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REGULAR ARTICLES

Genetic parameters of growth traits, trend of production and reproduction traits, and meat quality status of Ghagus, an indigenous chicken of India

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Abstract

Indigenous chickens play a vital role in providing nutritional security and economic support for the rural and tribal people in tropical countries like India. Ghagus, an indigenous chicken breed of India, was characterized for growth, production, and reproduction (fertility and hatchability) traits over different generations and for carcass and meat quality traits. Heritability, and genetic and phenotypic correlations among growth traits were estimated using mixed model least squares and maximum likelihood methods. Estimates of heritability of growth traits such as bodyweights at different age and 8-week shank length were high (0.32 to 0.39) in initial generation and moderate to high during latest generation (0.20 to 0.42). The correlations of growth traits with 40-week egg production were positive and significant ($P<0.001$). There was improvement in 8-week bodyweight (559.3 ± 4.40 g) by 177 g over the generations. The average egg production up to 40 weeks over the generations was 35.66 eggs. There was also a significant ($P<0.001$) increase in egg weights over the generations. The fertility (mean 89.3%) ranged from 85.2 to 92.3%. The hatchability on fertile egg set (mean 90.8%) ranged from 86.5 to 94.1% and it was improved by 3.9% over the generations. The carcass and meat quality study revealed that this breed has the lean meat, high protein, and attractive meat color with desirable meat quality characteristics. The study concluded that the Ghagus breed with self-propagation capacity has the potential to be improved as an indigenous meat-type breed to meet the ever-increasing demand for indigenous chickens' meat in the country.

Keywords Growth · Production · Reproduction · Carcass · Meat · Ghagus

Introduction

Indigenous chickens (IC) play a vital role in providing nutritional security and economic support for the rural and tribal people in developing and underdeveloped countries in Asia and Africa (Padhi 2016). In India, consumers are showing considerable interest in IC due to increasing awareness about the health benefits associated with their meat and eggs. Therefore, the demand for their meat and eggs is continuously increasing over the years and hence they are commanding higher prices in niche markets. Egg production in India grew at the rate of 10.19% during 2019–20 with the production of 114.38 billion eggs and per capita availability of 86 eggs per annum. IC contributed about 10.89% to the total egg production in the year 2020. Poultry alone contributed 50.5% (4.34 million tons) of the total meat produced in the country (BAHS 2020). Broilers are main contributors to the poultry meat production. Although precise figures are not available, IC also contributed substantially to the total poultry meat production. The population of IC increased from 109.22 to 114.38 million in 2019–20 (BAHS 2020). Recently, growing of IC has become a business model (start up with e-commerce tie up) due to higher demand for their produce in both urban and rural areas (Rajkumar et al. 2021). Therefore, IC are now being grown under small-scale intensive and semi-intensive systems near urban areas. Growing of IC in such high input systems requires feeding with balanced ration. However, the cost of feed is increasing rapidly

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over the years. Hence, there is a need for the enhancement of the growth and production performance of IC through selective breeding in order to increase the production performance and feed efficiency.

Within breed selection rather than crossbreeding must be used for the improvement of indigenous chickens in order to maintain their unique attributes that are appreciated by consumers, farmers, and other stakeholders (Rajkumar et al. 2021). Before initiating the breeding programs for the improvement, the IC breeds need to be characterized for genetic parameters of growth traits. Previous studies reported the higher genetic variability for bodyweight and shank length in Aseel and Kadaknath breeds (Haunshi et al. 2012, 2021; Dalal et al. 2022). Fertility and hatchability are also important economic traits that also need to be studied. Furthermore, IC are required to be characterized for meat quality parameters before initiating the breeding program. The carcass characteristics, meat quality, and proximate composition of meat of other IC breeds such as Aseel and Kadaknath were reported previously (Haunshi et al. 2013; Rajkumar et al. 2016; 2017; Devatkal et al. 2018). Ghagus is an important Indian chicken breed. Its native tract is located in the southern bordering districts of Karnataka and Andhra Pradesh states (Anonymous 2011). About nine years back, this breed was collected from its native tract and reared under the intensive system. The uniqueness of this breed is that it has high broodiness and mothering ability (Naveen et al. 2021). The aim of the study was to investigate the genetic parameters of growth traits, trend of growth, production and reproduction performance of the Ghagus breed over nine generations, and to assess the meat quality of Ghagus indigenous chicken.

