDS	LB	NB	NC	LD
Mortality (% over 44 weeks)	1.70[b]	0.74[c]	1.52[b]	2.06[a]	0.55[c]	1.73[b]	0.84[c]	2.03[a]	1.07[c]	2.00[a]

[a–c]Means with different letters within rows differ significantly by the Tukey test at P<0.05.
[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color; LD = Lohmann Dual.
[2]DRKK = Dominant Red Barred hens × Koekoek males; DSDR = Dominant Sussex hens × Dominant Red Barred males; KKDS = Koekoek hens × Dominant Sussex males.

4.3.6. Males body weight and feed intake

The males' body weight (BW-M) for meat production curves from six Commercial layers (ComL) & three Experimental crosses (ExpCr) at 3 ages, from the start (4 weeks) to the end (16 weeks) of the trial are presented in Figure 13. Average males BW-M at the end of the trials (16 weeks), body weight gain (BWG-M) between age in weeks (0-4, 5-8 & 9-16weeks), and average feed intake cumulative (g) (AFI) (between 0-16weeks) and feed conversion ratio (FCR) between (0-16 weeks) are presented in Table 18. The most economic criterion, followed by dressing percentage, for marketing in Ethiopia was live body weight (since selling live body was common) especially at holidays to prepare the traditional '*Doro wat*' (chicken stew) and the NC would be the best in this trial, followed by NB. From 4 weeks of age to the end of the trials, NC male was significantly the highest in BW-M (about 1582.7g from the lowest of DSDR and 515.5 from the higher NB BW-C at the end of the trials), while KK, DRKK, KKDS, DR, LB and DS were ranked third to eighth and showed almost similar BW-C during these meat production trials. There were differences (P<0.05) among ComL & ExpCr males, within age and (ComL & ExpCr x Age interactions) in BW-M, BWG-M, AFI cumulative and FCR cumulative over the entire trials due to the highest performance showed in NC males in all parameters due to the genetic background during their male parents stocks combinations study.

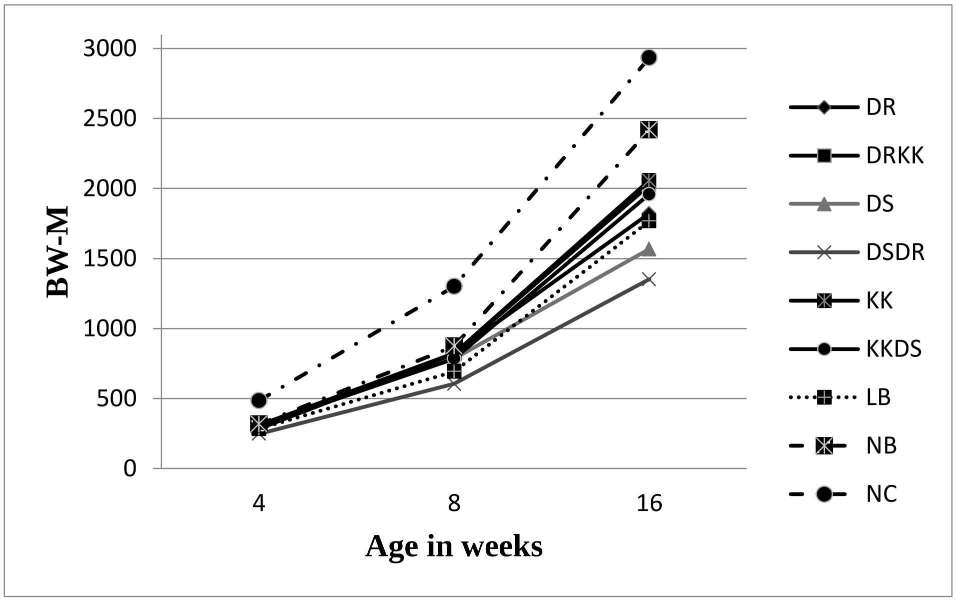

Figure 13. Average body weight of males from the six Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2] at 3 ages of the trial.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color; LD = Lohmann Dual.

[2]DRKK = Dominant Red Barred hens × Koekoek males; DSDR = Dominant Sussex hens × Dominant Red Barred males; KKDS = Koekoek hens × Dominant Sussex males.

More than 50% of growths or increments of BWG-M was showed in six males (NC, NB, KK, DRKK, KKDS and LB), while the lowest increments was recorded in other three males (DR, DS and DSDR). NC was best in BWG-M (about 111g from the lowest DSDR and 11.1g from the second ranked of NB) over the entire trial (0-16weeks) (Table 18 and Figure 13). Generally best growth or BWG-M leads us to apply the ideas to use the males for meat productions as an alternative meat production to broiler chickens in Ethiopia. These males' meat could be best for the preparation of Ethiopian traditional '*Doro wat'* (chicken stew) rather to use these as commercial broiler breeds due to the test of the meat and also it would not be change its meat in to tiny or small fragments of meats during these three to four hours of traditional '*Doro wat*' (chicken stew) preparations. The time to prepare this '*Doro wat*' (chicken stew) was taking three to four hours based on the types of the cooking materials they used.

Table 18. Least square means of final body weight, body weight gain, cumulative feed intake (CFI) and cumulative feed conversion ratio (FCR) of males from six commercial layers (ComL)[1] and three experimental crosses (ExpCr)[2].

	Age (wks)	DR	DRKK	DS	DSDR	KK	KKDS	LB	NB	NC
CFI (g)	0-16	6515.6[a]	6843.2[a]	6434.4[a]	5474.0[b]	6858.1[a]	6902.0[a]	6529.6[a]	6756.4[a]	6822.7[a]
FCR cumulative	0-16	3.67[abc]	3.46[abc]	4.28[a]	4.17[ab]	3.40[abc]	3.59[abc]	3.81[ab]	2.91[bc]	2.36[c]
BW-M (g/wk)	16	1821.7[bc]	2024.2[bc]	1567.2[c]	1351.7[c]	2057.8[bc]	1959.2[bc]	1767.8[bc]	2418.9[ab]	2934.4[a]
BWG-M (g/wk)	0-4	68.3[b]	68.8[b]	67.5[b]	53.3[b]	62.6[b]	68.1[b]	62.1[b]	70.6[b]	112.6[a]
	5-8	128.8[bc]	126.3[bcd]	119.6[bcd]	89.3[d]	133.7[b]	119.6[bcd]	102[cd]	139.0[b]	203.7[a]
	9-16	124.8[bc]	151.1[abc]	98.0[c]	93.3[c]	154.7[abc]	146.8[abc]	134.3[abc]	193.2[ab]	204.3[a]

[a–d]Means with different letters within rows differ significantly by the Tukey test at P<0.05.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color.

[2]DRKK = Dominant Red Barred hens × Koekoek males; DSDR = Dominant Sussex hens × Dominant Red Barred males; KKDS = Koekoek hens × Dominant Sussex males.

AFI cumulative and FCR Cumulative of males of six Commercial layers (ComL) & three Experimental crosses (ExpCr) at 3 age in weeks, from the start (0 weeks) to the end (16 weeks) of the trial are presented in Figure 14. The difference (P<0.05) in AFI cumulative was showed between the eight males and the lowest AFI cumulative in DSDR throughout the trials; otherwise there was no difference (P>0.05) in AFI cumulative among all the eight males Table 18. In general, there were higher (P<0.05) differences among all ComL & ExpCr males during these trials of meat productions over the age in weeks. The best FCR cumulative was recorded in NC (2.36), followed by NB (2.91) at the end of 16 weeks), while there is no differences (P>0.05) among seven ComL & ExpCr males, extreme FCR cumulative results was exhibited in DS (4.28 at the end of the trials) Table 18. Between 0-8 weeks of age, almost all ComL & ExpCr (except NC) showed similar FCR cumulative results Figure 14.

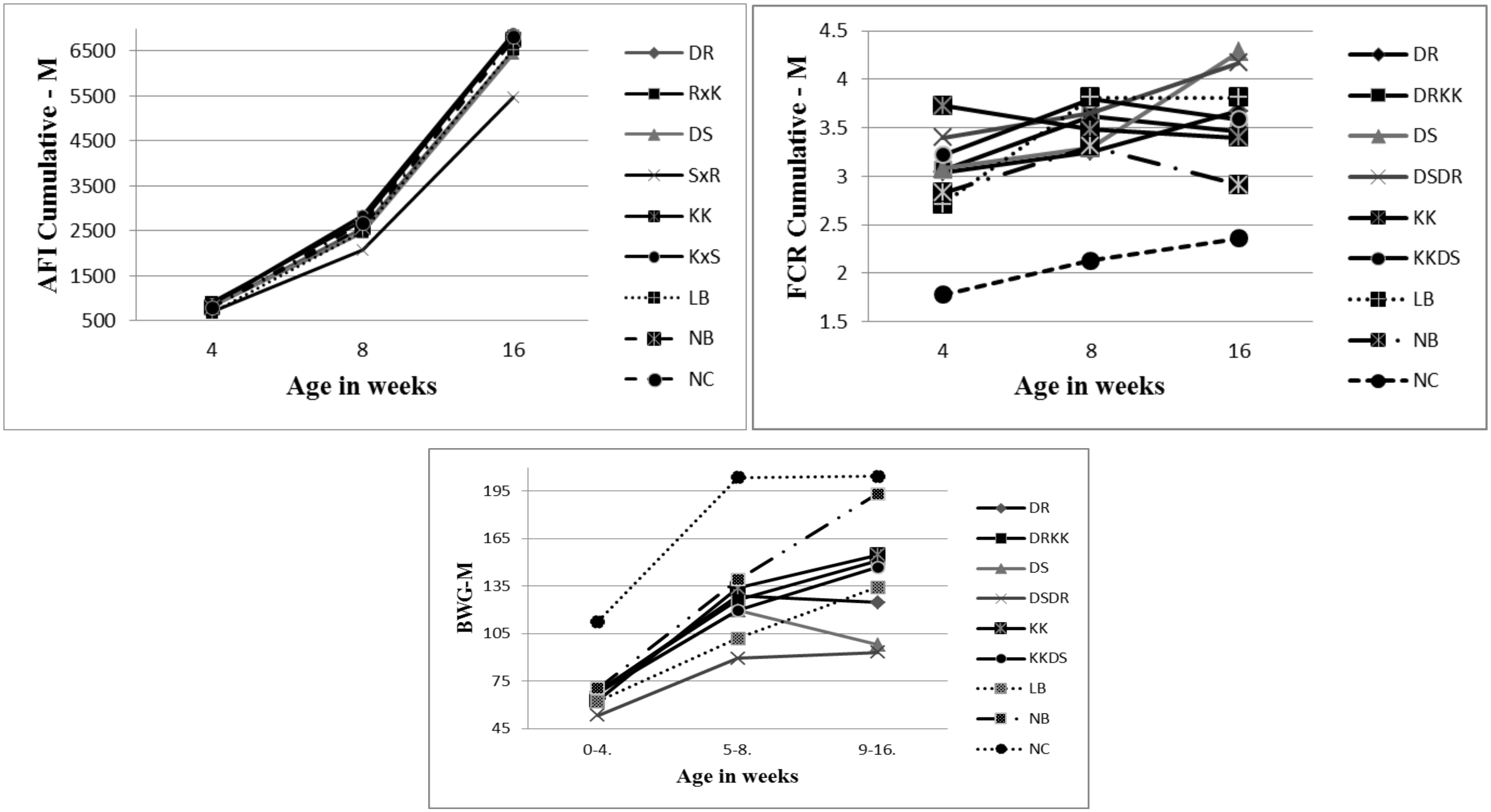

Figure 14. AFI Cumulative, FCR Cumulative and Body weight gain (BWG) of males from the six Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2] at 3 age (weeks) of the trial.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color.

[2]DRKK = Dominant Red Barred hens ×Koekoek males; DSDR = Dominant Sussex hens × Dominant Red Barred males; KKDS = Koekoek hens × Dominant Sussex males.

4.3.7. Male carcass analysis

Means of dressed carcass weight and the relative weight (% of live body weight) of dressed carcass, main carcass part and internal organs of 16-weeks-old males from six Commercial layers (ComL) & three Experimental crosses (ExpCr) are presented in Table 18. There were differences ($P<0.05$) among ComL & ExpCr males due to the highest percentages of (dressed, rear parts, thighs, drumsticks and other organs) showed in NC males. Significantly the highest % dressed was recorded in NC (70.2%), while NB, KKDS, DRKK, KK, DS, LB and DR were ranked second to eighth on average ~ 68% and the lowest % dressed was recorded in DSDR (64%). More or less similar results were exhibited in the percentages of (rear, thighs, drums, breast) like the results showed in % dressed in these males as meat production trials.

Dressing percentage is the most economic criterion next to body weight for marketing carcasses, within this idea it was strongly used to compare the performances of the males in this trial and making NC the best male meat producer or meatiness, followed by NB, while others were intermediate and DSDR was the lowest to be selected in this trial (Table 19 and Figure 12). If we take breast as the main parts in meat production, NB was the highest in breast (22.2 %) followed by NC (21.6%) and LB (20.2%), other males were showed almost similar breast percentages in these trials on average ~ 19.7%.

Significantly the highest % wing was recorded in DS male, followed by six males (LB, DRKK, DR, KK, KKDS and NB) from the higher to the lower order respectively). DSDR and NC were the lowest in % wings compared to the rest of ComL & ExpCr during these trials. Other edible and non-edible parts of means of the relative weight (% of live body weight) of dressed carcass were presented in Table 19. These all above results showed that meat productions using males are effective rather to kill or culling day-old layer types of males at the time of hatching in layer industries.

Table 19. Least square means of the relative weight (% of live body weight) of dressed carcass, main carcass parts and internal organs of 16-weeks-old males from six Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2].

Body parts (% of live BW)	DR	DRKK	DS	DSDR	KK	KKDS	LB	NB	NC
Live body weight (g)	1817.2^{cde}	2024.2^{bcd}	1567.2^{de}	1351.7^{e}	2057.8^{bc}	1959.2^{bcd}	1767.8^{cde}	2418.9^{b}	2934.4^{a}
Dressed carcass[3] (g)	1217.5^{cd}	1378.5^{bcd}	1060.0^{de}	863.0^{e}	1400.6^{bc}	1343.5^{bcd}	1192.0^{cde}	1684.4^{b}	2059.8^{a}
% Dressed	67.0^{bc}	68.1^{ab}	67.6^{ab}	64.0^{c}	68.1^{ab}	68.5^{ab}	67.3^{b}	69.5^{ab}	70.2^{a}
% Rear[4]	31.2^{bcd}	32.4^{abc}	30.6^{cd}	29.5^{d}	32.8^{ab}	32.7^{abc}	30.9^{bcd}	31.9^{bc}	33.9^{a}
% Thighs	11.8^{b}	11.7^{b}	11.3^{b}	11.4^{b}	12.3^{b}	12.5^{ab}	11.6^{b}	12.3^{b}	13.6^{a}
% Drums	10.1^{cd}	11.2^{ab}	9.76^{d}	8.10^{e}	11.4^{a}	11.1^{abc}	10.3^{bcd}	10.3^{bcd}	11.4^{a}
% Backs	9.30^{ab}	9.61^{ab}	9.47^{ab}	10.0^{a}	9.08^{ab}	9.16^{ab}	8.99^{ab}	9.32^{ab}	8.87^{b}
% Breast	19.8^{c}	19.4^{c}	20.4^{bc}	19.1^{c}	19.5^{c}	19.7^{c}	20.2^{bc}	22.2^{a}	21.6^{ab}
% Wings	4.47^{ab}	4.53^{ab}	4.81^{a}	4.23^{b}	4.44^{ab}	4.52^{ab}	4.59^{ab}	4.44^{ab}	4.20^{b}
% Neck	6.30^{a}	6.74^{a}	5.98^{a}	5.77^{a}	6.26^{a}	6.80^{a}	6.17^{a}	6.14^{a}	6.47^{a}
% Heart	0.59^{a}	0.57^{ab}	0.52^{ab}	0.49^{b}	0.54^{ab}	0.59^{ab}	0.54^{ab}	0.54^{ab}	0.55^{ab}
% Liver	1.87^{bc}	1.95^{abc}	2.29^{a}	2.13^{ab}	1.92^{abc}	1.85^{abc}	2.05^{ab}	1.88^{bc}	1.64^{c}
% Gizzard	2.49^{a}	2.26^{ab}	2.63^{a}	2.41^{a}	2.31^{a}	2.11^{ab}	2.54^{a}	2.12^{ab}	1.58^{b}
% Spleen	0.29^{ab}	0.29^{ab}	0.33^{a}	0.35^{a}	0.27^{ab}	0.24^{ab}	0.33^{a}	0.26^{ab}	0.22^{b}
% Ab. fat	1.03^{bc}	0.19^{c}	1.23^{bc}	3.29^{a}	0.78^{bc}	1.62^{bc}	0.29^{c}	1.23^{bc}	1.66^{b}
% GIT wt	3.03^{ab}	2.96^{ab}	3.25^{a}	3.15^{ab}	2.94^{ab}	2.66^{bc}	3.36^{a}	2.92^{ab}	2.27^{c}
% Shank	4.55^{a}	4.34^{a}	4.40^{a}	3.02^{b}	4.46^{a}	4.34^{a}	4.26^{a}	4.25^{a}	4.26^{a}
GIT length	180.0^{cd}	206.3^{abc}	184.1^{bcd}	153.3^{d}	195.0^{abc}	181.5^{bcd}	209.89^{ab}	222.1^{a}	215.9^{a}

[a–e] Means with different letters within rows differ significantly by the Tukey test at $P<0.05$.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color

[2]DRKK = Dominant Red Barred hens × Koekoek males; DSDR = Dominant Sussex hens × Dominant Red Barred males; KKDS = Koekoek hens × Dominant Sussex males.

