Evaluation of Reciprocal Crossing Koekoek and White Leghorn Chicken Breeds on Growth Performance, Feed Intake, Feed Conversion Efficiency, Linear Body Measurements, Age at Sexual Maturity and Mortality

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Abstract: Koekoek and White Leghorn (WLH) pure chicken breeds were crossed in 2×2 diallel mating at Haramaya University (HU) poultry farm with the objective of evaluating growth performances, feed intake, feed conversion efficiency, and age at first egg. The four genetic groups (Koekoek, WLH, Koekoek male× WLH female and WLH male × Koekoek female crosses) were obtained from 160 hens (80 from each breed) and 12 cocks (6 form each breed) using artificial insemination mating system. From a total of 172 chickens (12 cocks and 160 hens), 3 cocks and 40 hens were used from each genotype for sire and dam line, respectively. Performance of the genetic groups were monitored using 733 mixed sex chicks (from hatching to 4 weeks) and 288 four week old chicks (144 male and 144 female). Birds in each genetic group were divided into three replications and housed separately in a deep litter pen. The design of the experiment was completely random design (CRD) and data were analyzed using the General Linear Model (GLM) of SAS software. The result showed that there were significant ($p<0.05$) differences in growth performance, body conformation measurements and feed conversion efficiency among genetic groups. The main cross and pure Koekoek exhibited significantly higher growth performance, low (efficient) feed conversion ratio and body conformation measurements (shank length and breast girth) than reciprocal and WLH genotypes. For age at first egg and mortality traits significantly better or higher performance were exhibited by main cross than all genotypes. From this study it is plausible to conclude that, the result shall encourage poultry breeders and farmers to cross these two pure breeds to exploit heterosis for production and reproduction traits in traditional poultry production system. Thus, the cross between White Leghorn pullet and Koekoek cockerels is recommended for poultry breeders to take advantage of heterosis for growth performance, feed efficiency, age at first egg (AFE) and mortality.

Keywords: *Cross breed, Dual purpose chicken, Egg type line, Reciprocal cross, Survivability*

Introduction

The local poultry flocks in Ethiopia are considered to be very poor in egg production performance, which is attributed to the low genetic potential (slow growth, late sexual maturity, and broodiness for an extended period). In order to improve the productivity of various local chicken breeds, commercial chickens have been imported and disseminated to rural and urban-based small-scale poultry producers (FAO, 2018). These efforts, however, were not successful (Wondmeneh, 2015). The strategy failed to become a sustainable option mainly because imported birds were not adopted by the rural farmers due to several socio-economic and environmental challenges (Reta *et al.*, 2012).

Moreover, the imported high-producing breeds were established for an intensive management system and less adapted to extensive system. Therefore, a critical step was required to increase the availability of adaptable and affordable chicken breeds that fulfill the protein demand and income of rural and peri-urban smallholder producers.

Genetic improvement can be accomplished either by selection or crossbreeding (Adebambo *et al.*, 2010). Crossbreeding maximizes the expression of heterotic, or hybrid vigor in the cross and is normally reflected in improved fitness and production characteristics (Hoffmann, 2015). A good combining ability resulting from a choice of the best-performing crossbred could lead to the production of birds that would be better in growth rate, efficiency of feed conversion, reproductive traits and carcass performance. The improved performance should be achieved without losing adaptation to the local environment, thereby resulting in reduced costs of production (Khawaja *et al.*, 2016). However, comparative evaluation studies on the performance of straight and reciprocal crossing of different breeds to suit small scale and intensive production system is scanty in Ethiopia. For this study White Leghorn was preferred due to earliest age at first egg (AFE), average hen-day egg production of (HDEP, 82%) and this adaptive breed was selected from flock maintained at the Haramaya University for a long time and closed for succeeding generations (Senbeta and Balcha, 2020). But, the white plumage color of the breed makes liable to predators and as a result not

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preferred by traditional production system. On the other hand, the Koekoek is a large dual purpose tropically adapted breed and their color is less liable to predators. This breed has high feed requirement as compared to White Leghorn and this may not suit with the smallholder traditional production system. Therefore, this study was designed to evaluate the performance and potential of straight and reciprocal cross breeds in comparison to the parents (pure Koekoek and pure White Leghorn breeds) for growth, feed efficiency traits, and linear body measurement.

Materials and Methods

Description of the Study Area

The study was conducted at Haramaya University poultry farm located at 42°3'E longitude, 4°26'N latitude, and at an altitude of 1980 meter above sea level. The average annual rainfall of the area is 780 mm and the average minimum and maximum temperatures are 8.25 °C and 23.4 °C, respectively (Ewonetu, 2017).