Materials and methods

The approval of Institute Animal Ethics Committee (IAEC) was obtained to carry out the experiment.

Management

The experiment was conducted at ICAR-Directorate of Poultry Research, Rajendranagar, Hyderabad, India (17.35 N, 78.41E). A total of 8530 chicks of Ghagus breed produced in nine generations with an average of 947 chicks hatched per generation were evaluated in the experiment. Number of chicks hatched in each generation is given in Table 1. Chicks were identified by putting wing-bands and vaccinated for Marek's disease at the hatchery. Straight run chicks were reared on deep litter in open sided brooder cum grower houses up to 20 weeks. As no sexing of chicks was done, mixed sex rearing was practiced up to 16 weeks of age. The proportion of male and female chicks was expected to be equal, i.e., around 50% in the population. Male and female birds were identified by morphological features at 16 weeks of age and reared separately. From 20 weeks onward, female birds were reared in individual layer cages and male birds were reared in male cages in open-sided cage houses. Curtains were used to prevent the direct draft and rain flashing in to the sheds whenever required. The chicks were provided with chick starter ration (2600 kcal/kg metabolizable energy (M.E.) and 18% crude protein (C.P.) up to 8 weeks and grower ration (M.E. of 2500 kcal/kg and C.P. of 16%) from nine to 20 weeks and pre-layer ration (mix of grower and layer ration in equal proportion) from 21 to till the start of egg production (first egg in the flock). Subsequently, layer ration (M. E. of 2600 kcal/kg and C.P. of 16%) was provided to the hens. Birds had continuous access to clean drinking water and given feed in ad libitum quantity. Light for a duration of 16 h per day was provided to hens. The standard healthcare practices were followed throughout the experiment. The mortality rate for the chicken flock in each generation observed was 6.99, 9.79, 13.05, 7.27, 14.13, 10.77, 9.66, 15.25, and 9.26%, respectively, from first to ninth generations.

Table 1 Fertility and hatchability traits of Ghagus birds over nine generations

Generation	Fertility (%)	Hatchability (%)		Chicks produced (Nos.)
		FES	TES	
1	89.0	90.2	80.2	773
2	90.8	89.6	81.4	1073
3	90.5	90.2	81.6	1195
4	92.3	90.6	83.6	825
5	90.1	86.5	77.9	934
6	85.2	91.2	77.7	910
7	90.8	90.8	83.1	1014
8	89.6	92.8	83.2	931
9	85.3	94.1	80.2	875
Average	89.3	90.8	81.0	-
b ± S.E	-0.41 ± 0.21	0.45 ± 0.09	0.04 ± 0.29	-
P value	0.213	0.097	0.894	-

FES: fertile eggs set, TES: total egg set

Regeneration of the population

During initial generations, the Ghagus breed was maintained as a random bred population without any selection. During the last 4 generations, this breed was subjected to the selection for higher bodyweight at 8 weeks through mass selection. Hens (100 to 255 numbers in each generation) were reared in individual layer cages from 20 weeks onward for recording the production traits up to 40 weeks. Similarly, 100–110 roosters in each generation were housed in male cages at 20 weeks. From this population, 50 cocks and 150 hens were further selected and mated in 1:3 ratio (through artificial insemination) for producing subsequent generation.

Traits studied

Reproduction traits

Fertility and hatchability on fertile eggs set and total eggs set over the generations were recorded.