[3]Dressed carcass included Thighs; Drums; Back; Breast (including back bones and skin); Wings; Neck; Heart; Liver; Gizzard; and Spleen.

[4]Rear includes Thighs; Drums and Back.

4.3.8. Male mortality

The least square means of average % mortality over the entire trial (week 1 to 16) of males from six Commercial layers (ComL) and three Experimental crosses (ExpCr) are in presented Table 20. In these males' trials for meat productions, zero mortality was presented in ExpCr of DSDR and ComH of KK throughout the study periods; additionally no health problems were recorded in these males' trials for meat productions study. Significantly very low mortality (0.16% in DRKK, 0.21% in LB, NB and NC) were recorded. The highest total % mortality was recorded in DR (0.64%), while DS (0.53%) and KKDS (0.32%) males were intermediates over the entire trials. There was significant difference (P<0.05) among ComL and ExpCr on average % mortality throughout the study periods but there were no significant differences (P>0.05) on average % mortality at the different ages in week and the interaction (ComL and ExpCr x ages) at all stages of the study periods.

Table 20. Least square means of % mortality of males from six Commercial layers (ComL)[1] and three Experimental crosses (ExpCr)[2].

Parameters	DR	DRKK	DS	DSDR	KK	KKDS	LB	NB	NC
Mortality (% over 16 weeks)	0.64^{a}	0.16^{b}	0.53^{a}	0.00^{c}	0.00^{c}	0.32^{b}	0.21^{b}	0.21^{b}	0.21^{b}

[a–c]Means with different letters within rows differ significantly by the Tukey test at P<0.05.
[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color
[2]DRKK = Dominant Red Barred hens × Koekoek males; DSDR = Dominant Sussex hens × Dominant Red Barred males; KKDS = Koekoek hens × Dominant Sussex males.

4.4. Females' Eggs and Males' Meat Productions (on-Farm Trials)

4.4.1. Females feed intake

The average daily feed intake (ADFI g/bird/day) at 6 age in weeks, from the start (0-8 wks) to the end (40-48 wks) of the trial, total average feed intake (AFI kg/hen) and the feed conversion ratio (FCR) for the six ComL is shown in Table 21 and Figure 15. The average feed intake during the study age in weeks (0 to 48 wks) was on average ~ 88.5g/bird per day in all ComL. Significantly higher ADFI difference was recorded after 16-24 weeks of age weeks in all ComL. During the study age in weeks (0-8 to 41-48 weeks of age) all ComL showed similar ADFI but DS was exhibited at lower rate compared to the others after 16-24 to 41-48 weeks of age (Figure 15). There was high Significant difference (P<0.05) among ComL, within age and (genotype by age interactions) in ADFI (g/bird/day) of female due to the higher ADFI in NC during the laying stages.

The overall feed intake was significantly higher in four ComL of KK, NC, LB and DR over the entire trial (16-48 weeks) ranging 93.5-120 g/hen/day, accumulating to mean total average feed intakes (AFI) around 23kg/hen over the trial's 210 days. Significantly the lowest overall total average feed intakes (AFI) was exhibited by DS (about 21.8kg/hen), while ComL of NB was intermediate in total average feed intakes (AFI) (about 22.7kg/hen) (Table 21).

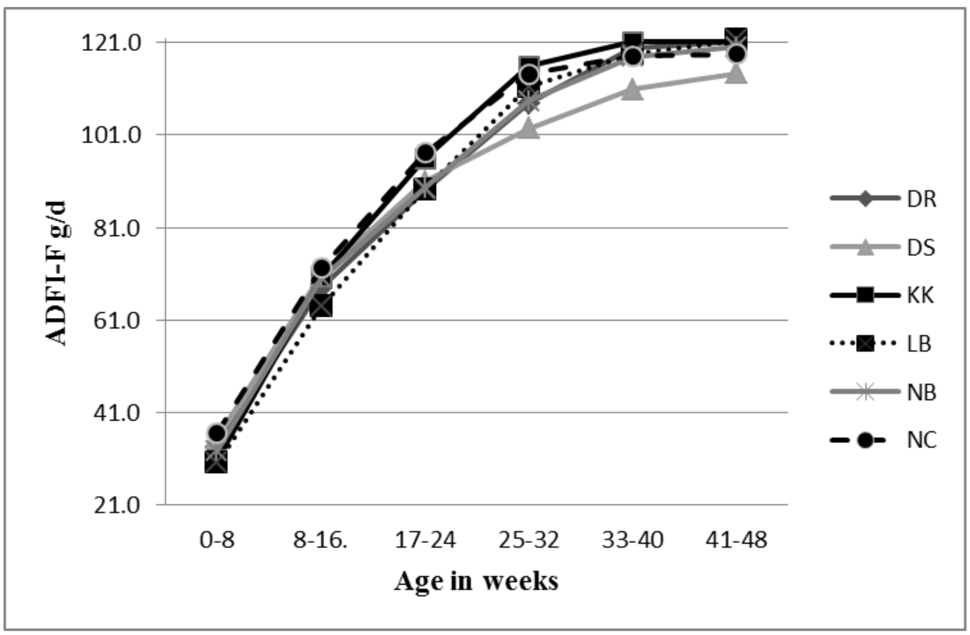

Figure 15. Average daily feed intake (ADFI) per chicken from the six Commercial layers (ComL) females at 6 age periods of the trial.

(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color).

The female bird's ability to convert nutrients to an important aspect of overall performance is expressed in feed conversion ratio (FCR). Significantly better FCR was recorded in NB (about 3.18), followed by NC (about 3.54) and in contrast to bad FCR was recorded in KK (about 4.08), while DR, LB and DS were intermediates over the entire trials (Table 21). It is important to note that these poorest FCR was observed due to nature of the experiments that was one on-farm by itself and this relates to inappropriate feeding managments (feeder management will affect flock FCR through its effect on feed intake and feed spillage), Measurement failure (over-estimation of actual feed usage and / or under-estimation of actual live weight will certainly lead to reduction of FCR), water management problems (the provision of adequate drinking space and a source of clean water are essential. A reduction in water intake will lead to a reduction in feed intake and an increase in FCR) and others.

Table 21. Means body weight (BW-F), body weight gain (ABWG-F), and daily feed intake (ADFI-F), %Lay (hen-day), egg weight, total numbers of eggs, egg mass, total feed intake (AFI-F) and FCR of females from six Commercial layers (ComL)[1].

	Age (wks)	DR	DS	KK	LB	NB	NC
Daily feed intake (g/bird/day)	0-48	88.3^{b}	85.6^{c}	89.9^{ab}	88.1^{b}	88.3^{b}	91.1^{a}
Body weight (g)	16	1764.5^{a}	1753.3^{a}	1626.0^{b}	1692.5^{b}	1705^{ab}	1576.7^{c}
	48	2006.7^{b}	1926.7^{c}	2100.0^{ab}	2000.0^{b}	2026.7^{b}	2203.3^{a}
Body weight gain (g)	16-48	77.0^{b}	52.5^{c}	85.6^{a}	73.3^{b}	74.1^{b}	88.9^{a}
% Lay (hen-day)	16-48	45.7^{ab}	41.9^{b}	45.9^{ab}	49.6^{ab}	56.1^{a}	47.3^{ab}
Source of variation							
ComL		****	****	****	****	****	****
Week		****	****	****	****	****	****
ComH × week		****	****	****	****	****	****
Total feed intake (kg/hen)	16-48	23.0^{ab}	21.8^{b}	23.4^{a}	23.3^{ab}	22.7^{ab}	23.3^{ab}
Feed conversion ratio (FCR)	16-48	3.76^{bc}	3.85^{b}	4.08^{a}	3.77^{bc}	3.18^{d}	3.54^{c}
Egg weight (g)[2]	16-48	57.8^{bc}	58.3^{ab}	50.9^{d}	56.7^{c}	57.1^{bc}	59.2^{a}
Total number of eggs/hen/30wks	16-48	107.1^{c}	98.2^{d}	107.6^{c}	116.4^{b}	131.5^{a}	111.3^{b}
Egg mass (Kg/hen)	16-48	6.19^{b}	5.73^{c}	5.79^{c}	6.42^{b}	7.51^{a}	6.59^{b}

$^{a–d}$Means with different letters within rows differ significantly by the Tukey test at P<0.05. ****P<0.0001
[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color. Wks = weeks.
[2]Eggs weight was collected when the hens were at 28, 36 and 44.weeks of age only.

4.4.2. *Females body weight*

The females' body weight (BW-F) at five ages, from the start (16 weeks) to the end (48 weeks) of the trial, onset of laying (16 weeks) and end of the trails of (48 weeks), average body weight gain (ABWG-F) between age in weeks (16-48 weeks), total average feed intake (AFI kg/hen in 30 weeks) and FCR are presented in Table 21 and Figure 16.

The body weight (BW-F) curves of females from the six Commercial layers (ComL) exhibited differences ($P<0.05$) among ComL, within age and (genotype by age interactions) in body weight and body weight gain during these 30 weeks of age. At the end of the trails (48 weeks of age), BW-F of NC was significantly the highest (about 2203.3g) than others ComL and the lowest BW-F was recorded in DS (about 1926.7g). The KK female ranked second heavier BW-F (about 2100g at 48 weeks of ages), while the others (NB, DR and LB) were intermediate in these egg production (females) trials (Table 21). One of the remarkable BW-F was observed after 32 weeks of age in NC where continues to increase at higher rate than others due to the genetic background during their broiler male parents stocks combinations study, followed by KK until the end of the trials (Figure 16). Significantly higher average body weight gain (BWG-F) was recorded in NC (88.9g) and KK (85.6g) females than other ComL and the lowest BWG-F was observed in DS (52.5g), while the others DR, NB and LB were intermediate (Table 21).

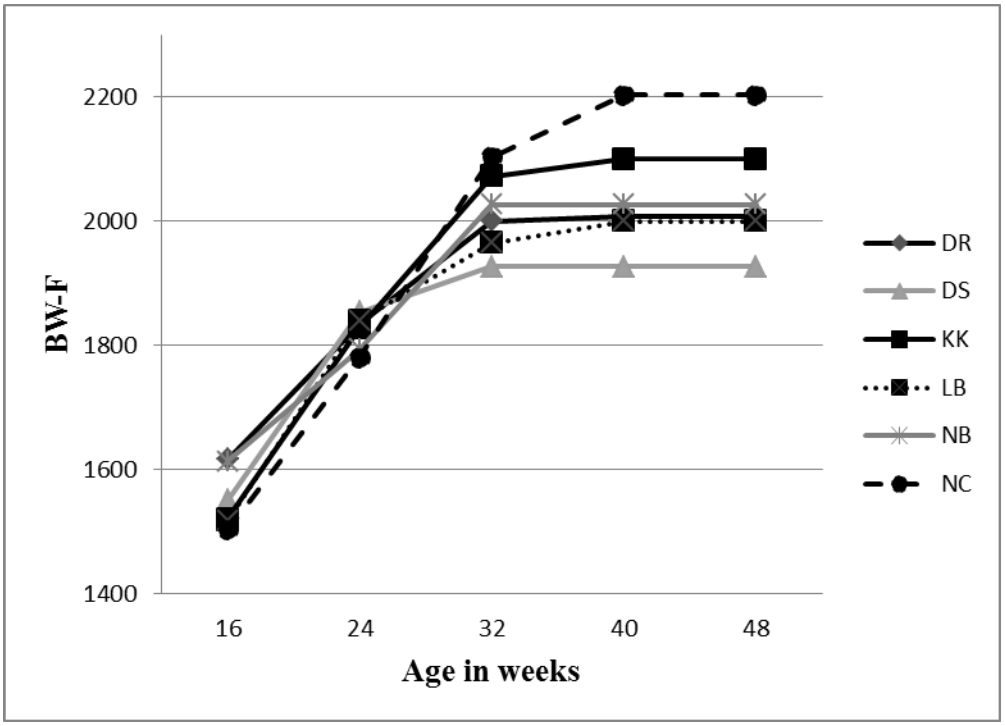

Figure16. Average body weight of females from the six Commercial layers (ComL) at 5 ages.

(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color).

4.4.3. Egg production

Average means of age at first egg and 5% lay (days), % lay at peak of lay (from 16 to 48 weeks of age) are presented in Table 22 for all the six Commercial layers (ComL). Except age at first eggs, there was significant effects ($P<0.05$) at 5% lay (days) and % lay at peak of lay in these egg production performance traits during the laying stages except for age at first egg (days). The earliest sexual maturity at 5% lay (days) was exhibited ~119 days in NC than other ComL, followed by DR, KK and NB at ~126 days, while the DS and LB were reached sexual maturity at older age ~ 135 day during the study age in weeks. NB (86.4%) was top in average % Lay at peak of lay and DS (62.4%) was the lowest, while LB, NC, KK and DR were intermediates in average % Lay at peak of lay as presented in Table 21.

Table 22. Means of age at first egg and at 5% Lay and peak % Lay of six Commercial layers (ComH)[1].

Parameters	DR	DS	KK	LB	NB	NC
Age at first egg (days)	119.0	128.3	124.6	127.8	119.0	112.0
Age at 5% Lay (days)	126.0[ab]	135.3[a]	128.8[ab]	134.8[a]	126.0[ab]	119.0[b]
% Lay at peak of lay	70.2[ab]	62.4[b]	76.2[ab]	77.7[ab]	86.4[a]	77.5[ab]

[a–b]Means with different letters within rows differ significantly by the Tukey test at P<0.05.
[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color.