Chicken Breeds and Mating Plan

Two pure chicken breeds (White Leghorn and Koekoek) were crossed in 2 X 2 diallel mating to develop the four genetic groups used in this study. The two breeds are currently reared by the University for Teaching and research purpose. A total of 160 hens and 12 cocks (80 hens and 6 cocks from each breed) were maintained for 60 days for the production of hatching eggs. Mating was undertaken by artificial insemination (AI) using appropriate procedure and techniques. Mating was done using the two exotic breeds (Koekoek and White Leghorn) as a maternal and paternal-line and a total of 4 genotypes (treatments) were produced during the study time. Then eggs were collected from the inseminated females and weighed according to sire and dam lines. A total of 982 eggs were collected, respectively. Incubation was done following the standard procedure. The eggs were separately hatched based on their genetic group. The mating plan were arranged into the mating groups as described below in Table 1.

Table 1. Mating plan for the production experimental birds.

Females	Males[1]	
	WH	KK
WH	WH ×WH	KK ×WH
KK	WH ×KK	KK ×KK

[1]The first letter is given to male parents; WH= White Leghorn; KK= Koekoek.

Management of Experimental Chickens

Immediately after hatched, chicks from each genotype were properly identified, weighted, and wing tagged before transferred to disinfected brooding pen house. Chicks were vaccinated against New Castle disease, HB1 and fowl fox within 3-7, and at 21, 42 and 60 days, respectively. The birds were raised in the brooding pens using infrared lamps as a heat source until 4 weeks, while they reared in the grower pens under natural lighting from 5 to 20 weeks.

A total of 560 chicks from all treatments and 140 chicks from each genotype were selected and kept as mixed-sex day old chicks until 4 weeks of age. After 4 weeks of age sex identification was done and 72 chicks from each genotypes were chosen randomly and grouped into 36 male and 36 female and kept in growing pens in three replicates (12 per replication) in one genotype. For each genotype six (6) and for all treatments twenty four (24) pens were used as growing pens. During the brooding (0-4 weeks) and growing (5-20 weeks) phases, birds were offered a measured quantity of feed and clean water ad libitum throughout the study period. An adjustment to the amount of feed offered was made every week based on the development stages of the birds (NRC, 1994). From hatching to 4 weeks, a ration provided to chicks had 20% crude protein (CP) and 2800 kcal/kg metabolizable energy (ME), and then the birds' feed was changed into a grower ration having 16% CP and 2800 kcal/kg ME until 20 weeks of age. Nutrient compositions of diets fed to experimental chickens during brooding (from hatching to 4 weeks), growing (from 5 to 20 weeks) phases are presented in Table 2.

Performance Traits Measured

The body weight of chickens were measured at hatching and at four weeks interval then after. The average body weight of birds in a pen was calculated by dividing total weight of birds in the pen by the number of birds. The daily weight gain of birds was determined as the difference between the final and initial body weight divided by the number of experimental days in each stage. The amount of feed offered to birds and refusals were weighed and recorded daily for each pen. Feed consumption was calculated as the difference between feed offered and feed leftover. Feed efficiency was assessed using feed conversions ratio (FCR) determined at pen level as feed consumption per body weight gain (kg feed/ kg gain). Age at first egg (AFE) was determined by counting the number of days or weeks from day old to the first egg-laying. Shank length (SL) was measured in centimeter as the distance from the footpad to the hock joint at 12^{th}, 16^{th}, and 20^{th} days (Ige *et al.*, 2016). The breast girth was measured in centimeters with the help of a measuring device consisting of two graduated-rulers with one arm being stationary and the other one movable (Adeleke *et al.*, 2011).

Statistical Analysis

Data were analyzed using the General Linear Model (GLM) procedures of the Statistical Analysis System (SAS, 2008, version 9.1) by fitting genetic group as a single fixed factor. The means showing significant difference among the genetic groups in F-test were compared by Duncan's multiple range test and values were considered significant at P<0.05. The following two model were used to analyze the data in this study.

Model one: Data collected from 0- 4 weeks of age:
$Yij = \mu + Gi + \varepsilon ij$,
Where: Yij = performance of the j[th] individual of the i[th] genotype; μ = Over all mean effect; Gi = fixed effect of the ith genotype; εij = random error.
Model two: Data collected from 4-20 weeks of age:
$Y_{ij} = \mu + G_i + S_j + e_{ij}$

Where:
Y_{ij} = performance of the j[th] individual of the i[th] genotype
μ = general mean of the parameters (population mean)
G_i = fixed effect of the i[th] genotype (i=1, 2, 3, and 4)
S_j=effect of the j[th] Sex (j=male and female), e_{ij} = residual error.

Table 2. Nutrient composition of diet feed to experimental birds.

Nutrient composition	Starter ration	Grower ration
ME, kcal/kg	2800.00	2800.00
CP, %	20.00	16.00
CF, %	5.67	5.64
EE, %	4.23	4.31

ME= Metabolizable energy; CP= Crude protein; CF= Crude fiber; EE= Either extract.