Growth traits

The growth traits such as bodyweight at 0 day, 4, 8 and 16 weeks and shank lengths at 8 and 16 weeks of age were recorded in all surviving birds on pooled sex (unsexed) to the nearest of 0.1 g and 0.01 mm accuracy, respectively. Sex-wise body weight was recorded at 20 weeks of age. The number of males on which bodyweight and shank length were recorded at 20 weeks of age was 118, 87, 85, 94, 100, and 104, respectively, from fourth to ninth generations.

Production traits

A total of 100, 233, 250, 239, 215, 215, 255, 253, and 200 hens were housed in individual cages, respectively, from first to ninth generations for recording of production and growth traits. The production traits studied were age at first egg, 40-week egg production and egg weights at 28, 32, and 40 weeks. The egg weights were recorded for the eggs produced consecutively for five days at each age (0.01 g accuracy).

Carcass and meat quality traits

The carcass traits (dressing percentage, cut-up parts, giblets, etc.) of Ghagus males at 20 and 24 weeks were studied by slaughtering 20 male birds at each age in two (second and sixth) generations. The meat qualities (pH, water holding capacity, shear force value, instrumental color, proximate composition, etc.) were studied in cocks slaughtered at the age of 24 weeks. The dressing percentage was calculated as the percentage of dressed carcass weight to that of fasting live weight. The pH of chicken meat was determined as per Trout et al. (1992). The water holding capacity was determined according to Wardlaw et al. (1973). The shear force values were measured by the method of Berry and Stiffler (1981). The instrumental color units (L, a, and b) of meat were measured by using Hunter lab colorimeter (MiniScan EZ, Hunterlab, USA). The moisture content was determined by oven drying. Level of crude protein was determined by Kjeldahl method of nitrogen estimation, and fat by Soxhlet extraction with petroleum ether (AOAC 2002).

Statistical analysis

Descriptive statistics was used to determine the means and standard errors of each trait. Regression analysis by plotting the average of each trait (generation means) over generation numbers was done to study the trend in the performance over the generations (MS excel 2019). Least-squares means, heritability estimates, and genetic and phenotypic correlations of growth traits were estimated using mixed model least squares and maximum likelihood (Harvey 1990) computer program (PC-2 version) as per the model explained previously (Haunshi et al. 2021). Variance was partitioned into sires, dams, and sire + dam components (King and Henderson 1954; Becker 1992). Pearson correlation coefficient between growth and production traits was estimated using SPSS.

Results

Reproduction traits

Consistently better fertility was observed in the Ghagus breed over nine generations (Table 1). The highest fertility recorded was 92.3%, and the lowest was 85.2% with average fertility of 89.3%. Similarly, better hatchability (FES) was observed over the generations. The highest hatchability and lowest hatchability (FES) recorded were 94.1 and 86.5%, respectively, with an average of 90.8%. The hatchability on total eggs set was in the range of 83.6 and 77.7%, with an average of 81.0% (Table 1).

Growth during juvenile and grower stage

The means of juvenile growth traits are presented in Table 2. There was significant improvement in 0-day bodyweight (6.1 g) over the generations. The 4-week bodyweight recorded during third and ninth generations was 169.3 ± 1.60 and 182.2 ± 1.54 g, respectively. There was a significant ($P < 0.01$) improvement in 8-week bodyweight (177 g) over 9 generations. Likewise, improvement in 8-week shank length (5.58 mm) was seen. The highest bodyweight and shank length were observed in the latest generation (Table 2). The bodyweight at 16 weeks increased from 1165 ± 9.82 g (second generation) to 1364 ± 10.3 g (eighth generation).