Average egg production performances % lay (hen-day) at 4 age periods, from the start (16 wks) to the end (48 wks) of the trial, average egg weight, total number of eggs/hen/30wks, egg mass (kg/hen) for the six ComL is shown in Table 21 and Figure 17. The ComL differed in % lay, especially during the 25-32 age in weeks, with NB is leading with an average of 67.4 %, followed by NC ~ 60.4% lay, while DS (47.2%) was the lowest whereas LB, KK and DR were intermediate with an average of DS 51% lay during the 25-32 age in weeks (Figure 17). Except one of the ComL (DR), the laying rate of others ComL continues to increase up to 33-40 age in weeks. One of the notable performances observed in NC and NB were continued increment at higher rate than others. Unfortunately, rather to continue at higher rate of % lay in all the ComL already started to decline after 40 weeks of age as presented in Figure 17. The average egg production-hen-day (%) of NB (56.1%) was higher than other of the five ComL layers, while LB, NC, KK and DR were intermediates; however, the lowest egg production hen-day was recorded in DS (41.9%) over the entire trials as indicated in table 21. There was significant difference (P<0.05) among ComL, age in age in weeks and (genotype by age interactions) in % lay (hen-day) over the entire trials of egg production performance the start (16 wks) to the end (48 wks) of the trial.

Figure 17. Average % Lay (hen-day) from the six Commercial layers (ComL) at 4 age periods of the trial.

DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color.

The highest average egg weight was recorded in NC (about 59.2g), followed by DS (about 58.3g), while DR, NB and LB were intermediate; however, the lowest average egg weight was recorded in KK (about 50.9g) during the laying stages.

The overall laying percentages were multiplied by 210 (number of days in 30 weeks) to calculate the mean total number of eggs per hen. Significantly the highest total number of eggs/hen was recorded in NB (about 131.5 eggs/hen), followed by LB (about 116.4 eggs/hen) and NC (about 111.3eggs/hen), while DR and KK were intermediate; however, the lowest total numbers of eggs/hen over the entire trial was recorded in DS (about 98.2 eggs/hen) as presented in Table 21 during these 30 weeks of age under on-farm trials, due to poor laying consistency, with the lowest egg production (~ 41.9 % lay).

In these (females' egg) production performance the relation to total numbers of egg/hen and the mean egg weight, the highest egg mass (Kg/hen) was recorded in NB (about 7.51kg/hen), while DS (5.73kg/hen) and KK (5.79kg/hen) was the lowest whereas NC, LB and DR were intermediate with an average of 6.4kg/hen during the laying stages (Table 21). The main parameters related to ComL performance are egg production on the income side, feed intake on the costs side and their combination (FCR) were considered to compare the female' as egg productions, so that, the NB was the best in higher egg production, in lowest feed intake, higher egg mass and better in FCR, followed by LB and NC, while DS was the least in egg production performance during these 30 weeks of age under on-farm trials.

4.4.4. Females mortality

The least square means of average % mortality over the entire trial (Week 16 to 48) of females and (Week 0 to 12) of males from six Commercial layers (ComL) are presented in Table 23. In these on-farm (females' egg) production trials, significantly higher average % mortality was recorded in DS (1.15%) than other ComL, followed by DR, NB and NC females. The lowest average % mortality was recorded in KK (0.29%) and LB (0.20%) females.

Table 23. Least square means of % mortality of females and males from six Commercial layers (ComL)[1].

Parameters	DR	DS	KK	LB	NB	NC
Average female mortality (%) (Weeks 16 to 48)	0.70[ab]	1.15[a]	0.29[b]	0.20[b]	0.31[ab]	0.41[ab]
Source of variation						
ComH	****	****	****	****	****	****
Week	****	****	****	****	****	****
ComH × week	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

[a–d]Means with different letters within rows differ significantly by the Tukey test at P<0.05. ****P<0.0001; NS, not significant

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color.

4.4.5. Males body weight and feed intake

The males' body weight (BW-M) for meat production curves from six Commercial layers (ComL) at 3 ages, from the start (4 weeks) to the end (12 weeks) of the trial are presented in Figure 18. Average males BW-M at the end of the trials (12 weeks), body weight gain (BWG-M) between age in weeks (0-12 weeks), and cumulative average feed intake (g) (CFI) (between 0-12weeks) are presented in Table 24. The most economic criterion for marketing male chickens in Ethiopia was live body weight (since selling live body was common) especially at holidays to prepare the traditional '*Doro wat*' (chicken stew). In these on-farm meat production (males) trials, significantly higher BW-M was recorded in these three ComL of DR, KK and NB with the range of 1600g, followed by NC (about 1525g); while LB and DS was intermediate about 1400g (Table 24). The average body weight of males at 3 ages of specific age in week was observed a continue increment at higher rate in similar way over the entire trials (0 to 12 weeks of age) in all ComL (Figure 18).

There were differences ($P<0.05$) among ComL males, within age and (genotype by age interactions) in average feed intake (AFI cumulative) but in BW-M and BWG-M the significant difference ($P<0.05$) was only in ComL and within ages not in ComL x Age interactions over the entire trials.

Like BW-M, significantly higher BWG-M was recorded in these three ComH of NB, KK and DR with the range of 525.2g, followed by NC (about 497.6g); while LB and DS was intermediate about 458.5g (Table 23). Generally best growth or BWG-M leads us to apply the ideas to use the males for meat productions as an alternative meat production to broiler chickens in Ethiopia. These males' meat could be best for the preparation of Ethiopian traditional '*Doro wat'* (chicken stew) rather to use these commercial broiler strains in other forms due to the test of the meat and also it would not be change its meat in to tiny or small fragments of meats during these three to four hours of traditional '*Doro wat*' (chicken stew) preparations. The time to prepare this '*Doro wat*' (chicken stew) was taking three to four hours based on the types of the cooking materials they used.

Table 24. Least square means of average body weight gain, final body weight and cumulative feed intake (CFI) of males from six Commercial layers (ComL)[1].

	Age (wks)	DR	DS	KK	LB	NB	NC
Cumulative Feed Intake (g)[2]	0-12	4403.8[b]	4448.1[ab]	4462.1[ab]	4471.6[ab]	4626.2[a]	4559.8[ab]
Average Body Weight Gain (g)	0-12	522.0[a]	455.0[b]	523.7[a]	462.6[b]	530.0[a]	497.6[ab]
Body Weight (g)	12	1600.0[a]	1400.0[b]	1600.0[a]	1420.0[b]	1620.0[a]	1525.0[ab]
Source of variation							
ComH		****	****	****	****	****	****
Week		****	****	****	****	****	****
ComH × week		*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

[a–b]Means with different letters within rows differ significantly by the Tukey test at P<0.05.

[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color. Wks = weeks.

[2]ComH*Age interaction was significant

Significantly higher cumulative feed intake (CFI) was showed in NB (4626.2g) and the lowest cumulative feed intake (CFI) was showed in DR (4403.8) throughout the trials; while others were intermediate in AFI cumulative (Table 24) over the entire trials (0 to 12 weeks of age).

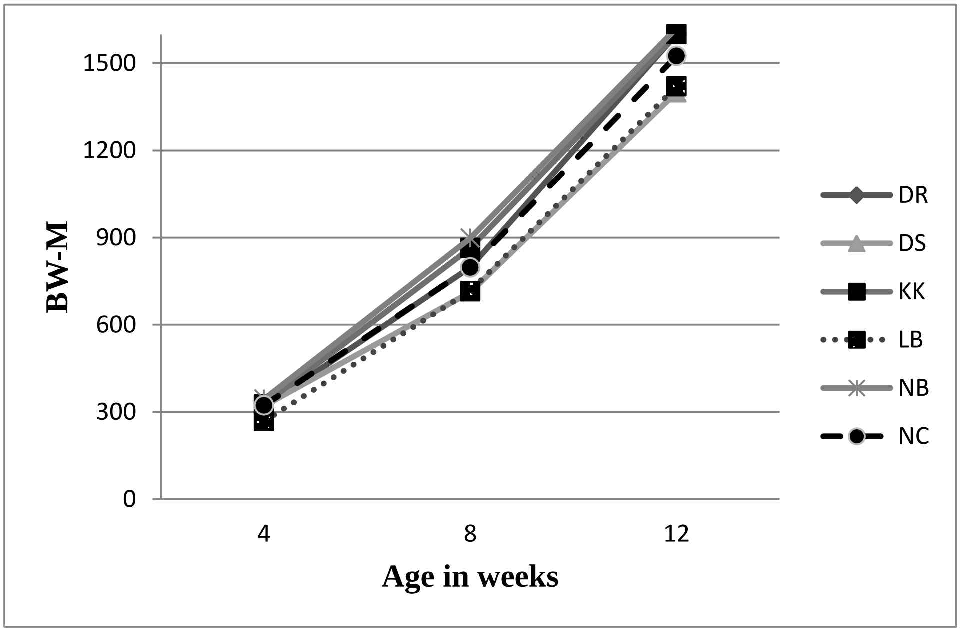

Figure 18. Average body weight of males from the six Commercial layers (ComL) at 3 ages of specific periods of the trial.
(DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color). Wks = weeks.

4.4.6. Males mortality

The least square means of average % mortality over the entire trial (Week 0 to 12) of males from six Commercial layers (ComL) are presented in Table 25. During (males' meat) production trials, significantly very low mortality (0.40%) was recorded in NB males. The highest average % mortality was recorded in DR (4.25%) followed by LB (2.80%) males, while DS (1.35%), NC (1.25%) and KK (1.00%) males were intermediates over the entire trials (weeks 0 to 12). There were significant ($P<0.05$) effects of ComL and ages but the genotype by age interactions effect on the average % mortality of the females during the laying phases and males growth stages was not significant ($P>0.05$).

Table 25. Least square means of average % mortality of females and males from six Commercial layers (ComL)[1].

Parameters	DR	DS	KK	LB	NB	NC
Average males mortality (%) (Weeks 0 to12)	4.25[a]	1.35[c]	1.00[cd]	2.80[b]	0.40[d]	1.25[cd]
Source of variation						
ComH	****	****	****	****	****	****
Week	****	****	****	****	****	****
ComH × *week*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*

[a–d]Means with different letters within rows differ significantly by the Tukey test at P<0.05.
****P<0.0001
[1]DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color.

5. DISCUSSION

The actual conditions at the DZ farm were like those in medium-scale commercial farms in Ethiopia and quite different from those in developed counties where the commercial strains under this study have been bred and tested. Therefore, the performance and mortality are hardly comparable to those in the breeders' guidelines and in publications from high-level research organizations in developed countries.

In this section, results from the different experiments are discussed in the order presented in the result section. Accordingly, results from evaluation of the production and reproduction performances of commercial layer parent stock in Debre Zeit and Hawassa University on- station management conditions in Ethiopia are discussed respectively in the first two consecutive sub-sections (5.1-5.2). Results that dealt with the evaluation of egg and meat production performances of commercial crosses and experimental crosses on-station management conditions are discussed under the third sub-section of (5.3). Similarly, results from evaluation of egg and meat production performances of commercial crosses under on-farm management conditions in Debre zeit town in Ethiopia are discussed in the fourth (5.4) sub-sections , in that order.

5.1. Parent Stock at Debre Zeit Agricultural Research Center

5.1.1. Feed intakes

The feed intake was measured daily in all pens and divided by the number of live birds/pen. The average daily feed intake (ADFI), from 16 to 60 weeks of age, of LB, NB and NC were like the standards reported by the breeding companies (Lohmann and Novogen), with the report of (Amin, 2014; Singh *et al.*, 2009 and Dawud *et al.*, 2011) for the same ages. The feed intake means of DR and DS were higher than the standards reported by the breeding company (Dominant CZ), and those of KK were higher than the report by Wondmeneh *et al.* (2011) for the same age in weeks as in the present study. It is notable that the NB and NC being from the same maternal line, exhibit very similar feed intake, and significantly lower than the LB as they have been similarly selected for efficient egg production. The lower feed intake, especially of NB from 16 to 32 weeks, and of both (i.e., NC) up to 48 weeks, could be related to higher mortality often associated with morbidly that cause reduced appetite, and to lower egg production. Environmental factor like temperature was found to contribute about 97.2% showing that it has the greatest effect on feed intake. Resulting in, a decrease in rate of feed intake in any poultry farms as reported by Obayelu *et al.* (2006). The effects on higher temperature (above 27°C) on feed consumption also reported by Talukder *et al.* (2010).

5.1.2. Body weight

The average weekly body weights of DR, DS, LD, and KK for females were relatively comparable with the standards reported by the breeder's company and Wondmeneh *et al.* (2011) with similar age in weeks of our study. The NB and NC exhibited the lowest BW among the females and NB and LB among the males (Figure 3), in agreement with their long-term breeding for economically efficient production of brown eggs, based on high laying rate and low BW. LB was lower in average female body weight than reported by (Singh *et al.*, 2009) (1950 g at 50 weeks of age) but much better than (1412g at 52 weeks of age) the report of Dawud *et al.* (2011). Similar average body weight with our findings (on breeds of DR and DS) was reported by Amin. (2014) on breed of exotic parental strains of Italian (1950g) age at 50% of egg productions.

The lower body weight among few females and males PS was due to the environmental factors as reported by Doni *et al.* (2015) that, temperature more than 28°C, weight gains are lowered. If condition remains for prolonged period, there may be loss in body weight. In contrast, DR and DS have been bred by Dominant CZ as layers with higher BW, in order to withstand below-optimum conditions in East Europe and developing countries. In agreement with their breeding history, the DR and DS females in this study exhibited the highest BW during the entire trial, and their male counterparts were heavier than the males of the two brown-eggs layers (LB and NB). The KK breed has been developed (originally in South Africa and later evaluated in Ethiopia) mainly for semi-intensive and extensive production conditions, by combining reasonable laying rate with relatively high BW. Accordingly, mean BW of KK females ranked third after DR and DS, and the BW of their male counterparts was like the males of DR and DS (Figure 2). Similar findings were reported by Wondmeneh *et al.* (2011) on average body weight (2653g) of KK male and with the standards reported by the breeder's company (3583g) of LD males.

Two recent attempts to produce heavy body weight layer chickens, each based on a different genetic concept, were included in this study. In NC, hens from the same egg-type maternal line of NB were mated to males from a meat-type paternal line. Indeed, BW means of the NC females were as low as the means of the NB females, whereas NC males exhibited extremely high BW, averaging about 5000g towards the end of the trial (Figure 2). In LD, the hens were from a medium-BW maternal line, and indeed their BW means were higher than those of LB during the entire trial. The parental LD males were also meat-type (as in NC) but dwarf, a phenotype known to reduce BW by ~30%. Accordingly, from 32 weeks to end of the trial, mean BW of the LD males were about 70% of the corresponding means of the NC males (Figure 3). The LB male mean body weight was comparable with the report of male Lohmann Silver (2348g at 52 weeks of age) Dawud *et al.* (2011).

5.1.3. Egg productions

The six PS (DR, DS, LB, LD, NB and NC) started to lay egg later and produced less egg than the standards given by the respective breeding companies (Dominant, Lohmann and Novogen). KK was similar with the onset of lay but lower in egg production than in the studies of Wondmeneh *et al.* (2011) and Grobbelaar *et al.* (2010). The differences between age of sexual maturity and the levels of egg production reported here and those reported by the breeders and other studies could be attributed to differences in management and environmental conditions.

The European breeding companies develop and test their PS under better conditions than the conditions in this study, that were intentionally similar to those prevailing in poultry farms in Ethiopia. The levels of peak laying rate (% lay at peak, Table 5) were quite like those indicated by the breeding companies and Wondmeneh *et al.* (2011). These results suggest the relatively low levels of total egg production were mainly due to late onset of lay and slow elevation in laying rate (Figure 3). Accordingly, LB and LD, the first PS to lay eggs, produced more eggs that the other PS, but LD hens were significantly better than LB (average laying rate of 64.2 vs. 56.3, respectively) because their % lay elevated faster and was significantly higher than that of LB (and all other PS) during the 25-32 period (Figure 3). The hens of NB and NC were actually the same maternal line and indeed, they exhibited similar low egg production during the entire trial. Their low egg production (Figure 3) appears to be associated with low feed intake (Figure 2), possibly related to higher morbidity and mortality (Table 9).