Results and Discussion

Bodyweight

There was significant (P<0.01) difference among the four genotypes on body weight of mixed sex chicks at day old and 4 weeks of age (Table 3). Higher average body weight at hatching was observed in pure Koekoek followed by main cross (WH male × KK female) whereas, the main cross exhibited higher bodyweight at 4 weeks of age followed by pure Koekoek. The least body weight at 4 weeks of age was exhibited by pure White Leghorn followed by reciprocal cross. The higher average body weight of main (WH male × KK female) cross than the reciprocal, pure Koekoek and pure White Leghorn genotypes at 4 weeks of age is due to the maternal genetic effect of Koekoek breed which inherited its higher body weight to the main cross. This implies that Koekoek genotypes passed on genes responsible for growth performance. In support of this, Musa *et al.* (2015) described that the large dual-purpose breed and reciprocal crosses involving Fayoumi × Koekoek and Koekoek × Fayoumi attained higher body weight than Fayoumi and White Leghorn genotypes. Similarly, Taye *et al.* (2022) indicated that from reciprocal mating of Horro with KK and Kuroiler, reciprocal crosses of Kuroiler and Horro had the highest growing body weight, followed by Kuroiler and reciprocal crosses of KK with Horro, but purebred KK and Horro showed the lowest performance.

Table 3. Least square mean body weight of mixed sex chickens from the four genetic groups at hatching and four weeks of age.

Genetic group[1]	Body weight at hatching and 4 weeks of age	
	Hatching	4 weeks
KK × KK	34.96 [a] ±0.14	121.13[b] ±1.14
KK× WH (reciprocal)	29.06 [c] ±0.31	111.73[c] ±1.34
WH × KK (main)	32.82 [b]±0.97	132.13[a] ±2.74
WH × WH	28.64 [c] ±0.31	101.14[d]±2.60
CV	2.90	3.10

[a, b, c, d] Means value with the same letter in the same column are not significantly different at p<0.05; Males are listed first in the cross; WH= White Leghorn; KK= Koekoek.

The average body weight of male main cross chicken was comparable with male pure Koekoek at weeks 8 and 16 and higher at week 12 (Table 4). In the current study the least average body weight at brooding and growing age up to 20 weeks were recorded for pure White Leghorn genotype.

The higher growth performance of the two crosses implies that the growth genes of the dual purpose genotype inherit growth performance to the F1progenies of the two crosses. In addition to that, this result shows that using Koekoek as a parent during crossing with White Leghorn, the former genotype shows high general combining ability (GCA) for growth trait. This implies that the presence of desirable additive genes for growth trait in Koekoek genotype and crossing with White Leghorn most likely pass in to cross breed progenies having this breed as a parent. In line with this, Khalil and Abou-Khadiga (2020) stated that positive and higher GCA in KK for growth trait indicates the accumulation of favorable alleles in comparison to White Leghorn and Fayoumi genotypes, which had negative and lower values. Similarly, Hanafi and Iraqi (2001) explained that crossings constitute one of the tools for the exploitation of the genetic variation and the hybrid vigor of favorable genes of each breed.

The current result of growth performance of female main and reciprocal crosses at 16 weeks exhibited 1491.13gm and 1357.80 gm which were higher and lower than the dual-purpose Sandy laying hens at 16 weeks, which exhibit 1423gm live weight, respectively (Baldinger and Bussemas 2021).

With regard to the average body weight of female cross breeds comparable and statistically non-significant result was obtained from 8th up to 20th weeks of age between pure Koekoek and main cross breeds (Table 4). This indicates the higher direct additive genetic contribution of the mother (both chromosomes of x and z) from parental stock. This implies that both male and female of F1 progenies from crossing of White Leghorn male and Koekoek female performed similar growth performance with Koekoek but higher than reciprocal progenies (Koekoek male with White Leghorn female) and pure White Leghorn chicken breed.

The current result with higher performance of the main cross than reciprocal was similar with Amin *et al.* (2017), who indicated that main cross (Sasso × Gimmizah) chicks were superior at different ages compared to reciprocal cross (Gimmizah × Sasso) chicks. But the higher body weight of the main cross than reciprocal cross was due to the Gimmizah effect of female Sasso breed.

Table 4. Least square mean bodyweight (gram) of male and female genotypes at different age.