Table 2 Juvenile growth traits of Ghagus breed in different generations on pooled sex (straight run)

Generation	Bodyweight (g)		Shank length (mm)
	0 day	8 weeks	8 weeks
1	29.6 ± 0.13	382.2 ± 4.07	68.10 ± 0.30
2	28.3 ± 0.10	387.3 ± 3.76	66.30 ± 0.28
3	31.8 ± 0.12	428.8 ± 3.61	69.01 ± 0.25
4	30.3 ± 0.12	401.5 ± 0.18	67.39 ± 1.33
5	32.1 ± 0.01	383.8 ± 0.17	64.19 ± 0.01
6	31.8 ± 0.01	427.1 ± 4.31	68.85 ± 0.31
7	32.9 ± 0.10	435.2 ± 4.29	66.40 ± 0.29
8	33.2 ± 0.11	471.7 ± 4.42	70.09 ± 0.30
9	35.7 ± 0.33	559.3 ± 4.40	73.68 ± 0.28
Average	31.7	430.8	68.22
b ± S.E	0.71 ± 0.13	16.67 ± 4.59	0.49 ± 0.32
P value	0.001	0.008	0.164

b = regression coefficient, S.E.: standard error

Genetic parameters

Heritability estimates of growth traits were estimated in third and ninth generations (Table 3). The heritability estimates of bodyweight at 4, 8, and 16 weeks and 8-week shank length were high, while they were moderate for 16-week shank length in third generation. They varied from moderate to high in the latest generation. Similarly, the heritability of 16-week bodyweight (estimated in the eighth generation) was also moderate (0.23 ± 0.14 sire, 0.39 ± 0.18 dam and 0.31 ± 0.09 sire + dam components) in magnitude on sire component of variance (Table 3). These results indicated that there was a high genetic variation in the population of Ghagus for growth traits and that trend continued in the latest generation.

The correlations (genetic and phenotypic) among juvenile growth traits were studied in third and latest generation (Table 4). The correlation between 8-week bodyweight and shank length was positive and high. Similarly, correlations between 4-week bodyweight with 8-week bodyweight and shank length were high during initial generation. Similar association was observed among the growth traits during the latest generation as well although estimates were relatively lesser (Table 4).

Growth traits in adult birds

The results of growth traits of Ghagus cockerels and pullets are presented in Table 5. There was an improvement of 436 and 259 g in bodyweight of males and females at 20 weeks, respectively, over the generations. The average (three generations) 24-week bodyweight of cocks and hens was 2098 and 1526 g, while their shank length at the same age was 126.2 and 100.5 mm, respectively. The 40-week bodyweight of cocks and hens averaged over seven generations was 2678 ± 48.4 and 1670 ± 32.6 g, respectively, while shank length of cocks and hens at same age was 128.1 ± 0.68 g and 101.1 ± 0.62 mm, respectively.

Production traits

The means of age at first egg (AFE) and survivors' egg production up to 40 weeks (SEP40w) are presented in Fig. 1. The AFE declined by 15.8 days from first to latest generations. There was an increase in SEP40w by 5.6 eggs

Table 3 Heritability estimates of growth traits of Ghagus breed

Components of variance	Third generation					Ninth generation		
	Bodyweight			Shank length		Bodyweight		Shank length
	4 weeks	8 weeks	16 weeks	8 weeks	16 weeks	4 weeks	8 weeks	8 weeks
h^2 Sire	0.39 ± 0.15	0.32 ± 0.14	0.35 ± 0.17	0.32 ± 0.14	0.22 ± 0.13	0.42 ± 0.15	0.29 ± 0.12	0.20 ± 0.12
h^2 Dam	0.57 ± 0.16	0.63 ± 0.17	0.61 ± 0.20	0.51 ± 0.15	0.37 ± 0.18	0.22 ± 0.14	0.14 ± 0.13	0.31 ± 0.15
h^2 Sire + Dam	0.48 ± 0.09	0.48 ± 0.09	0.48 ± 0.10	0.42 ± 0.08	0.30 ± 0.08	0.32 ± 0.09	0.21 ± 0.07	0.25 ± 0.07

Table 4 Genetic (sire) and phenotypic correlations among juvenile growth traits of Ghagus