In this study, we found that egg production-hen-day (%) of LB was lower than reports (87.5%) by (Singh *et al.*, 2009) but much better results was recorded than the report of (Dawud *et al.*, 2011) with similar age in weeks of our study.

5.1.4. Fertility and hatchability

Fertility and hatchability were measured three times, when the birds were 28, 34 and 44 weeks of age. At 28 weeks, the percentage of fertile eggs (% fertility) varied considerably among the PS, ranging from around 80% (DR, DS and KK) to 62% (LB) and 46% (NB), down to very poor fertility in LD and NC (32% and 22%, Table 6). Six weeks later, % fertility of the top three PS remained at 80-88%, and it increased to a reasonable level in LB (~75%) and in NB (63%). It also increased in LD and NC, but only to 40%, a non-acceptable level. Because LD and NC were bred as produce heavy layer chickens, the males in these two PS originate from meat-type paternal lines, and therefore their genetic potential for growth and BW was much higher than the growth and BW of their female counterparts. In terms of final BW, in LD the females averaged ~1670 g and the males averaged 3660 g, a difference of almost 2000 g; and in NC the females averaged 1642 g and the males averaged 5027 g, a difference of almost 3400 g (Table 4), whereas in all other PS, the difference in BW between the males and the females ranged between 900 to 990 g only. It is possible that the high BW of the males in NC and LD made it difficult for them to naturally mate with their much smaller female counterparts.

To test the possibility that the low fertility was due to difficulty in natural mating's, the hens of LD and NC in each pen were artificially inseminated with semen collected from the males in the same pen, starting from 44 weeks of age. The artificial insemination (AI) elevated the % fertility of LD and NC to almost 80%, the same level as all other PS, proving that the overweight of the males was the only reason for the low fertility. This problem was foreseen by the breeders of LD and NC, and therefore their guidelines emphasis the need to restrict the males' feed intake. However, doing it while allowing the females in the same pens to consume feed ad-libitum proved to be very difficult, especially under the local conditions where separate-sex feeding equipment is not available.

The practice of AI, that successfully solved this problem, had been established many years ago, but later it was abandoned in all developed countries due to high labor costs. However, in many countries, low-cost farm labor is available and therefore AI is a very feasible practice. It is already used quite widely in China and India, and to some extent in Nigeria, but it can easily be adopted in all developing countries, to facilitate efficient production of day-old chicks from PS with large males and small females, as LD and NC in this study (Personal communication).

The percentage of fertile eggs that hatched (% hatch/fertile) at 28 weeks was very similar (~80%) in all PS and over 90% in KK. At 34 weeks, the %hatch/fertile of NC dropped to 35%, whereas the percentages of all other PS were quite similar to those of 28 weeks. At 44 weeks, the %hatch/fertile of NC was 83.3%, suggesting that the 35% at 34 weeks was accidental rather than real reduction in hatchability. All seven PS exhibited quite similar % hatch/fertile at 44 weeks, ranging from 75 to 88% (Table 6, Figure 5).

The percentage of all set eggs that hatched (% hatch/set) combines %fertility and %hatch/fertile. At 28 and 34 weeks, the means of the seven PS where females and males have comparable BW were spread over a very wide range, from 85% to 37%. Due to the poor % fertility, means of %hatch/eggs set were much lower in LD (24 and 29%) and further lower in NC (17 and 8%). However, at 44 weeks all seven PS exhibited similar % hatch/eggs set, ranging from 66 to 54%; and with AI, the two heavy-males PS (LD and NC), reached ~66% hatch/set, similar or superior to the other PS (Table 6, Figure 5). These results suggest that only at the 3rd incubation test (at 44 weeks); the seven PS exhibited their true potential of fertility and hatchability. KK was comparable in egg fertility (%), hatchability (%) per set of eggs and hatchability (%) per fertile eggs with the report of Wondmeneh *et al.* (2011) also comparable with the genotype of Mandarah local strain, Sasso and Italian exotic parental commercial strain with the report of Amin (2014) but other PS layers not comparable with the standards reported by the breeder's company with similar age periods of our study.

The result of this study on effects of PS strain on fertility was in contradiction with the findings of Olawumi and Salako (2011) who reported no significant effect of strain on fertility in Barred Plymouth Rock and White Plymouth Rock but similar results were reported for the effects of strain on hatchability. Our findings on fertility (%), hatchability (%) per fertile eggs and hatchability (%) per set of eggs was lower than the reports of Islam *et al.* (2002) on breeds of Barred Plymouth Rock, White Leghorn, Rhode Island Red and White Rock for fertility (%) was (88.8, 94.8, 88.3 and 92.2 respectively), hatchability (%) per fertile eggs (88.6, 90.2, 88.4 and 91.9 respectively) and for hatchability (%) per set of eggs (81.3, 86.1, 79.6 and 84.9 respectively) with similar age in weeks of our study. LB was comparable in egg fertility (%), hatchability (%) per set of eggs and hatchability (%) per fertile eggs with the report of Dawud *et al.* (2011)

Accordingly, the expected number of chicks per hen in each pen was calculated by multiplying the calculated total number of eggs per hen (Table 6) by % hatch/eggs set at 44 weeks. By this calculation, LD lead with a mean of 131.5 expected chicks, followed by DR, LB, KK and NC with means ranging from ~106 to ~92 chicks, and finally DS and NB with ~78 chicks (Table 6).

Fertility and hatchability are known to be improved by heterosis resulting from crossing genetically remote parents. Some investigators agreed with the superiority of crossbreds over their parental breeds. Strain crosses in poultry industry are considered an effective method to produce hybrid vigor due to the improved reproductive traits as fertility and hatchability in commercial stocks as reported by El-Dlebshany *et al.* (2013) and Amin. (2014). Moreover, these findings agreed with the reported of Crossbreds were found to have higher fertility percentage than their parental pure strains (Gad *et al.*, 1991). Significant differences between strains, lines and crossbreds in hatchability traits were reported by Mostafa and Younis (2001) and Amin (2014) in chickens found that cross of El-Salam x Mandarah strains recorded the highest significant averages for fertility and hatchability compared to the pure strains. In LB, LD, NB and NC, the females and males are coming from genetically remote parental lines and therefore heterosis is "built in". But in DR, DS and KK, the females and males differ only in a single sex-linked gene (to allow sexing of day-old chicks) and otherwise they share the same genetic background and therefore no (or very limited) heterosis is expected in these three PSs.

There were three such crosses in this study: DR hens were mated with KK males (DRKK 'Cross'), DS hens were mated with DR males (DSDR 'Cross'), and KK hens were mated with DS males (KKDS 'Cross'). The data (% fertility, % hatch/fertile and % hatch/eggs set) obtained at the three ages (28, 34 and 44 weeks) from these six PS combinations were analyzed by a two-way model with hens genetics (DR, DS, KK) being one factor and parents' similarity within the PS ('Pure' versus 'Cross') being the second factor. Within each hen PS (DR or DS or KK), % fertility of the 'Cross' eggs was significantly higher than in the 'Pure' eggs, and averaged over the three hens' PS, fertility was 86% in 'Cross' eggs and only 81.3% in 'Pure' eggs. Also for % hatch/fertile there was a significant advantage of 'Cross' over 'Pure' averaging 85.9% vs. 83%, and for % hatch/eggs set there was a highly significant advantage of mating between genetically remote parents, with 74% hatch/eggs set from 'Cross' mating’s compare to 67.7% hatch/eggs set from 'Pure' mating (Table 7). These results confirm the positive effect of heterosis on fertility and hatchability, and suggest that where PS such as DR, DS and KK are used, the rate of hatchability of all set eggs can be improved by about 10% by crossing between them.

5.1.5. Egg size and quality

Egg parameters were measured when the hens were at five different ages (26, 30, 36, 40 and 44 weeks) during the trial and with no PS by age interactions, PS mean ages were compared. The DR and DS hens laid the largest eggs, KK hens laid the smallest eggs, and the other PS (LB, LD, NB and NC) were intermediate (Table 8). Weight was recorded also for the eggs set for incubation (at 28, 34 and 44 weeks) and the hatching chicks. Similar average egg weight with our findings (on breeds of DR and DS) was reported by Amin (2014) on breeds of exotic strains of Italian (61g) but higher average egg weight than our findings was reported compared with others breeds at the 1st 180 days of egg productions. The eggs and chicks of DR and DS were the heaviest, and the eggs and chicks of KK had the lowest weight (Table 8). Higher average chick weight than our finding was reported by Islam *et al.* (2002) on breeds of Barred Plymouth Rock, White Leghorn, Rhode Island Red and White Rock (39.0g, 39.0g, 39.0g and 38.1g, respectively) with similar age in weeks of our study.

The PSs were ranked similarly for all size-related measurements: yolk weight, albumen weight and egg width and length. Only shell weight was somewhat independent of egg weight, being similar in DR and DS (largest eggs) and KK (smallest eggs). Accordingly, KK eggs exhibited the highest % shell weight and consequently the lowest % albumen. The seven PS did not differ significantly in all the other egg measurements: % yolk weight, egg shape index, shell thickness, yolk height and albumen height. Jana *et al.* (2014) for Lohmann breeds in egg weight, albumen weight and yolk weight were reported (60.05g, 36.6g and 16.24g respectively) higher than our findings with similar age in weeks of our study. Relatively similar egg weight for Lohmann Silver (52.9g) was reported by Dawud *et al.* (2011) with similar age periods of our study. KK was not comparable in average shell thickness, albumen height, yolk color, albumen weight, (0.29mm, 5.53mm, 10.3, 26.07g respectively) but comparable in average yolk height, yolk weight, (17.59mm, 14.54g respectively) with the reports of Desalew *et al.* (2015). The difference between the results obtained during this investigation and the results obtained by breeder's company and other studies could be attributed to genotype-environment interactions or unrealistic advertisement of the companies for their markets.

5.1.6. Mortality

Mortality was exceptionally high in NC, due to an outbreak of the Gumboro disease that occurred in all PS at growing stages due to vaccine failure but apparently, the NC birds were more susceptible. In all other PS, average mortality over the entire trial of females ranged between 0.21 and 1.26%, quite reasonable for the Ethiopian conditions. The lower mortality was found in both sexes as compared to the standards reported by the breeder's company. In a study with KK in South Africa (Grobbelaar *et al.*, 2010) mortality in both sexes was around 22%, slightly higher than females (0.46%) and lower than males (0.77%) reported here. Higher average mortality percentage than our finding was reported by Amin (2014) on breeds of exotic strains of Italian (7.3%). Lower female mortality of Lohmann Silver (0.41%) was reported here as compared to Dawud *et al.* (2011).

5.2. Parent Stock (HU Trials)

5.2.1. Feed intake

Significantly higher average daily feed intakes were recorded in DR and DS than other PS in week 16 to 24 and 25 to 32, followed by the KK, while the lower average feed intakes were recorded in LB and LD. This superiority in PS DR and DS may be due to heavy body weight of the PS layers. The average feed intake (between 33 to 60 weeks of age) was not significantly different (P>0.05) among PS across all the ages. The result also showed a significant difference (P<0.05) in average feed intakes (g/bird/day) for both sexes. The average feed intake of LB, LD, DR, and DS (both female and male) during 16 to 60 weeks of age was comparable with the standards reported by the breeder's company (117, 115, 119 and 119g/bird/day respectively). The daily feed intakes of Lohmann strain was close to a value of 114.5g reported by Singh *et al.* (2009), but that of PS KK was lower than the value of 123 g/bird/day (Wondmeneh *et al.,* 2011). Lower average daily feed intakes than our finding was reported by Amin (2014) on breeds of exotic strains of Italian (110g/hen/day). A different result on feed intake was found as environmental factor like temperature was found to contribute about 97.2% showing that it has the greatest effect on feed intake. Hence, a decrease in rate of feed intake in any poultry farms as reported by Obayelu *et al.* (2006). The effects higher temperature (above 27°C) on feed consumption was also reported by Talukder *et al.* (2010).

5.2.2. Body weight

Significantly higher (P<0.05) average female body weight was recorded in DR, followed by DS and KK. The lowest average female body weights were recorded in LD and LB at all ages of the laying phases. The average weekly female body weight of KK was relatively comparable with the report by Wondmeneh *et al.* (2011), (1873 g/bird/wk). But average weight at 60 weeks of age of LB was lower than 1950g at 50 weeks of age as reported by Singh *et al.* (2009). However, the average weekly females body weight of DR, DS, LD and LB PS layers were lower than the standards reported by the breeding company (2150, 2150, 1894 and 1897 g/bird/wk respectively) during the laying stages. Similar average body weight with our finding was reported by Amin, (2014) on breeds of exotic strains of Italian (1950g). The reasons may be due to the environmental factors as reported by Doni *et al.* (2015) that, temperature more than 28°C, weight gains are lowered. If condition remains for prolonged period, there may be loss in body weight. From the initial to the end of this study the average female body weight records shows that there were big differences among the strains.

The average male body weight (g/bird/wk) of LD was significantly higher than other PS, followed by DR, KK and DS, the lowest average male body weights were recorded in LB during studies. This (LD) superiority was from the dwarf (homozygous dw/dw) meat-type line of LD. The other males were from the layer-types and hence lowest in body weight during the laying stages compared to that of LD male. The results were similar to findings reported by Wondmeneh *et al.* (2011) on average body weight (2653g/bird/wk) of male PS KK and with the standards reported by the breeder's company (3583g/bird/wk) of male LD. Reference cannot be found specifically on body weight at later ages of parental male line strains because most of the companies record shows weight recording up to 18 weeks of age only. From this study we found out that, there is a big difference among the PSs in terms of average male body weight at the different growth stages.

5.2.3. Egg production

The average egg production of LB and LD were significantly higher than the rest, followed by KK, DS and DR. The average egg production of DS and DR were lower than the standard production given by the breeding company (81.2and 81.2%/wk respectively) but the average egg production of LB, LD and KK PS were similar with the standards of 87.0 and 82.5% /in wk, respectively, given by the breeders 57.0 to 63.7 % wks reported by Wondmeneh *et al.* (2011) and 60.4% by Grobbelaar *et al.* (2010). Compared to other PS LD and LB performed well in egg production but DS and DR had irregular and lower egg production performance. The difference between the results obtained during this investigation and the results obtained by breeders' company and other studies could be attributed to genotype-environment interactions. The environment where the strains were developed might be different with the testing environment of the current study.

5.2.4. Fertility and hatchability

The result on performance of KK obtained in the current study was not comparable with the report of Wondmeneh *et al.* (2011) in average age at first egg drops (147 days) and 5% egg production or in reaching sexual maturity. On the contrary findings are comparable to the sexual maturity or production of first egg drops found by Grobbelaar *et al.* (2010) who stated that the sexual maturity for the Potchefstroom Koekoek was 138.5 days.

The performance of DR, DS, LB and LD layers were comparable to the standards reported by the breeders' manual (140, 140, 133and 133 days, respectively). LD and LB layers were top in average peak percent of lay (% in wks), followed by DB, DS and KK parent layers. KK was comparable in average age at peak of lay (days) and in average peak percent of lay (252 days and 72.4% in wks respectively) to what had been reported by Wondmeneh *et al.* (2011) for the same strain. In terms of average weekly peak percent lay, LB and LD were comparable but not with the standards provided by the breeders (94 & 91) % in wks and 175 & 189 days). DR and DS PS layers were not comparable in terms of average age at peak of lay (days) and average peak percent of lay (% in wks) with the standards reported by the breeder's company (203 and 203 days and 92 and 92 % in wk, respectively). LD and LB were the highest in egg production-hen-day (%) and average number of eggs/hen/44wks, followed by PS layers of DB, DS and KK. In this study, we found that % hen-day egg production of LB was lower than reports (87.5%) by Singh *et al.* (2009).