Body weight in weeks	Genetic group			
	KK × KK	KK × WH	WH×KK	WH × WH
	Males			
W8	487.21^{a}±13.34	424.79^{b}±11.54	439.79^{ab}±21.14	307.5^{c}±10.99
W12	859.2^{b}±7.75	787.8^{c}±14.52	952.89^{a}±20.64	564.0^{d}±30.79
W16	1708.98^{a}±55.24	1572.67^{a}±66.43	1698.67^{a}±24.37	1193.70^{b} ±55.74
W20	2227.53^{a}±56.03	1986.73^{b}±70.46	1998.87^{b}±46.95	1441.53^{c}±52.19
CV	6.20	4.40	5.90	5.20
	Pullets			
W8	363^{a}±18.72	334.79^{a}±7.09	373.33^{a}±9.53	307.5^{c}±10.99
W12	773.0^{a} ±41.05	609.93^{b} ±32.44	720.46^{a}±24.52	564.0^{d}±30.79
W16	1458.33^{ab}±19.46	1357.80^{b}±42.88	1491.13^{a}±58.61	1193.70^{b} ±55.74
W20	1701.46^{a}±16.44	1501.13^{b}±55.05	1677.87^{a}±59.34	1441.53^{c}±52.19
CV	6.70	8.60	5.20	5.21

a, b, c, d Means value with the same letter in the same row are not significantly different at p<0.05; BWt_8= Bodyweight of 8th weeks; BWt_{12}= Bodyweight of 12th weeks; BWt_{16}= Bodyweight of 16th weeks; BWt_{20}= Bodyweight of 20th weeks; WH= White Leghorn; KK= Koekoek.

Daily Body Weight Gain

There were significant (p<0.01) differences among the four genotypes on their average daily body weight gain from day old to week 20 of the current study (Table 5). Generally pure male and female Koekoek genotype attained higher and significantly different DBWG than all genotypes of this study and White Leghorn is the least. At brooding age (day old up to 8 weeks of age), both sex of main and reciprocal crosses attained significantly similar average DBWG whereas, at growing age from 9 week up to 16 weeks of age main crosses were more efficient on DBWG than F1 reciprocal cross breed (Koekoek male and White Leghorn female)(Table 5).

In pullets and aggregate sexes, main cross genotype achieved higher DBWG than reciprocal genotypes from day old to 20 weeks of ages. This imply that the adaptability of female Koekoek and transmission of growth genes to the main cross was higher than the female White Leghorn in the reciprocal cross. This difference between the two reciprocal crossbreds may be an indication that sex-linked genes may be influencing average daily gains in these chicken populations. In line with this, the study by Nath *et al.* (2014) explained that the higher parental effect of Koekoek crossing with White Leghorn for growth traits of cross breed would manifest higher additive genetic variances and the existence of favorable alleles in this breed. Due to adaptability of Koekoek breed to tropical environment, using this breed as a female line for cross breed than temperate breed of White Leghorn had provided efficient and consistent growth and DBWG to main cross at growing phase. The difference of the two crosses on DBWG in the current study is consistent with Ibrahim *et al.* (2019), who stated that Koekoek and Sasso crossbred chickens had significantly (P < 0.05) higher daily weight gains (23.7 g) than the reciprocal crossbred chickens (18.3 g).

Feed Consumption and Feed Conversion Ratio for Different Genotypes and Ages

The results of average feed consumption in the current study indicated that there were significant (p<0.01) differences among genotypes, sexes and weeks of age (Table 6). At brooding age of male chicken the average feed consumption of the two crosses were significantly higher than pure Koekoek and pure White Leghorn consume the least. Similarly at grower age the average feed consumption of male and female reciprocal genotypes were significantly higher than all genotypes followed by main cross and pure Koekoek with non-significant different. The higher feed consumption of sexes of the two crosses from the average value of the two pure breeds may be due to the higher combining ability of Koekoek with White Leghorn and inheritance of genes to cross genotypes.

The current result of 90 and 91gm/day/hen feed consumption from 9-20 weeks for mixed sex of the two crosses were higher than Novo Brown dual purpose chicken breed and comparable with Novo

Color and Lohman Brown chicken breeds reared from 16-24 weeks as indicated by Ibrahim *et al.* (2019) that implies the better feed intake performance of the two crosses in this study. The higher or lower feed intake in chickens is sometimes related to higher output or higher productive performance. In this regard, Ibrahim *et al.* (2019) described that the lower feed intake of NB chicken breed from 16 to 32 wks, and NC chicken breed up to 48 wks, could be related to their lower level of egg production.

The higher feed intake in both crosses than the pure Koekoek may be due to the influence of non-additive genes in the F_1 which are transmitted from their parents, the maternal genetic and sex-linked effect. Besides, the higher feed intake in F_1 crosses are due to the presence of higher hetrozygotic alleles through heterosis than the two pure lines. In support of this, Willham and Pollak (1985) described that the magnitude of heterosis is inversely related to the degree of genetic resemblance between parental populations and is expected to be proportional to the degree of heterozygosity of the crosses (Sheridan, 1981).