Genetic / Phenotypic	Third generation			Ninth generation		
	4 wks bwt	8 wks bwt	8 wks SL	4 wks bwt	8 wks bwt	8 wks SL
4 wks bwt	1.00	0.88 ± 0.05	0.93 ± 0.03	1.00	0.75 ± 0.13	0.87 ± 0.14
8 wks bwt	0.73	1.00	0.99 ± 0.01	0.73	1.00	0.89 ± 0.09
8 wks SL	0.73	0.93	1.00	0.66	0.85	1.00

wks: weeks, bwt: bodyweight, SL: shank length, genetic: above diagonal, phenotypic: below diagonal

Table 5 Growth performance of Ghagus pullets and cocks in different generations at 20 weeks of age

Generation	Bodyweight (g)		Shank length (mm)	
	Males	Females	Males	Females
4	1809 ± 20.6	1320 ± 11.3	127.5 ± 0.58	103.1 ± 0.38
5	1829 ± 32.9	1308 ± 12.1	125.4 ± 0.93	101.6 ± 0.40
6	2020 ± 23.9	1400 ± 10.9	126.5 ± 1.09	102.8 ± 0.49
7	1900 ± 27.0	1346 ± 12.8	125.7 ± 0.94	101.4 ± 0.33
8	2120 ± 18.6	1514 ± 11.1	129.9 ± 0.58	103.4 ± 0.29
9	2245 ± 27.1	1579 ± 15.3	127.2 ± 0.63	103.7 ± 0.52
Average	1936	1411	127.2	102.7
b ± S.E	69.3 ± 26.9	75.3 ± 46.3	0.62 ± 0.49	1.27 ± 0.69
P value	0.082	0.245	0.301	0.208

b = regression coefficient, S.E.: standard error

in the latest generation. Similarly, there was a significant ($P < 0.001$) increase in egg weight recorded at 28, 32, and 40 weeks by 3.49, 4.81, and 3.99 g, respectively (Fig. 2). The survivors' egg production up to 72 weeks recorded in the eighth generation was 118.8 ± 3.19 with 72-week egg weight of 52.65 ± 0.39 g. The 72-week HHEP and HDEP were 117.8 ± 3.13 and 122.9, respectively. The bodyweight of hens at 72 weeks was 2288 ± 54.5 g.

Correlations between growth and production traits of hens were estimated using data of six generations (Table 6). Moderate and positive correlations ($P < 0.001$) were observed between juvenile and adult growth traits. However, negative and moderate correlations ($P < 0.001$) were observed between bodyweights (8 and 20 weeks) and shank length (8 weeks) with AFE. Similarly, SEP40w was negatively correlated with AFE ($P < 0.001$). The interesting observation made was that the correlation of bodyweights at 8 and 20 weeks and 8-week shank length with SEP40w was positive and significant ($P < 0.001$) although low in magnitude (Table 6).

Carcass and meat quality traits

The carcass characteristics of Ghagus roosters were studied at the age of 20 and 24 weeks (Table 7). Results revealed that dressing percentage, cut-up parts yield (breast, legs, and wings), and heart and testes proportion were significantly higher at 24 weeks as compared to those at 20 weeks. All other parameters such as the proportion of gizzard, spleen, and giblets remained almost same while proportion of liver was significantly higher at 24 weeks. The findings of the meat quality traits studied at the age of 24 weeks (Table 8) revealed that the water holding