DR, DS, KK and LB were higher in egg fertility and hatchability per set eggs, followed by LD. The present result clearly indicated that the LD was poor in fertility (%) and hatchability (%) per set eggs at all stages of the laying phases. These lowest records were come from the meat-type male line of LD. KK had the highest and PS LD was the lowest, while other PS layers (DR, DS and LB) were intermediate in hatchability per fertile egg during the evaluation periods. PS KK was comparable in egg fertility (%), hatchability (%) per set of eggs and hatchability (%) per fertile eggs with the report of Wondmeneh *et al.* (2011).

The performance of the other PS was not comparable with the standards reported by the strainer's company. The result of this study on effects of PS strain on fertility was in contradiction with the findings of Olawumi and Salako (2011) who reported no significant effect of PS on fertility in Barred Plymouth Rock and White Plymouth Rock but similar results were reported for the effects of strain on hatchability). Islam *et al*. (2002) reported that strain had little effect on hatchability (%) per fertile eggs which contradict with our findings. Our findings on fertility, hatchability per fertile eggs and hatchability per set of eggs was lower than the reports of Islam *et al.* (2002) on strains of Barred Plymouth Rock, White Leghorn, Rhode Island Red and White Rock for fertility (88.8, 94.8, 88.3 and 92.2, respectively), hatchability (%) per fertile eggs (88.6, 90.2, 88.4 and 91.9, respectively) and hatchability per set of eggs (81.3, 86.1, 79.6 and 84.9, respectively).

5.2.5. Egg size and quality

DS, DR and KK had white-creamy egg shell color, while LB and LD had brown egg shell color. Shell color of DR, DS and KK were light brown to brown and not similar with the description of the breeders' manual and Grobbelaar *et al.* (2010), while for the other layers egg shell color was brown, which was in agreement with the breeders'. Islam *et al.* (2002) reported that genetic variation had little effect on egg weight in contrary to our findings. The average shell thickness, albumen height, albumen weight, (0.29 mm, 5.53 mm, and 26.07g, respectively) of KK was not comparable reports of Desalew *et al.* (2015) but similar in terms of average yolk height, yolk color, yolk weight, (17.59 mm, 10.3 and 14.54g, respectively) reports of Khan *et al.* (2004).

For best result of hatchability, egg shell thickness should be between 0.33 and 0.35 mm and few eggs with a shell thickness of less than 0.27mm will hatch which was similar our findings. It was found out that DR had the highest egg weight (g) while KK had the lowest weight, while the other PS layers of DS, LB and LD were intermediate in egg weight (g). DR, DS and KK were comparable in egg weight (g) with the standards reported by the breeders' manual and findings of Wondmeneh *et al.* (2011) (61.5, 61.5. 51.9g, respectively) but for PS KK heavier (55.7g) (Grobbelaar, 2008) and lighter (47.79g) (Desalew *et al.*, 2015) were reported. The egg weights of LB, and LD were not comparable with the standards of the breeding company (63.3, 63.2, and 62g respectively). Jana *et al*. (2014) also found (60.1g) heavier (60.05g) egg weight than our findings for Lohmann strains. Similar egg weights to what has been found in the current study for PS DS and DR was reported by Islam *et al.* (2002) with the strains of Barred Plymouth Rock, White Leghorn, Rhode Island Red and White Rock (58.04g, 59.48g, 58.18g and 58.3g respectively). Similar average egg weight with our findings (on breeds of DR and DS) was reported by Amin (2014) on breeds of exotic strains of Italian (61g) but higher average egg weight than our findings was reported compared with others breeds at the 1st 180 days of egg productions. Eggs from PS DR had significantly the highest albumen weight (g) while eggs from PS KK had the lowest albumen weight. PS layers of DS, LB and LD were intermediate in albumen weight at 26, 30, 36, 40 and 44 weeks of age. Jana *et al.* (2014) have reported 36.6g of albumen weight for Lohmann strains which is higher than our findings but similar findings in yolk weight (16.24g).

5.2.6. Mortality

The highest average female mortality was recorded in DR, followed by KK, DS and LD, while the lowest average female mortality was recorded in LB PS layers. Lower average male mortality was recorded in all the five PS layers. Lowest mortality results were found in both sexes in most of the PS layers as compared to the standards reported by the breeder's company, except highest mortality rate in DR PS. Higher average mortality percentage than our finding was reported by Amin (2014) on breeds of exotic strains of Italian (7.3%). For PS layer KK 22.2 % of mortality for both sexes was reported by the Grobbelaar *et al.* (2010) which indicate higher than our findings.

5.3. Females' Eggs and Males' Meat Productions (On-Station Trials)

5.3.1. Female feed intake

The feed intake was measured daily in all pens and divided by the number of live birds per pen. The average daily feed intake (ADFI), from 16 to 60 weeks of age, of the five ComL DR, DS, KK, LB and LD were much lower than the standards reported by the breeding companies (Lohmann, Dominant CZ and Novogen), Wondmeneh *et al.* (2011)

and Singh *et al.* (2009, while the only comparable ADFI was recorded in NC (114.4g) with the standards reported by the breeding company of Novogen (Figure 9).

The results reported here and those reported by the breeders and other studies could be attributed to differences in management and environmental conditions. Environmental factor like temperature was found to contribute about 97.2% showing that it has the greatest effect on feed intake. Hence, a decrease in rate of feed intake in any poultry farms as reported by Obayelu *et al.* (2006). The effects on higher temperature (above 27°C) on feed consumption also reported by Talukder *et al.* (2010). Mean ADFI of the ExpH of DRKK (103.5g) and DSDR (107.1g) were similar to the local reference of KK (97g) in this study (Table 15 and Figure 10) but KKDS was lower in ADFI by 14g from KK. Those three ExpCr of (DRKK, DSDR and KKDS) were higher in ADFI than the standards reported by the breeding company (Dominant CZ) but were relatively similar in BW-F.

5.3.2. Female body weight

The mean body weight (BW-F) of NC and DR were significantly highest as compared with the standards reported by the breeder's company with similar age in weeks of this study, but NC was by far higher than DR, while, BW-F of DS and KK were relatively comparable with the standards reported by the breeder's company and Wondmeneh *et al.* (2011), whereas LB, NB and LD were lower than the standards reported by the breeder's company. The lower in body weight among few females of ComL could be due to sub-optimal environmental conditions e.g. high temperatures (Doni *et al.*, 2015; Obayelu *et al.*, 2006); Talukder *et al.*, 2010). If condition remains for prolonged period, there may be loss in body weight. Relatively similar BW-F means were exhibited by the ExpCr DRKK (2160g), DSDR (1795.6g) and KKDS (1902.2g), similar also to the local reference of KK (1971.7g), thus achieving the objective of producing new heavy layer hybrids (KKDS, DRKK & DSDR) with body weight as high or higher than the local reference KK.

5.3.3. Egg production

The six ComL (DR, DS, LB, LD, NB and NC) started to lay later and produce less egg than the standards given the respective breeding companies (Dominant, Lohmann and

Novogen). Additionally, the ExpCr (DRKK, DSDR and KKDS) was started lately to lay than local reference of KK but produce higher total number of eggs than local reference of KK. KK was similar with the onset of lay but lower in egg production than in the studies of Wondmeneh *et al.* (2011) and Grobbelaar *et al.* (2010). The differences between age of sexual maturity and the levels of egg production reported here by the breeders and other studies could be attributed to differences in management and environmental conditions. The European breeding companies develop and test their ComH under better conditions than the conditions in this study, that were intentionally similar to those prevailing in poultry farms in Ethiopia.

The levels of peak laying rate (% lay at peak, Table 16) for ComL (DR, DS, LB, LD, NB and NC) were not similar to those indicated by the breeding companies. These results suggest the relatively low levels of total egg production were mainly due to late onset of lay, slow elevation and early dropping in laying rate before they reach to their genetic potential as presented in Figure 12. Higher % at peak of lay was recorded in KK than the reports of Wondmeneh *et al.* (2011). Similar results were recorded in % at peak of lay in ExpCr of DRKK (72.7%), DSDR (74.6%) and KKDS (77.7%), but higher in % lay (hen-day) in DRKK (55%) and KKDS (58.5%) as compared to local reference KK except lower results in DSDR (40.1%) in % lay (hen-day) (Table 16). Except LD and DR, the obtained values of other ComL & ExpCr in % Lay at peak of lay were comparable to those of Lamberts *et al.* (2018) for two chicken types of pure and crosses.

Significantly the higher egg production % was observed in LB (average laying rate of 57.7) because of its % lay elevated faster, long % of laying consistency than that of KKDS (and all other ComL and ExpCr), followed by KKDS (average laying rate of 51.3), While NB, NC, DRKK, DR, KK and DSDR ranked third to eighth respectively; however, the lowest egg production % was recorded in DS and LD due to poor laying consistency as presented in Figure 12. It was identified the productive layer than non-layers as follow, if feel around an egg laying chickens breastbone, it should be quite large – around 4 fingers in width. Their abdomen was about 3 fingers in width. This was less for non-layers. Other methods were also applied to identify correctly the open hens from close hens throughout this study. The average % lay of open hens or the highest probability for egg production, over the entire trial was recorded in LB (68%) and NB

(65.9%), followed by DRKK (62.8%), KKDS (62.2%), DR (58.7%) and NC (56.4%). DSDR and KK were ranked third and DS & LD were ranked last at all ages. Practicing this trial on the closed hens was so important to identify the source of the problem and to correct it immediately since any factors can affect egg production, with management or health (before and after lay) being one of the most significant. The average % closed hens or the least probability for egg production, over the entire trial were recorded in DS and DSDR, followed by NB, DRKK, KK and LD, while DR and KKDS were intermediates; however, LB and NC were the lowest % closed hens at all ages as presented in Table 16.

The overall laying percentages were multiplied by 308 (number of days in 44 weeks) to calculate the mean total number of eggs per hen. Total number of eggs per hen recorded in six European ComL (DR, DS, LB, LD, NB and NC), and one local ComL of KK were lower than the standards reported by the breeding companies (Lohmann, Dominant CZ and Novogen), Wondmeneh *et al.* (2011) and Grobbelaar *et al.* (2010). Relatively similar resulted showed in total number of egg production within those three ExpCr (DRKK, DSDR & KKDS) and the local reference KK in this study. Upgrading the local reference KK using high producing European breeds was seen as the quickest way of achieving genetic improvement, thus increasing the total number of egg in this study. LB exhibited the potential to produce more total number of eggs/hen (about 181.8 eggs/hen), followed by KKDS (about 162.3 eggs/hen), While NB, NC, DRKK, DR, KK and DSDR ranked third to eighth respectively; however, the lowest total numbers of eggs/hen over the entire trial was recorded in DS (126.7 eggs/hen) and LD (123.4 eggs/hen) as presented in Table 15, due to poor laying consistency, with the lowest egg production (~44 % lay) staring from 40 weeks to the end of the 60 weeks period (Figure 11).

The lower total number of eggs per hen in six European chickens as compared to the standards reported by the breeding companies (Lohmann, Dominant CZ and Novogen), Wondmeneh *et al.* (2011) and Grobbelaar *et al.* (2010) may they require high-level inputs in terms of nutritional and health management, to fully express their genetic potential (FAO, 2014) but for the case of lower total number in local reference KK may be the reduction of their performance throughout those ten years in DZARC so it indicates the replacements of the stock from the original paces.

The egg mass (Kg/hen) was calculated as the total number of eggs per hen per pen over the entire trials multiplied by average egg weight per hen per pen divided by 1000 as presented in table 14. Even though, the LB was intermediate in egg weight as compared with other ComL and ExpCr, the highest egg mass (Kg/hen) was recorded in LB (about 10.4) due to highest total number of eggs per hen. The value of higher egg weight contributes the higher rank for NC and NB in egg mass than the ExpCr of KKDS; whatsoever, KKDS exhibited the higher total number than NC and NB in this study. KKDS, DR and DRKK ranked fourth to sixth respectively in egg mass; however, the lowest egg mass was recorded in DS, DSDR, KK and LD over the entire trials (Table 15).

The feed conversion ratio is measured as the amount of feed required (in kilograms) to produce one kilograms of chicken eggs. To compare the female bird's ability to convert nutrients to an important aspect of overall performance is expressed in feed conversion ratio (FCR). The female FCR was calculated as the total average feed intake over the entire 308 days in Kg divided by sum of the total egg mass (kg/hen in 44 weeks) plus the female body weight gain 16 – 60 weeks as presented in table 15. Relatively, the best FCR than all ComL & ExpCr was recorded in LB and it was comparable to the standards reported by the breeding company (Novogen). The rest of nine ComL & ExpCr was much lower as compared to the standards reported by the breeding companies (Lohmann, Dominant CZ and Novogen) and Wondmeneh *et al.,* 2011).

5.3.4. Egg weight

There were significant difference ($P<0.05$) among ComL & ExpCr and age in periods in egg weight (g) during the laying stages (16 to 60 weeks of age). The highest average weight was recorded in NC (about 62.3g), followed by DR (about 58.6g), DSDR (about 58.4g) and DS (about 58.2g). NB, LB, LD and DRKK ranked fifth to eight respectively; however, the lowest average egg weight was recorded in KKDS and KK during the laying stages. Islam *et al.* (2002) reported that genotypic variation had little effect on egg weight which contradicts with this finding of breed effects. Relatively similar egg weight (60.1g), for Lohmann breeds was reported by Jana *et al.* (2014) with this finding but it was higher than the report of Dawud *et al.* (2011) for Lohmann Silver (52.9g) with similar age periods of the study. Desalew *et al.* (2015) for KK in egg weight were reported (47.8g) lower than this finding with similar age periods of the study. The obtained values of all ComH & ExpH in egg weight were lower than to those of Lamberts *et al.* (2018) for two dual purpose chicken types of pure and crosses.

5.3.5. Female mortality

In all ComL and ExpCr, the average % mortality over the entire trial of females ranged between 0.55 and 2.06%. A smaller amount of average % females mortality results were found as compared to the standards reported by the breeder's company with similar age periods of the study period. In a study with KK in South Africa (Grobbelaar *et al.*, 2010) mortality in both sexes was around 22%, which was the highest than KK females (0.55%) reported here. Comparable average % mortality of LB female was reported here as compared to Dawud *et al.* (2011) with Lohmann Silver (0.41%).

5.3.6. Males feed intake

The average feed intake of DSDR was much lower than the experimental crosses done in Europe reported by Mueller *et al*. (2018), while other ComL & ExpCr (as presented in Table 18) were comparable with Lohmann Brown plus and Schweizerhuhn but lower than the fast and slow-growing broiler types of Ross PM3, Sasso 51 and Lohmann Dual. All the ComL & ExpCr were higher than the standards reported by the breeding companies (Lohmann, Dominant CZ and Novogen), Wondmeneh et al. (2011) and Grobbelaar *et al.* (2010) in BWG-M with similar age periods of the study; however, fed for the males were differs from the breeding companies.

The FCR recorded in NC (2.36) and NB (2.91) were best than the report of Lichovníková *et al.* (2009) for the feed conversion ratio Ross 308 (3.1) and ISA Brown males (3.8), also higher than the standards reported by the breeding company of Novogen, while the other ComH & ExpCr (KK, DRKK, KKDS, DR and LB) were comparable with ISA Brown males, the standards reported by the breeding companies and Wondmeneh *et al.* (2011) except DSDR and DS (Table 18 and Figure 13) but not comparable with Ross 308 as reported by Lichovnikova *et al.* (2009).

5.3.7. Male body weight

The males' body weight (BW-M) for meat production curves from six Commercial layers (ComL) & three Experimental crosses (ExpCr) at 3 ages, from the start (4 weeks) to the end (16 weeks) of the trial are presented in Figure 12. The ComL BW-M of NC, NB, KK and DR were highest as compared with the standards reported by the breeder's companies and Wondmeneh *et al.* (2011), while, BW-C of LB and DS were comparable with the standards reported by the breeder's company (Table 18). Moderately similar resulted exhibited in BW-M of those two ExpCr (DRKK & KKDS) and the local reference KK and also with the standards reported by the breeder's company (Dominant CZ) in this study (Table 18). The BW-M of DSDR was much lower than our local reference KK and the standards reported by the breeder's company (Dominant CZ) in this study but higher than Wondmeneh *et al.* (2011).