Table 5. Least square mean daily body weight gain (DBWG) for all genotypes at different ages

DBWG in weeks	Genetic groups				
	KK × KK	KK × WH	WH × KK	WH × WH	CV%
	Male				
0-8	6.86^a±0.44	6.16^b±0.38	6.64^b±0.73	4.58^c±0.45	9.04
9-12	28.23^b±0.26	25.91^c±0.47	31.42^a± 0.67	18.57^d±1.03	4.47
13-16	28.33^a±1.96	26.16^{ab}±2.67	24.86^{ab}±0.94	20.99^b±2.08	13.68
17-20	17.88^a±4.69	14.28^b±0.34	10.35^c±0.78	8.54^c±0.52	9.41
0-20	75.67^b±0.95	79.23^a±9.41	77.34^{ab}±3.60	64.20^c±1.52	10.22
	Pullet				
0-8	5.63^{ab}±0.65	5.32^b±0.23	5.97^a±0.23	4.16^c±0.48	10.45
9-12	25.50^a±1.39	20.08^b±1.08	23.75^a±0.82	14.61^c±0.86	8.77
13-16	22.83^{ab}±1.91	24.93^a±1.02	25.69^a±2.48	17.68^b±1.49	13.74
17-20	8.38^a±0.76	5.94^{bc}±0.49	6.44^b±0.09	4.69^c±0.33	13.17
0-20	61.96^b±1.22	61.38^b±1.02	65.05^a±4.51	57.53^c±0.36	5.63
	Mixed sex				
0-8	6.86^a±0.48	6.19^b±0.69	6.65^{ab}±0.32	4.60^c±0.37	11.25
9-12	26.87^a±0.56	23.00^b±0.69	27.59^a±0.73	16.59^c±0.45	9.11
13-16	25.58^a±2.58	25.55^a±1.55	25.28^a±2.28	19.34^b±1.34	14.36
17-20	13.13^a±0.13	10.11^b±0.40	8.39^c±0.41	6.62^d±0.43	13.89
0-20	72.66^a±0.14	70.12^b±4.82	71.84^a±4.05	65.29^c±0.58	8.33

BWt_{0-8}= Bodyweight hatching up to 8th weeks; BWt_{9-12}= Bodyweight from 9 to 12th weeks; BWt_{13-16}= Bodyweight from 13 to 16th weeks; BWt_{17-20}= Bodyweight from 17 to 20th weeks; WH= White Leghorn; KK= Koekoek.

Table 6. Least square mean feed consumption (FC) gram/bird/day for all genotypes and sex (male, female, and mixed) at different ages.

Feed consumption in weeks	Genetic groups				
	KK × KK	KK × WH	WH × KK	WH × WH	CV%
	Male				
0-8 weeks	34.14^b±0.53	35.80^a ±0.16	36.27^a± 0.05	30.34^c±0.20	0.98
9-12	54.79^b±0.67	63.41^a±2.25	58.48^b±0.13	49.71^c±0.51	3.68
13-16	88.49^{ab}±0.95	89.45^{ab}±9.41	93.27^a±3.60	75.83^b±1.52	10.12
17-20	166.93^a±1.39	171.72^a±19.46	161.21^a±13.92	134.76^a±6.46	13.55
	Pullet				
0-8 weeks	29.21^b±0.39	31.16^a±0.25	29.32^b±0.32	28.50^b±0.35	1.26
9-12	47.69^b±1.05	52.12^a±0.74	53.41^a±0.93	50.85^a±0.67	2.93
13-16	74.05^{ab}±1.22	75.76^a±1.02	77.81^a±4.51	67.69^b±0.36	5.63
17-20	129.90^b±5.85	136.68^{ab}±12.35	115.38^b±9.25	163.11^a±10.36	12.38
	Mixed sex				
0-8 weeks	31.50^{ab}±0.45	33.70^a±0.21	32.89^a±0.14	29.76^b±0.58	1.20
9-12	51.24b±0.74	57.77^a±1.21	55.94^a±0.45	50.28^b±0.55	4.11
13-16	81.28^{ab}±0.14	82.61^a±4.82	85.54^a±4.05	71.76^b±0.58	10.80
17-20	143.42^a± 1.31	129.54^b±3.39	133.13^b± 2.33	127.27^b±2.01	14.23

$^{a, b, c, d}$Means value with the same letter in the same row are not significantly different at $p<0.05$; WH= White Leghorn; KK= Koekoek.