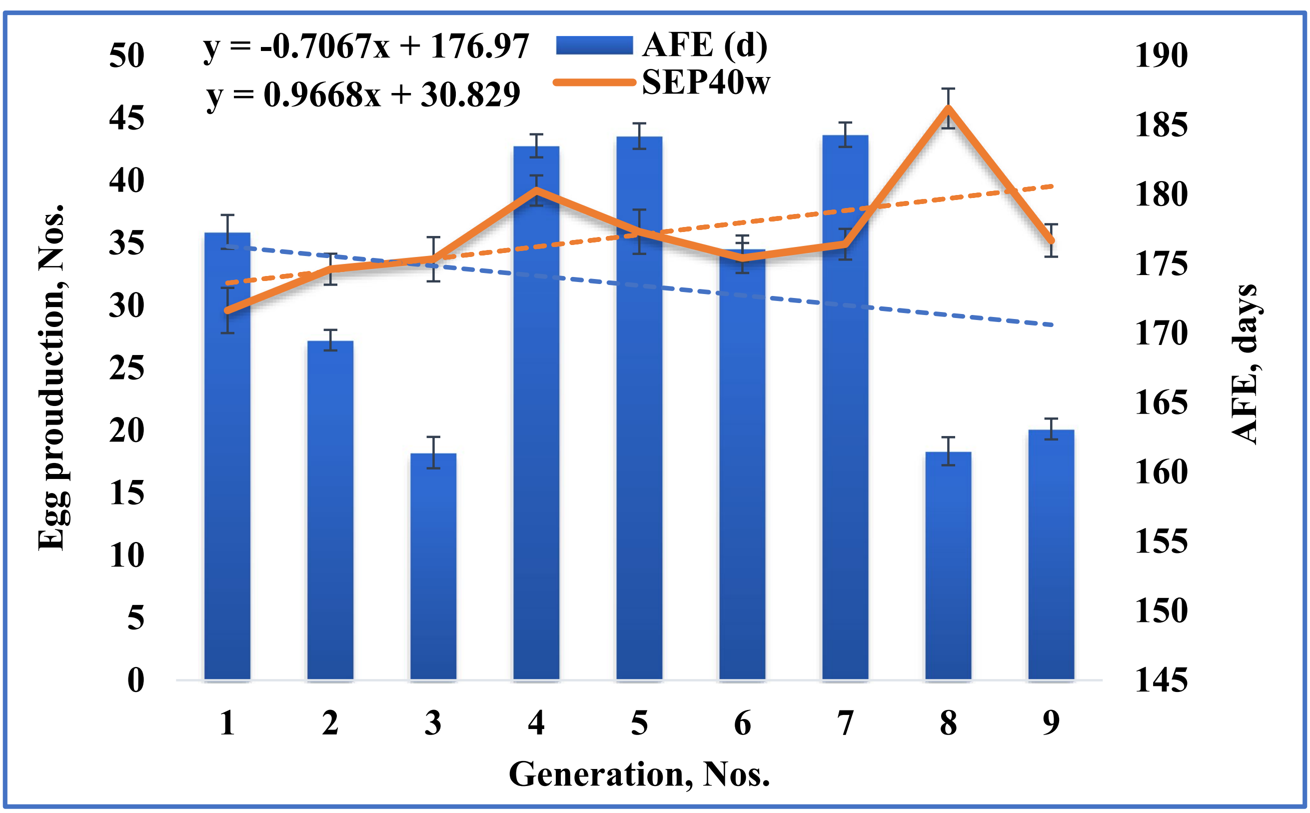

Fig. 1 Trend of egg production (40 weeks) and age at first egg of Ghagus breed over the generations