As expected, the six ComL & three ExpCr BW-M were significantly lower than reported by (Lichovnikova *et al.,* 2009) of fast-growing broiler types of Ross 308 (6000g). The BW-M of NC, NB, KK, DRKK, KKDS and DR were higher than reported by (Lichovnikova *et al.*, 2009) of ISA Brown males and lower results recorded in LB, DS and DSDR. The BW-M of NC (2934.4g) was higher than all the experimental crosses done in Europe with better managments and feeds in comparing to commercial fast-growing and slow-growing broiler types as well as males from a commercial layer reported by Mueller *et al.* (2018), while BW-M of NB, KK, DRKK, KKDS and DR were comparable with Sasso 51 (2423g), Ross PM3 (2415) and Lohmann dual (2161g), but higher than Belgian Malines (1718g), Schweizerhuhn (1317g) and Lohmann Brown plus (1227), whereas DS and DSDR were comparable with Schweizerhuhn (1317g) and Lohmann Brown plus (1227) as reported by Muller *et al.* (2018). The obtained value of NC in BW-M was higher, while NB BW-M was comparable to those of Lamberts *et al.* (2018) for two chicken types of pure and crosses.

The body weight gain of males (BWG-M) of most ComL & ExpCr was comparable with the experimental crosses done in Europe reported by Mueller, *et al.* (2018) except DS and DSDR. All the ComL & ExpCr were higher than the standards reported by the breeding companies (Lohmann, Dominant CZ and Novogen), Wondmeneh *et al*. (2011), Grobbelaar *et al.* (2010) and Lambertz *et al.* (2018) in BWG-C with similar age periods of the study (Table 18).

5.3.8. Carcass analysis

Dressing percentage and dressed carcass weights are the most valuable criteria next to body weight in marketing broiler meat production in Ethiopia. Additionally, the cuts of each organ are important marketing criteria in urban markets of Ethiopia. The differences in dressing percentage and carcass weight were like the ones found in final BW-M. Most remarkable differences were in rear and breast muscle percentages. The carcass weight at slaughter achieved in NC (2059.8g) in the present study was greater than the report of Lichovnikova *et al.* (2009) for carcass weight of ISA Brown and report of Mueller *et al.* (2018) for carcass weight of Sasso 51, Ross PM3 and Lohmann dual but much lower than the fast-growing broiler types of Ross 308 reported by Lichovnikova *et al.* (2009). The carcass weight recorded in NB was comparable with Ross PM3 and Sasso 51, while KK, DRKK and KKDS were comparable with Lohmann dual with the report of Mueller *et al.* (2018) and ISA Brown with report of Lichovnikova *et al.* (2009). The highest % dressed recorded in NC (70.2%) and NB (69.5%) were comparable with the fast-growing broiler types of Ross PM3 & Sasso 51 reported by Mueller *et al.* (2018) and with Ross 308 reported by Lichovníková *et al.* (2009).

The % dressed achieved in KKDS, KK, DRKK, DS, LB and DR in the present study were higher than ISA Brown (63%) reported by Lichovnikova *et al.* (2009) and higher than Lohmann dual (67%) and Lohmann Brown plus (62.9%) reported by Mueller *et al.* (2018). The smallest % dressed found in DSDR (64%) was comparable with the Schweizerhuhn, Lohmann Brown, and Belgian Malines reported by Mueller *et al.* (2018) and with ISA Brown reported by Lichovnikova *et al.* (2009). The obtained value of NC in % dressed was higher, while others of ComL & ExpCr were comparable to those of Lamberts *et al.* (2018) for two dual purpose chicken types of pure and crosses. This DSDR was much lower than our local reference KK (68.1%) but the two ExpCr of (KKDS & DRKK) was comparable with our local reference KK in this study.

Breast meat as main parts of cuts in any meat production for market, the results recorded in % breast in this study in all ComL and ExpCr were found greater than ISA Brown

(15.2%) but lower than the commercial broiler types of Ross 308 (27.2%) as reported by Lichovníková *et al.* (2009). The abdominal fat percentage recorded in this study of ComL & ExpCr was lower than the broiler types of Ross 308 (2.7%) reported by Lichovnikova *et al.* (2009) and Lamberts *et al.* (2018). This less fat content of male meat indorses the theories of Ethiopian local people that, meat from males and village chickens are tastier than meat from commercial broilers.

Considering these results observed found in males as potential meat birds' productions and the lack of nonexistence of Breeder Company that supply for commercial chicken production in broilers and layers in Ethiopia, suggest the use of us to apply the idea of these males for meat production. To alleviate animal protein shortage and reduce poverty by increasing the income of poultry farmers, additionally this trial justify could be the real solutions to avoid the practice against of the culling of males of commercial laying chicken. day-old layer types of males and also good news for the Ethiopian local people especially at holidays and events to enjoy the traditional 'Doro wet' (chicken stew) with these males, again it could be economical in both side, for the user (with cheap price) and for the business man (selling live or dressed).

5.3.9. Male mortality

In these males' trials for meat productions, zero mortality was found in ExpCr of DSDR and KK throughout the study period, additionally no health problems were recorded in this study. Significantly very low average % mortality (0.16% in DRKK, 0.21% in LB, NB and NC) were found as compared to NB (7.4%), NC (4.2%) to the standards reported by the breeder's company. Also very low average % mortality in DR 0.64%, in DS 0.53%, in KKDS and 0.32% as compared to the standards reported by the breeder's company and to KK (22.2 %) of mortality reported by the Grobbelaar *et al.* (2010) with similar age periods of the study.

In these males trial for meat productions, very low average % mortality was recorded in all ComL & ExpCr than the mortality till 90 days of age 9.1% in ISA Brown males and 8% in Ross 308 report of Lichovnikova *et al.* (2009). This trial would suggest to produce meat from males in Ethiopia might be economically feasible. In general, the mortality was mostly due to accident and also when the superior in body size or the aggressive one was try to mate the smaller in body size and then these smaller in body size males was restrained itself in one corner side of the pen without feed & water and tend to die finally unless they are fed by the persons.

5.4. Females' Eggs and Males' Meat Productions (On-Farm Trials)

5.4.1. Female feed intake

The average feed intake during the study periods (0 to 48 wks) was on average ~ 88.5g/bird per day in all ComL. Those finding were much lower than the standards reported by the breeding companies (Lohmann, Dominant CZ and Novogen) and Wondmeneh *et al.* (2011). The difference in results reported here and those reported by the breeders and other studies could be attributed to differences in management and environmental conditions. Environmental factor like temperature was found to contribute about 97.2% showing that it has the greatest effect on feed intake. Hence, a decrease in rate of feed intake in any poultry farms as reported by Obayelu *et al.* (2006). The overall feed intake was significantly higher in four ComL of KK, NC, LB and DR over the entire trial (16-48 weeks) ranging 93.5-120 g/hen/day, accumulating to mean total average feed intakes (AFI) around 23kg/hen over the trial's 210 days. Significantly the lowest overall total average feed intakes (AFI) was exhibited by DS (about 21.8kg/hen), while ComL of NB was intermediate in total average feed intakes (AFI) (about 22.7kg/hen) (Table 21).

5.4.2. Female body weight

At the end of the trails (48 weeks of age), the ComL body weight of female (BW-F) of NC and KK were significantly higher as compared with the standards reported by the breeder's company and Wondmeneh *et al.* (2011), with similar age periods of this study whereas, the rest of ComL (DR, DS, LB and NB) were lower than the standards reported by the breeder's company may relate to the lowest feed intakes and much lower body weight gains during on these on-farm trails. The lower in body weight among few females of ComL was due to the environmental factors as reported by Doni *et al.* (2015) that, temperature more than 28°C, weight gains are lowered. If condition remains for prolonged period, there may be loss in body weight. One of the remarkable BW-F was observed after 32 weeks of age in NC where continues to increase at higher rate than others due to the genetic background during their broiler male parents stocks combinations study, followed by KK until the end of the trials (Figure 16).

5.4.3. Egg productions

The egg production of the five ComL (DR, DS, LB, NB and NC) produces less egg than the standards given the respective breeding companies (Dominant, Lohmann and Novogen). All the five ComL were similar with the onset of lay but lower in egg production than in the studies of breeding companies but KK was earlier in these on-farm trials with the onset of lay and similar than the reports of Wondmeneh *et al.* (2011) and Grobbelaar *et al.* (2010) with in this 30 weeks of ages. The differences between age of sexual maturity and the levels of egg production reported here by the breeders and other studies could be attributed to differences in management and environmental conditions.

The levels of peak laying rate (% lay at peak of lay, total number of eggs production) of the five European ComL (DR, DS, LB, NB and NC) were not similar to those indicated by the breeding companies (Lohmann, Dominant CZ and Novogen), Wondmeneh *et al.* (2011) and Grobbelaar *et al.* (2010). These results suggest the relatively low levels of total number of egg production were mainly due to slow elevation and early dropping in laying rate before they reach to their genetic potential as presented in Figure 17, especially in DS; the lowest total numbers of eggs/hen over the entire trial was recorded (about 98.2 eggs/hen) as presented in Table 21, due to poor laying consistency, with the lowest egg production (about 41.9 % lay). Higher % at peak of lay was recorded in KK than the reports of Wondmeneh *et al.* (2011). The lower total number of eggs per hen in five European chickens as compared to the standards reported by the breeding companies may they require high-level inputs in terms of nutritional and health management, to fully express their genetic potential (FAO, 2014).

5.4.4. Egg weight

The highest average egg weight was recorded in NC (about 59.2g), followed by DS (about 58.3g), while DR, NB and LB were intermediate; however, the lowest average egg weight was recorded in KK (about 50.9g) during the laying stages. Relatively similar egg weight (60.1g), for Lohmann breeds was reported by Jana *et al.* (2014) with this finding but it was higher than the report of Dawud *et al.* (2011) for Lohmann Silver (52.9g) with similar age periods of the study. Desalew *et al.* (2015) for KK in egg weight were reported (47.8g) lower than this finding with similar age periods of the study.

In these (females' egg) production performance the relation to total numbers of egg/hen and the mean egg weight, the highest egg mass (Kg/hen) was recorded in NB (about 7.51kg/hen), while DS (5.73kg/hen) and KK (5.79kg/hen) was the lowest whereas NC, LB and DR were intermediate with an average of 6.4kg/hen during the laying stages (Table 21). The main parameters related to ComL performance are egg production on the income side, feed intake on the costs side and their combination (FCR) were considered to compare the female' as egg productions, so that, the NB was the best in higher egg production, in lowest feed intake, higher egg mass and better in FCR, followed by LB and NC, while DS was the least in egg production performance during these on-farm trial.

The feed conversion ratio is a measure of the amount of feed required (in kilograms) to produce one kilograms of chicken eggs. To compare the female bird's ability to convert nutrients to an important aspect of overall performance is expressed in feed conversion ratio (FCR). Relatively better FCR was recorded in NB (about 3.18), followed by NC (about 3.54) and in contrast to bad FCR was recorded in KK (about 4.08), while DR, LB and DS were intermediates over the entire trials (Table 21). All the five European and one local ComL much lower as compared to the standards reported by the breeding companies (Lohmann, Dominant CZ and Novogen) and Wondmeneh *et al.* (2011) due to lowest feed intakes and egg productions in general in these on-farm trails.

5.4.5. Females mortality

The performance of egg production (females) on-farm females' mortality trials, lowest average % mortality results were found in all ComL of females as compared to the standards reported by the breeder's company. In a study with KK (22.2 %) in South Africa (Grobbelaar *et al.* 2010) mortality was higher than our findings. In most of the farmers' houses occurred Gumboro out- break at growing stages even though the chickens were vaccinated though out the trials and then the farmers predominantly reason out to these mortalities to drop out from these trails and also their second intention was the economic problems to purchase feeds for their chickens. No one was interested to keep the chickens up to 52 or 60 weeks of chickens' age then this on-farm trial was done with 50% in egg production (females) and 23.8% in meat production (males) of the participant farmers due to dropped out circumstances.

5.4.6. Males feed intake

The average feed intake of all the ComL were comparable with the standards reported by the breeding companies (Lohmann, Dominant CZ and Novogen), Wondmeneh *et al.* (2011) and Grobbelaar *et al.* (2010) but much lower than the experimental hybrids done in Europe, whereas they were higher than the Lohmann Brown plus and Schweizerhuhn but lower than the fast and slow-growing broiler types of Ross PM3, Sasso 51 and Lohmann Dual reported by Mueller *et al*. 2018); however, feed for the males were differs from the breeding companies.

Considering these results found in males as meat productions and the nonexistence of breeder company for commercial broilers and layers in Ethiopia suggest us to apply the idea of males meat production to alleviate animal protein shortage and reduce poverty by increasing the income of poultry farmers, additionally this trial could be the real solutions to avoid the practice of culling day-old layer types of males and also good news for the Ethiopian local people especially at holidays and events to enjoy the traditional '*Doro wet'* (chicken stew) with these males, again it could be economical in both side, for the user (with cheap price) and for the business man (selling live or dressed).

5.4.7. Male body weight

In these on-farm meat production (males) trials, significantly higher males body weight (BW-M was recorded in these three ComL of DR, KK and NB with the range of 1600g, followed by NC (about 1525g); while LB and DS was intermediate about 1400g (Table 24). Like BW-M, significantly higher BWG-M was recorded in these three ComL of NB, KK and DR with the range of 525.2g, followed by NC (about 497.6g); while LB and DS was intermediate about 458.5g (Table 23). The ComL BW-M and BWG-M of DR, KK and NB were highest as compared with the standards reported by the breeder's companies and Wondmeneh *et al.* (2011), while, BW-C of NC, LB and DS were comparable with the standards reported by the breeder's companies (Lohmann, Dominant CZ and

Novogen), Wondmeneh *et al.* (2011) and Grobbelaar *et al.* (2010). As expected, the six ComL BW-M were significantly lower than reported by (Lichovnikova *et al.*, 2009) of fast-growing broiler types of Ross 308 (6000g). The BW-M of DR, NC, KK and NB were higher than reported by (Lichovnikova *et al.,* 2009) of ISA Brown males and lower results recorded in NC, LB and DS when compared with the 30 weeks of age only.

The BW-M of all the six ComL were lower than all the experimental layers done in Europe with better managments and feeds in comparing to commercial fast-growing and slow-growing broiler types as well as males from a commercial layer reported by Mueller *et al*. (2018), also not comparable with Sasso 51 (2423g), Ross PM3 (2415) and Lohmann dual (2161g), but the three ComH of DR, KK and NB were comparable with Belgian Malines (1718g), whereas they were higher than the Schweizerhuhn (1317g) and Lohmann Brown plus (1227), as reported by Muller *et al*. (2018).

5.4.8. Male mortality

In these meat production (males) on-farm males' mortality trials, significantly very low average % mortality (from the least NB (0.40%) to the higher in DR (4.25%) in all ComL were found as compared (from the least NC (4.2%) to highest KK (22.2%) to the standards reported by the breeder's company and Grobbelaar *et al.* (2010) with similar age periods of the study. In these males trial for meat productions, very low average % mortality was recorded in all ComL than the mortality till 90 days of age (9.1% in ISA Brown) males and (8% in Ross 308) report of Lichovnikova *et al.* (2009). This trial would suggest for the production of meat from males in Ethiopia is economical and truthful.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

The PS performance, as reflected in cost per chick, is also an important factor affecting the crossbreed economic value. The main parameters related to PS performance are chick number per hen on the income side, and feed intake on the cost side. Chick number per hen combines egg production, fertility, and hatchability, whereas feed intake relates to BW and to egg mass per hen.