The results of the feed conversion ratio in the current study indicated that there were significant ($p<0.05$) differences among genotypes and sexes at all ages (Table 7), except week 16. Feed conversion ratio of male pure Koekoek at brooding age (8 weeks) was significantly lower and efficient in feed utilization than all genotypes. The lower FCR in pure Koekoek at brooding age indicate that this genotype was most efficiently utilized the feed consumed and converted in to meat. The efficient FCR of Koekoek genotype is due to genetic selection undertaken for many generation on its growth performance. The FCR of both cross breed genotypes in the current study at 8th weeks of age were higher or less efficient than the study by Ekka *et al.* (2017), who reported that at 8th weeks of age for Indian improved colored synthetic male line (CSML), Hansli (local), and Hansli × CSML cross breed chicken genotypes with the FCR of 2.17, 2.58, and 2.26, respectively under intensive system of rearing. Another study from India by Nandi *et al.* (2017) reported that the 8th week cumulative FCR of Hansli chicken genotype was recorded as 4.52 which is comparative with the current study of pure Koekoek and main cross (White Leghorn Koekoek) breed genotypes. Similarly, the FCR at brooding age of all genotypes in the current study were higher (less efficient) than the study by Chali (2018) in Ethiopia, who indicated that the mean FCR of SassoT44, Koekoek and Dominant Red Barred chicken breeds were 2.88, 3.04 and 3.24, respectively. The efficient feed utilization of Sasso, Koekoek and their crosses is because of the two pure dual purpose breeds undergone genetic selection for generations during their initial gene stabilization. In the contrary, the FCR of the current study at brooding age of Koekoek and the two crosses were lower (efficient) than the study by Ogbu *et al.* (2015), who reported that FCR in two light and heavy indigenous Nigerian chicken breeds as 8.11 and 5.11, respectively up to 8 weeks of age.

Table 7. Least square mean feed conversion ratio (FCR) of all genotypes and sex at different ages.

Feed conversion ratio in weeks	Genetic groups				
	KK × KK	KK × WH	WH × KK	WH × WH	CV%
	Male				
8 weeks	4.97ᵃ±0.01	5.81ᵇ±0.01	5.46ᵇ±0.01	6.62ᶜ±0.01	9.74
12	1.94ᵃ±0.01	2.45ᵇ±0.01	1.86ᵃ±0.01	2.68ᵇ±0.02	5.34
16	3.12ᵃ±0.03	3.42ᵃ±0.03	3.75ᵃ±0.01	3.61ᵃ±0.03	14.32
20	9.34ᵃ±0.01	12.02ᵇ±0.01	15.57ᵇ±0.01	15.78ᵇ±0.02	0.03
	Pullet				
8 weeks	5.18ᵃ±0.02	5.86ᵇ±0.01	4.91ᵃ±0.01	6.85ᶜ±0.01	10.65
12	1.87ᵃ ±0.02	2.59ᵇ±0.03	2.25ᵇ±0.01	3.48ᶜ±0.01	7.55
16	3.24ᵃ±0.03	3.03ᵃ±0.02	3.03ᵃ±0.01	3.83ᵃ±0.01	11.50
20	15.50ᵃ±0.01	23.01ᵇ±0.01	17.91ᵃ±0.01	34.77ᶜ±0.01	0.01
	Mixed				
8 weeks	4.59ᵃ±0.01	5.44ᵇ±0.02	4.95ᵃᵇ±0.02	6.47ᶜ±0.01	12.56
12	1.91ᵃ±0.002	2.51ᵇ±0.01	2.03ᵃ±0.02	3.03ᶜ±0.003	8.37
16	3.18ᵃ±0.01	3.23ᵃ±0.01	3.38ᵃ±0.01	3.71ᵇ±0.01	16.22
20	10.92ᵃ±0.01	12.81ᵇ ±0.02	15.87ᵇ±0.02	19.23ᶜ±0.01	3.01

FCR_8= Feed conversion ratio of 8th week; FCR_{12}= Feed conversion ratio of 12th week; FCR_{16}= Feed conversion ratio of 16th week; FCR_{20}= Feed conversion ratio of 20th week; WH= White Leghorn; KK= Koekoek.

In most of the growing ages (12 and 16 weeks) both sexes and mixed sex of the two crosses, exhibited lower or efficient FCR and non-significantly similar with pure Koekoek. This implies the inheritance of hybrid vigor that exploit more weight by consuming less feed from Koekoek genotypes to the two crosses. The efficient FCR in the two crosses and Koekoek genotype is due to the lower positive genetic correlation of feed intake and FCR. In support of this, Gaya *et al.* (2006) indicated a genetic correlation of feed intake and feed conversion ratio with a value of 0.38. The result of FCR in the current study at 16 weeks of all genotypes were lower (efficient) than the study by Itafa *et al.* (2021), who stated that purebred Koekoek, pure breed Sasso, Sasso × Koekoek cross and reciprocal of Koekoek× Sasso crossbreds chicks exhibited FCR of 4.46, 5.10, 5.68, and 5.71, respectively. The current study shows that, as age of the genotypes increase at grower phase, FCR increase and simultaneously daily body weight gain decrease. In line with this, the study by N'dri *et al.* (2006) described that the genetic correlations between growth curve parameters and FCR is negative to low (-0.3-0.3) and indicate presence of negative genetic correlation between growth curve and FCR. Generally, the difference of FCR in different breeds and cross breeds are due to genetic variation and genetic selection, management and environmental differences.

White Leghorn genotypes exhibited the least FCR in all sex of different ages as compared to the other contemporary groups. This shows that White Leghorn at brooding and growing ages consumed more feed per unit weight gain than the other genotypes. This is because the White Leghorn genotype is light breed on which genetic selection was undertaken for egg production. Higher feed conversion ratio (FCR) at week 20 in all genotypes as compared to the other ages may be related with the utilization of feed for other purpose (abdominal fat accumulation, egg production and others) than weight gain. According to N'dri *et al.* (2006), abdominal fat yield (AFY) is highly correlated with FCR (0.44) and concluded that indirect selection for feed conversion ratio is possible by using growth curve parameters and abdominal fatness.

Shank Length and Breast Girth

There were significant (P<0.05) differences on the shank length of all genotypes at 12, 16, and 20 weeks. Pure Koekoek and main cross exhibited higher shank length for male chickens (Table 8). Similar shank lengths were exhibited in pure male Koekoek and males of the two crosses at week 12 and week 20. However, pure White Leghorn recorded the least Shank length in both sexes.

On shank length of female genotypes, pure Koekoek and main cross have the longest shank length at week 20 than reciprocal cross. In both crosses of male and female genotypes comparable breast girth were observed with the pure Koekoek genotype. The comparable result of cross breed shank length and breast girth with the best parent (Koekoek) implies that the two crosses exploited heterosis through dominant and epistatic genes on shank length and breast girth from the best parent. The study of El-Wardany (1999) showed that the estimated heritability value of shank length at 8 and 16 weeks of age are 0.40 and 0.90, respectively and this indicate the inheritance of shank length to the progenies and selection by shank length could improve body weight egg number and egg mass. The study by Atansuyi *et al.* (2018) in Nigeria stated a strong correlation between breast girth and body weight on FUNNAB Alpha, Isa Brown and Noiler chicken breeds. Another study by Tsudzuk *et al.* (2007) found a significant correlation between shank length, carcass weight and some carcass characters. Also, Ramadan *et al.* (2014) found that there were significant associations and correlation between shank lengths and live body weight, carcass weights, breast girth and other carcass parts. Another study by Debes *et al.* (2015) observed that chickens with long shank length produced more egg than chickens with short shank length and the authors concluded that shank length could be used as useful tool for improving body weight and egg production.

Table 8. Least square mean shank length (SHL) and breast girth (BRG) for all genotypes at different ages.

Shank length and breast girth in weeks	Genetic group				CV%
	KK × KK	WH × KK	KK × WH	WH × WH	
	Shank Length				
	Males				
12	15.30^{a}± 0.40	15.07^{a}±0.09	15.45^{a}±0.26	13.27^{b}±0.28	3.32
16	17.60^{a}±0.26	16.37^{bc}±0.24	17.17^{ab}±0.44	15.67^{c}±0.46	3.80
20	18.47^{a}±0.29	17.73^{a}±0.23	17.69^{ab}±0.24	16.57^{b}±0.54	16.50
	Pullets				
12	14.16^{a}±0.09	13.23^{b}±0.03	13.53^{b}±0.17	12.03^{c}±0.18	1.70
16	15.46^{a}±0.09	14.26^{b}±0.56	14.60^{ab}±0.30	13.15^{c}±0.13	3.96
20	15.10^{a}±0.06	14.77^{a}±0.12	14.83^{a}±0.03	13.69^{b}±0.44	13.69
	Breast girth				
	Male				
12	5.30^{ab}±0.25	4.93^{ab}±0.08	5.77^{a}±0.29	4.50^{b}±0.29	4.50
16	6.20^{a}±0.21	5.30^{a}±0.20	6.10^{a}±0.53	5.27^{a}±0.17	5.27
20	7.63^{a} ±0.22	6.47^{a}±0.26	7.71^{a}±0.28	6.67^{b}±0.27	6.67
	Female				
12	4.93^{ab}±0.08	4.53^{bc}±0.16	5.37^{a}±0.28	4.20^{c}±0.10	4.20
16	5.30^{a}±0.20	4.97^{ab}±0.08	5.60^{a}±0.31	4.38^{b}±0.10	4.38
20	6.47^{a}±0.26	6.17^{a}±0.12	6.37^{a}±0.12	5.46^{b}±0.07	5.46

12= Shank length at 12th weeks; 16= Shank length at 16th weeks; 20= Shank length at 20th week; 12= Breast girth at 12th week; 16= Breast girth at 16th weeks; 20= Breast girth at 20th weeks; WH= White Leghorn; KK= Koekoek.