From the on-station testing of these parents in DZARC, it is possible to conclude that, LD hens exhibited the highest overall laying rate (64.2%), much better than LB (56.3%). Indeed, mean BW of the LD hens was slightly higher (by 50 g) that of LB, NB and NC hens, but apparently the genetic tendency for slightly higher BW, typically combined with better appetite, was advantageous under the conditions of the present trial and are suitable for intensive production conditions. In order to combine the relative performance of each PS in six parameters, their values are visualized by histograms.

With AI, LD also exhibited high fertility and hatchability (66.6% hatch/eggs set), and the highest egg production, LD exhibited the potential to produce more chicks than any other PS. Along with intermediate mortality, LD appears to be the favorable PS in this study. Without the option of AI, LD had poor fertility and low number of chicks, but that possibly might be solved by mating the maternal hens of LD with males from a medium-size paternal line, such as DR or DS or KK. After LD, DR stands up as the second chick-producing PS, with reasonable egg production, good fertility and hatchability, but with high feed intake. The latter is related to the high BW of DR hens, which is an advantage because of the high demand for spent hens in developing countries as Ethiopia. LB, KK and NC were ranked third to fifth; however, NB & DS were ranked last during the study periods.

From the HU study we can conclude that Parent Stock (PS) layers LB, KK and DR performed best in most of the productive traits, followed by DS and LD at all ages of the laying phases. In order to combine the relative performance of each PS in which six parameters, their values are visualized by histograms. The performances of all the Parent Stock layers at Hawassa University are more or less comparable with the performance standards indicated by the breeding companies. Thus the Parent Stocks of LB, KK, DR, DS, and LD can be recommended, in their respective order, to the beneficiaries in Ethiopia under similar conditions.

The main parameters related to Commercial Layers (**ComL**) & Experimental Crosses (**ExpCr**) performance are the total number egg production throughout the life of the hen, body weight (since selling of live birds are common in Ethiopia) on the income side, feed intake on the costs side and their combination (FCR). Egg mass are also important in this final ranking of females' egg productions. In order to combine the relative performance of each ComL & ExpCr (females' eggs) in these five parameters, their values are visualized by histograms. LB exhibited the potential to produce more total number of (about 181.8), followed by KKDS (about 162.3), While others were intermediates; however, the lowest total numbers of eggs/hen over the entire trial was recorded in DS (126.7) and LD (123.4), due to poor laying consistency, with the lower egg production (~ 44 % lay) staring from 40 weeks to the end of the 60 age in weeks.

By the end of the trial, at 60 weeks of age, BW of NC was highest (~3011.3g), due to the genetic background during their male parents stocks combinations study but this ideas did not works in the case of LD and the result was the lowest body weight even than other ComL & ExpCr, While others were intermediates.

The overall feed intake was significantly highest in NC, with mean ADFI over the entire trial (16-60 weeks) ranging 99.5-120 g/h/d, accumulating to mean TFI around 35.3 kg/hen over the trial's 308 days. LD and DSDR was exhibited the lowest ranging 68.9-104.2 g/h/d, accumulating to 25.7 and 26.5 kg/hen, while others were intermediates. Due to the moderately feed intake and body weight, highest total egg number and egg mass ~ lead to conclude, LB and KKDS performed well and LD and DS were not, while others were intermediate. The causes may attributed to the poor adaptability of the chickens under our conditions, while for the case of KK may be the reduction of their performance throughout those ten years' service in DZARC so it indicates the need for replacements of the stock from the original paces.

In Ethiopia, live body weight is preferred especially at holydays and especial events in local market; thus dressing percentage and dressed carcass weights are the next valuable criterion in marketing chickens. Additionally, the cuts of each organ are important marketing criteria now a time, mainly in urban markets of Ethiopia. The differences in dressing percentage and carcass weight were similar to the ones found in final BW-M in this on-farm trial. Significantly the highest BW-M and % dressed was recorded in NC and making NC the best male meat producer or meatiness, followed by NB, while others were intermediate on BW-M and % dressed carcass and the lowest BW-M and % dressed was recorded in DSDR. More or less similar results was exhibited in the percentages of (rear, thighs, drums, breast) like the results showed in % dressed in these males as meat production trials as their values are visualized by histograms.

In case of females' eggs and males' meat on-farm trials, the main parameters related to Commercial layers (**ComL**) performance were egg production on the income side, feed intake on the costs side and their combination (FCR) were considered to compare the female' as egg productions, so that, the NB was the best in higher egg production, in lowest feed intake, higher egg mass and better in FCR, followed by LB and NC, while DS was the least in egg production performance during these 30 weeks of age under on-farm trials. The causes may attribute to the poor adaptability of the chickens under on-farm conditions. These results suggest the relatively low levels of total number of egg production were mainly due to slow elevation and early dropping in laying rate before they reach to their genetic potential as presented.

At the end of the trails (48 weeks of age), BW-F of NC was significantly the higher (about 2203.3g) than others ComL due to the genetic background during their male parents stocks combinations study and the lowest BW-F was recorded in DS (about 1926.7g). The KK female ranked second heavier BW-F (about 2100g at 48 weeks of ages), while the others (NB, DR and LB) were intermediate in these egg production (females) trials. The average feed intake during the study age in weeks (0 to 48 wks) was on average ~ 88.5g/bird per day in all ComH.

In this on-farm trials, significantly higher BW-M and ABW-G were recorded in these three ComL of DR, KK and NB with the range of 1600g, followed by NC (about 1525g); while LB and DS was intermediate about 1400g and making all the six ComL the better male meat producer due to similar results was exhibited in these on-farm trials.

The six Parent Stocks (PS) bred by European companies, one local PS in DZARC & HU, ten final hybrids of females and nine males Commercial Layers (ComL) and Experimental Crosses (ExpCr) on-station & on-farm trials, were evaluated for their chick production, reproductive performance and their progeny (females' eggs, males' meat) under typical conditions in Ethiopia. The LD PS exhibited the highest overall laying rate (64.2%), and with AI, LD PS hatchability of set eggs (66.6%) was the highest, making it the best chick producer. Thus, despite its high total feed intake (but similar to those PS of DR, DS and KK), LD was the best PS in this study (followed by DR) under floor pen management in Ethiopia. In case of their progeny (females' eggs, males' meat), LB and KKDS performed well in egg productions, while NC was the best male meat producer or meatiness, followed by NB, while others were intermediate on BW-M and % dressed carcass.

6.2. Recommendation

- The parent stocks of LD, DR, LB, KK, NC, NB and DS in DZARC trials with due consideration of AI and the parent Stocks of LB, KK, DR, DS, and LD in HU trials can be recommended, in their respective order, to the beneficiaries in Ethiopia under similar conditions.
- The Commercial Layers (**ComL**) & Experimental Crosses (**ExpCr**) in females' eggs production of LB, KKDS, NB, NC, DRKK, DR, KK DSDR, DS and LD and also in males' meat production of NC, NB, KKDS, KK, DRKK, DS, LB, DR and DSDR in DZARC on-station trials can be recommended, in their respective order, to the beneficiaries in Ethiopia under similar conditions.
- The Commercial Layers **(ComL**) females' eggs of NB, LB, NC, KK, DR and DS and finally in males' meat production of NB, KK, DR, NC, LB, and DS can be recommended, in their respective order, to the beneficiaries in Ethiopia under similar conditions.
- Testing the breeds on-station and on-farm should be done side to side then the better lines should be multiplied and distributed immediately to the farmers and other users.
- Gumboro disease outbreaks occurred due to vaccine failure. Therefore, research should also focus on vaccine and need to be educated to vaccinate their chicken before the disease outbreak occurred.
- Further research is still needed on economic analysis for all parent stock and their progenies under different management conditions to finally select relatively best performing breeds.
- The on-farm management conditions faced problem in various aspects. Testing chicken strains in villages is always challenging. The performance might not reflect the real situation and the fore another method should be devised.
- This study will serve as baseline information for medium scale company; breeders who are planning to import and use the parent stock for enhancing production and productivity of the chickens in Ethiopia.

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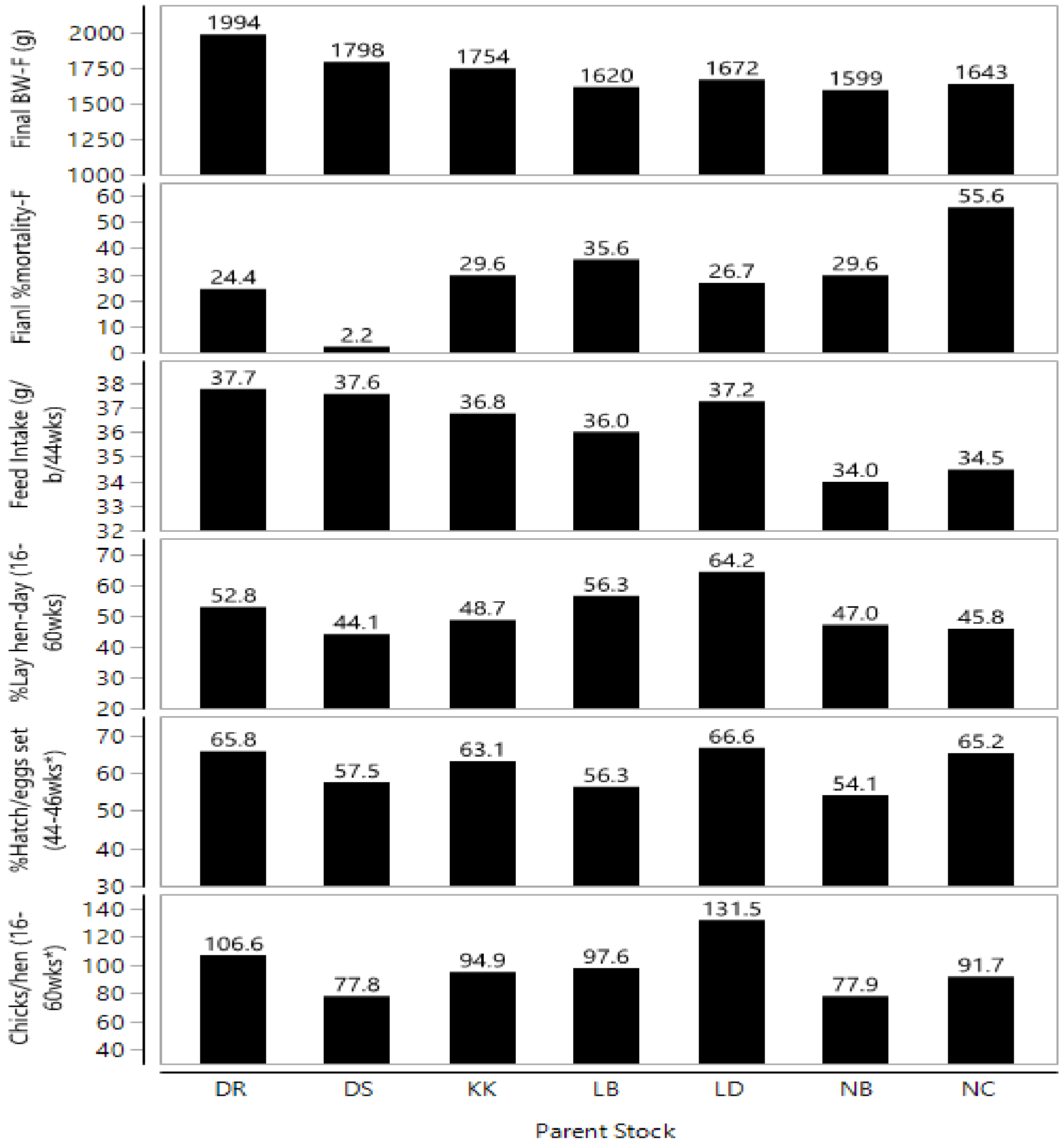
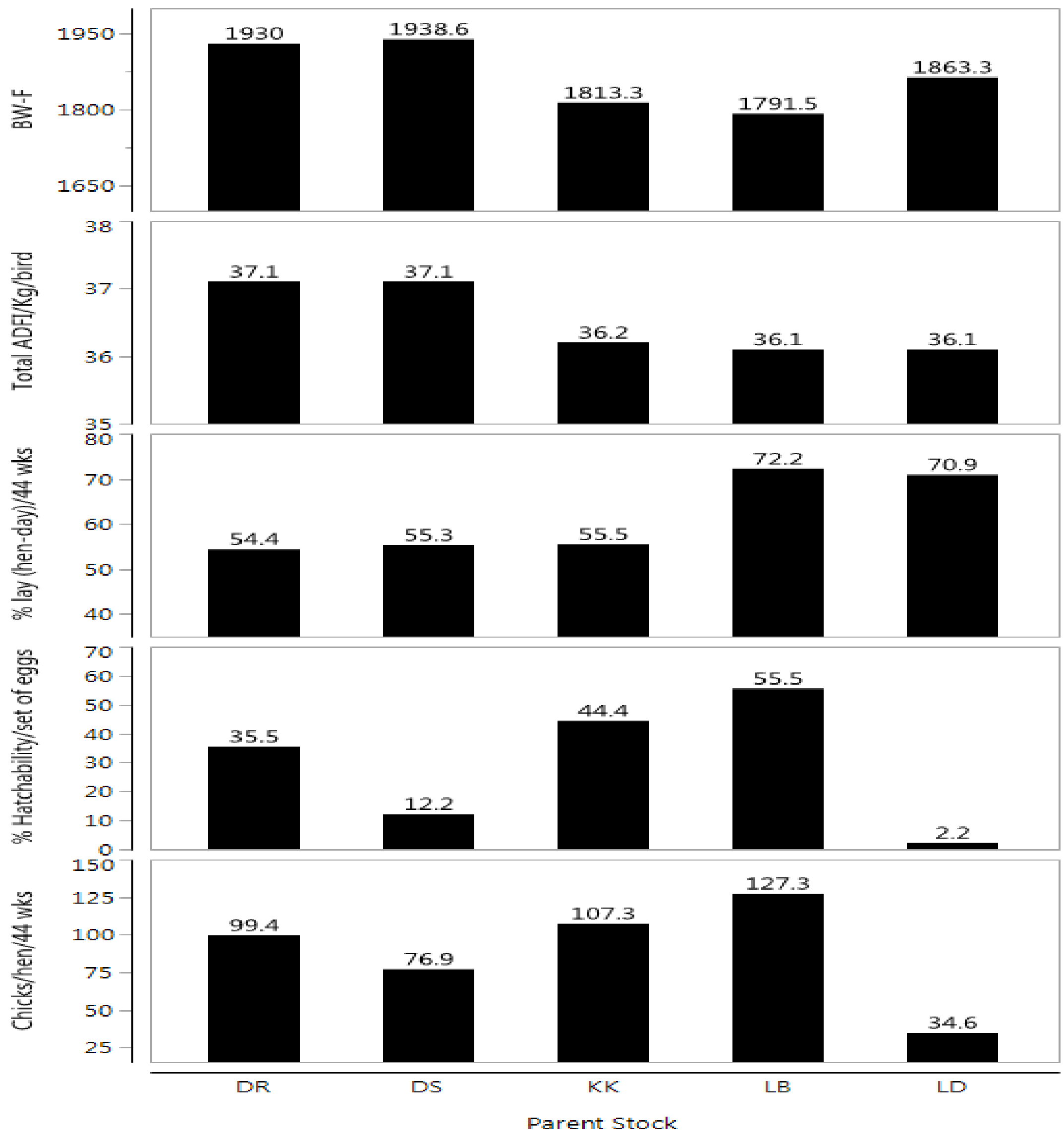
8. APPENDICES