Age at First Egg (AFE), Mortality and Plumage Colors

The main (White Leghorn male × female Koekoek) and reciprocal crosses attained early age at first egg (AFE) and the two pure genotypes were lately matured than the crosses (Table 9). The early maturity of the two crosses is due to heterosis (increase heterozygosity) effect which improves fertility performance.

Age at first egg of the two crosses were improved by 6 days (3.7 %) and 5 days (3.1 %) from pure Koekoek and White Leghorn, respectively. The early AFE in cross breeds is due to negative heterosis in both crossbreeds. In consistent with the current result the study by Soliman *et al.* (2020) reported significant positive heterosis (5.58%) for age at sexual maturity from reciprocal mating of pure Alexandria and pure Lohman chicken breeds in Egypt. The lower magnitude of cross breed hetrosis for AFE from parental breeds is due to the smallest genetic distance between Koekoek and White Leghorn chicken breeds. In this regard, Soliman *et al.* (2020) explained that the magnitude of heterosis increases with increasing genetic distance of the parental lines. In line with this, Soliman *et al.* (2020) explained that the reciprocal crossing between two parental chickens breeds have common genes that significantly enriched in the cell cycle, animal organ development, gonad development, calcium signaling pathway and GnRH signaling pathway. This shows the biological mechanisms of early sexual maturation of cross breeds chickens in comparison to parents. According to Hristakieva *et al.* (2014), the effect of heterosis is generally higher for reproduction traits than for growth potential and is influence by the maternal side and nutrition.

The main cross had the lowest percentage of mortality followed by pure Koekoek in the 20 weeks of experimental period. Pure White Leghorn chicken exhibited higher mortality. The lower mortality of main cross is due to maternal genetic effect inherited from Koekoek female. In support of this, the study by Hristakieva *et al.* (2014) indicated that the effect of heterosis is generally higher for reproduction traits and influence by the maternal side. Several studies (Khawaja *et al.*, 2016; Castellini *et al.*, 2016) have shown that crossbred chickens have lower mortality, higher body weights and better feed efficiency than purebred chickens.

The plumage color (Figure 1) of both crosses were different from the two parents. Both of the crossbreeds in the current study have white and dark barred plumage colors for main and reciprocal cross, respectively. This implies the importance of this barred plumage colors for traditional production system which could reduce the cause of chicken loss that observed on White Leghorn (WLH) chicken breed due to predators. With regard to predators, the study by Tadiose *et al.* (2017) explained that predators are among the major constraints that cause chicken deaths, especially in the village production system in Ethiopia.

Figure 1. Plumage colors of the four genotypes.

Table 9. Least square mean of mortality (%) and age at first egg (AFE) (days) at 5, and 10% production of different genotypes.

Parameters	Genetic group				
	KK × KK	KK × WH	WH × KK	WH × WH	CV
No. of chicks hatched	214	194	135	197	
Mortality (%)					
Brooding age (0-8 weeks)	2.68	7.07	3.80	8.00	7.20
Growing age (9-20 weeks)	1.79	3.03	0.00	6.10	5.11
Overall mortality (0-20 weeks)	4.47	10.10	3.80	14.10	8.45
Age at first egg (AFE) in days					
First egg laid	160^{b}±5.23	155^{a}±4.11	155^{a}±1.45	158^{ab}±3.91	2.41
5% egg laid from all layers	161^{b}±3.32	155^{a}±2.44	155^{a}±2.22	159^{b}±4.88	1.92
10% egg laid from all layers	163^{b} ±4.71	156^{a} ±4.11	155^{a} ±5.25	162^{b} ±3.66	1.85
Mean AFE	161.3^{b} ± 4.22	155.3^{a} ±3.99	155^{a} ±3.45	160^{b} ±4.88	2.11

WH= White Leghorn; KK= Koekoek.

Conclusion

General combining ability (GCA) of Koekoek breed was higher and better heterosis for cross breeds can be exploited by mating with White Leghorn breed for growth, feed conversion efficiency, body measurement, age at first egg and mortality traits. Significantly higher and comparable body weight, daily body weight gain, low or efficient feed conversion ratio were observed in main cross and pure Koekoek than reciprocal cross and WLH chicken breed. Low mortality and early age at first egg were observed in main cross than all genotypes. The result of the study shall encourage poultry breeders to cross these two pure breeds to exploit heterosis of production and reproduction traits. Thus, the cross between White Leghorn pullet and Koekoek cockerels is recommended for poultry breeders to take advantage of heterosis for growth performance, feed efficiency, age at first egg (AFE) and mortality.

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Conflict of Interests

The authors declare that they have no competing interests.

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