8.1. Supplementary data



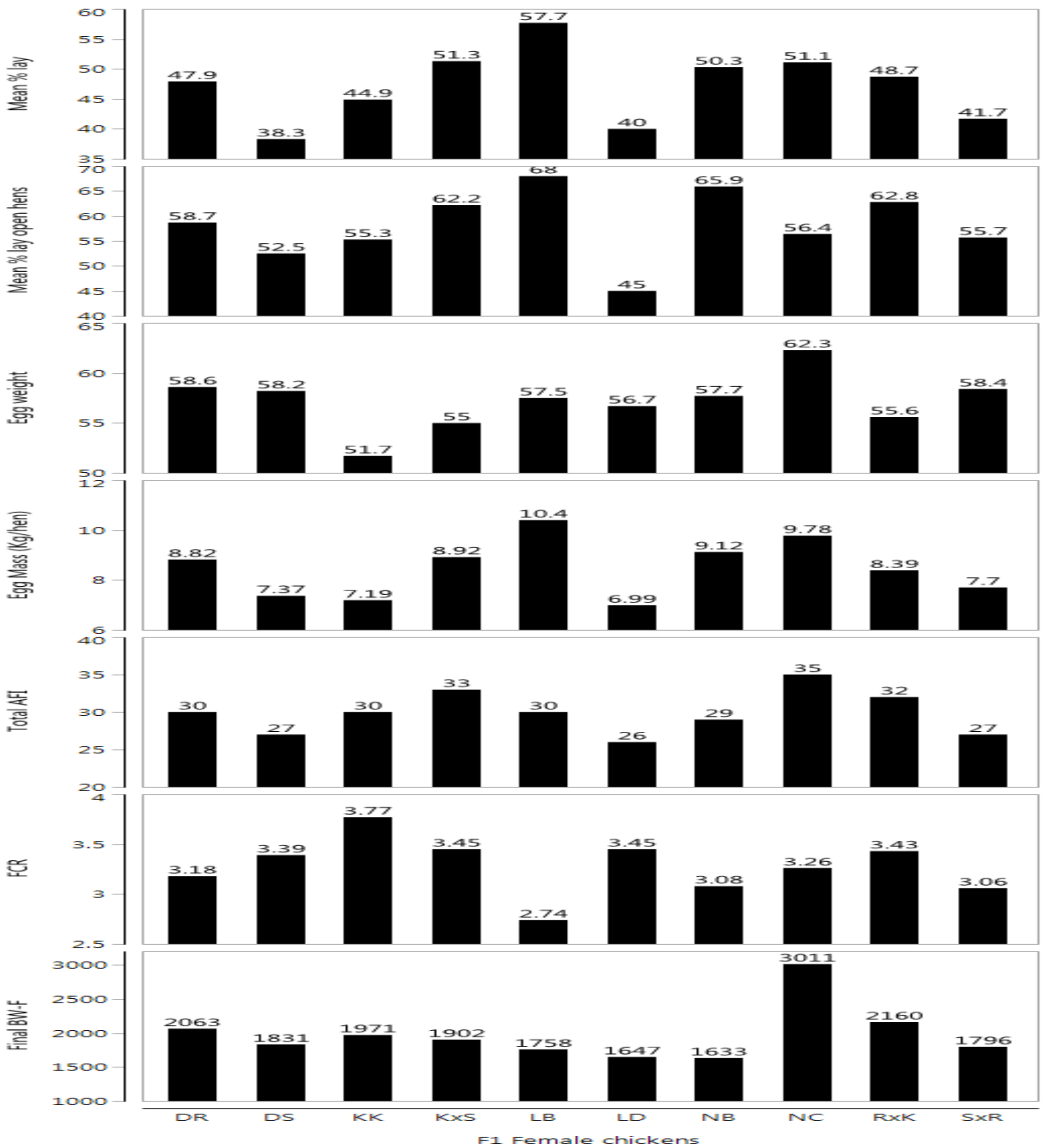
Appendix 1. Comparative presentation of DZARC Parent Stocks means of traits that are most important in commercial flocks: mortality, BW, feed consumption, %Lay, %Hatchability and total chick production.

DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual; NB = Novogen Brown; NC = Novogen Color.



Appendix 2. Comparative presentation of HU Parent Stocks means of traits that are most important in commercial flocks: BW, Total feed intake, %Lay, %Hatchability and total chick production.

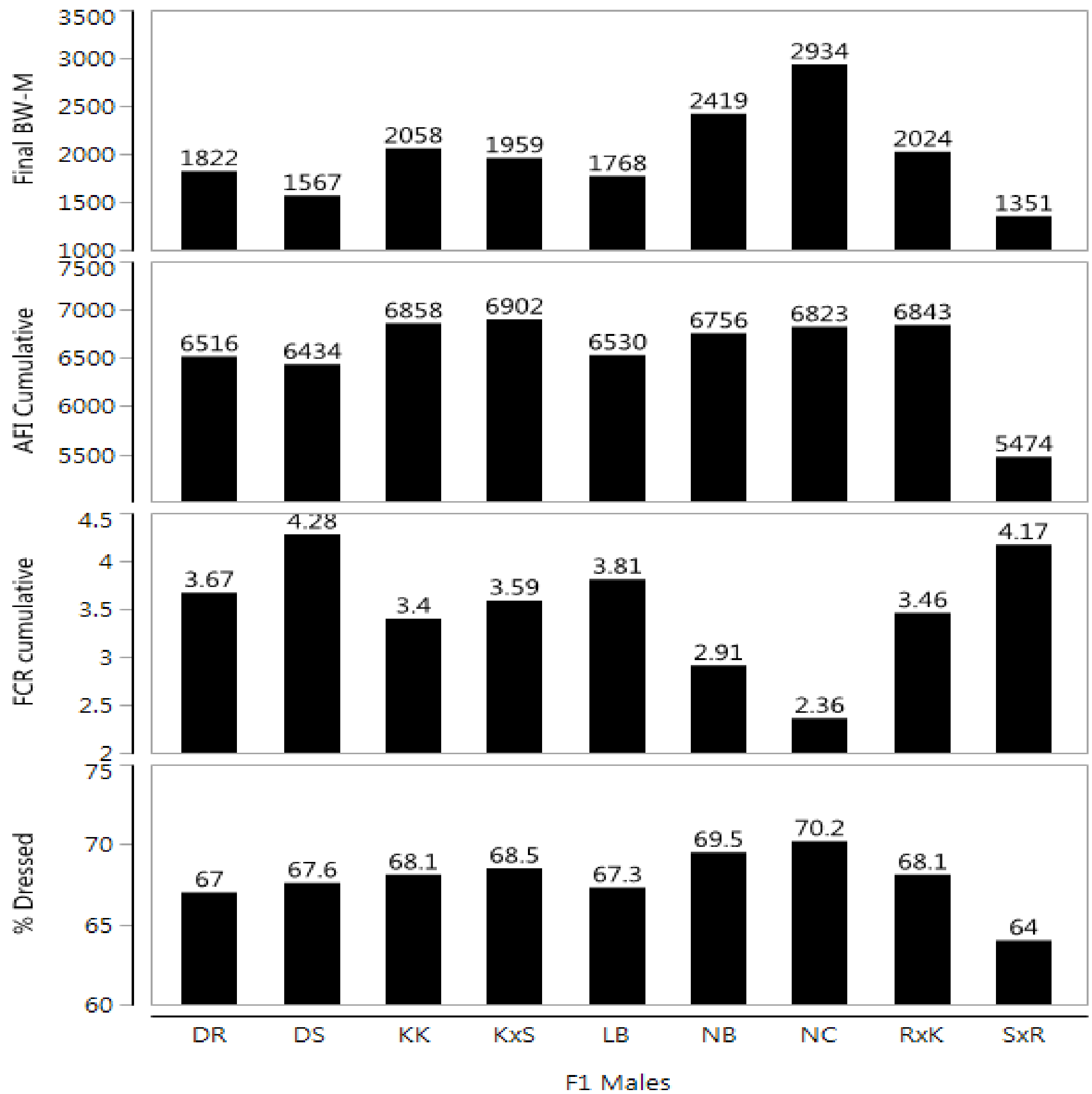
DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; LD = Lohmann Dual.



Appendix 3. Comparative presentation of the seven Commercial hybrids (ComH)[1] and three Experimental hybrids (ExpH)[2] females means of on-station traits that are most important in commercial flocks: % lay, % lay open hens, egg weight, egg mass, Total AFI, FCR and BW-F.

1 DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color; LD = Lohmann Dual.

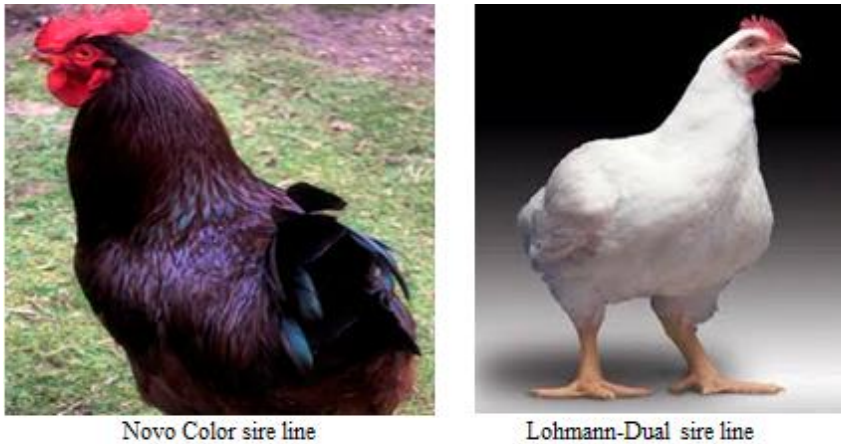
2 R×K = Dominant Red Barred hens × Koekoek males; S×R = Dominant Sussex hens × Dominant Red Barred males; K×S = Koekoek hens × Dominant Sussex males.



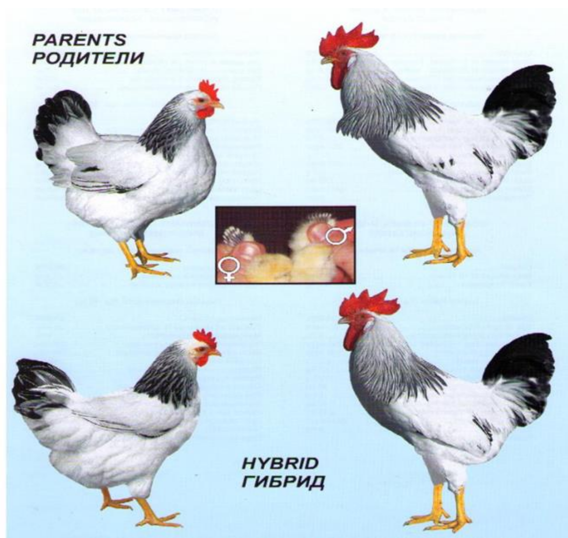
Appendix 4. Comparative presentation of the six Commercial hybrids (ComH)[1] and three Experimental hybrids (ExpH)[2] males means of on-station traits that are most important in breeder flocks: BW-M, AFI Cumulative, FCR cumulative and % Dressed.

1 DR = Dominant Red Barred; DS = Dominant Sussex; KK = Koekoek; LB = Lohmann Brown Classic; NB = Novogen Brown; NC = Novogen Color; LD = Lohmann Dual.

2 R×K = Dominant Red Barred hens × Koekoek males; S×R = Dominant Sussex hens × Dominant Red Barred males; K×S = Koekoek hens × Dominant Sussex males.

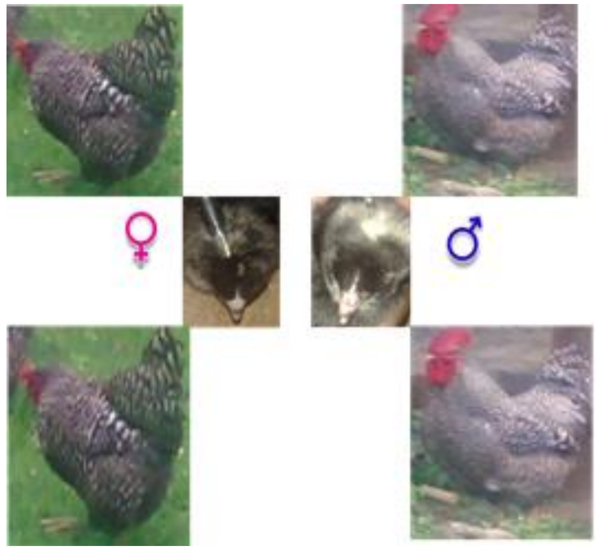


Appendix 5. The NC male was obtained from a medium-size meat-type paternal line and the LD was from a dwarf meat-types male paternal line.

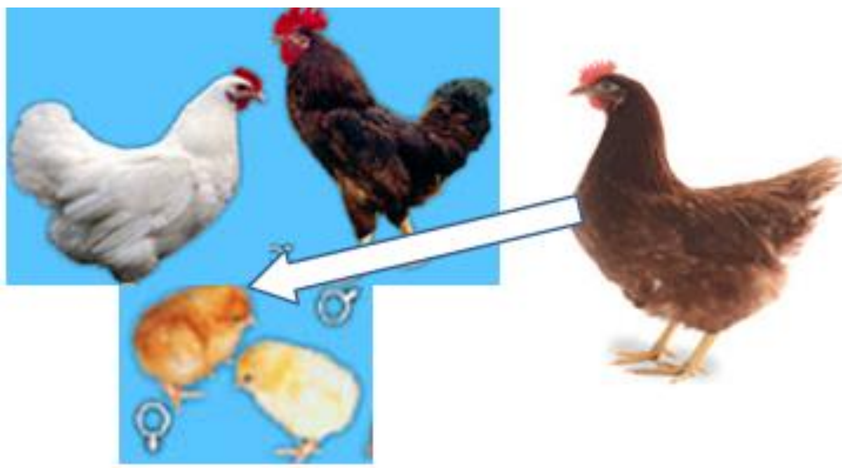


Appendix 6. Feather sexing method for Dominant Sussex D104.

Appendix 7. Spot and color sexing methods for Dominant Red Barred D922.



Appendix 8. Spot and color sexing methods for Koekoek.



Appendix 9. The brown ("gold") progeny are females, the white ("silver") progeny are males for LB, NB and NC except LD.

Appendix 10. On-Station experimental house at Debre Zeit Agricultural Research Centers (DZARC).

Appendix 11. The Experimental hybrids of Dominant Sussex D104 female × Dominant red Barred D922 male (DS×DR), Potchefstroom Koekoek female × Dominant Sussex D104 male (KK×DS) and Dominant red Barred D922 female × Potchefstroom Koekoek male (DR×KK) at Debre Zeit Agricultural Research Centers (DZARC).

Appendix 12. Few samples' of the On-farm experimental house Commercial Hybrids at Debre Zeit town around Babogaya village

Appendix 13. On-Station feed restriction methods at Debre Zeit Agricultural Research Centers (DZARC) for the Novo Color and Lohmann Dual male Parent Stocks.

Appendix 14. On-Station experimental house and Parent Stocks at Hawassa University (HU).

Barred Plymouth Rock, White Leghorn Black Australorp

Appendix 15. Potchefstroom Koekoek was developed by cross breeding of Black Australorp, White Leghorn, and Barred Plymouth Rock.

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Dawud Ibrahim, Gebeyehu Goshu, Wondmeneh Esatu, Gashahun Bino and Tesfaye Abebe (2018). Comparative Study of Production and Reproductive Performance of Various Strains of Chicken Parent Layers Raised in Floor Pens. Eth. J. Agric. Sci. 28 (3) 79-93 (2018). ISSN: 2415-2382. https://www.ajol.info/index.php/ejas

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Dawud Ibrahim, Gebeyehu Goshu, Wondmeneh Esatu and Avigdor Cahaner (2019). Dual-purpose production of genetically different chicken crossbreeds in Ethiopia. 2. Egg and meat production of the 'final-crossbreed' females and males. Poultry Science 0:1–13

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