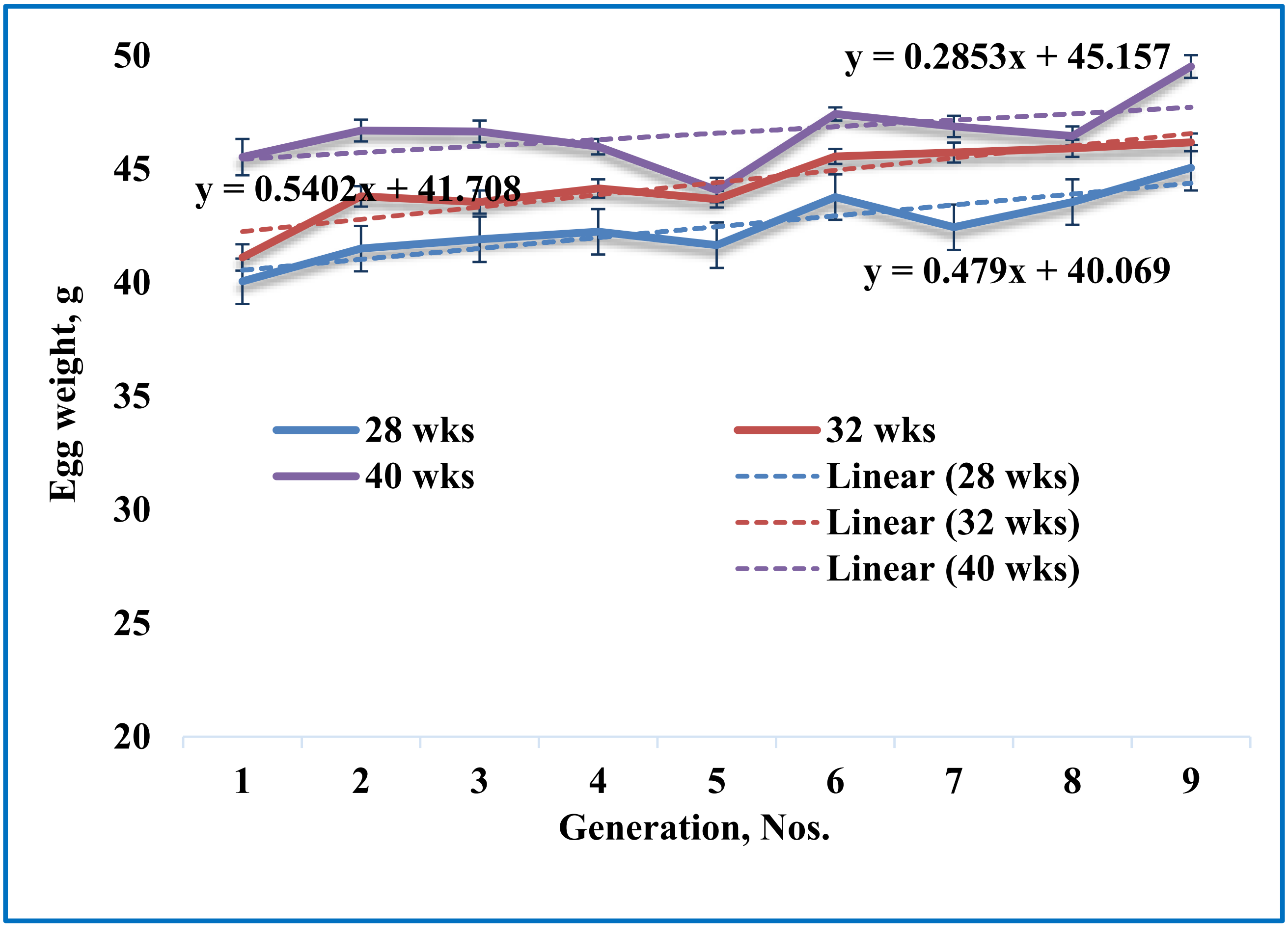

Fig. 2 Trend of egg weights of Ghagus breed at different age over the generations

Table 6 Correlation coefficients (significant two tailed) among various growth and production traits of Ghagus breed (N = 1120)

Traits	8-wk bwt	8-wk SL	20-wk bwt	AFE	SEP40w
8-wk bwt	1	0.89(**)	0.43(**)	-0.21(**)	0.13(**)
8-wk SL	0.89(**)	1	0.37(**)	-0.24(**)	0.14(**)
20-wk bwt	0.43(**)	0.37(**)	1	-0.35(**)	0.16(**)
AFE	-0.21(**)	-0.24(**)	-0.35(**)	1	-0.33(**)
SEP40w	0.13(**)	0.14(**)	0.16(**)	-0.33(**)	1

*Significant at the 0.05 level (2-tailed), ** significant at the 0.01 level (2-tailed), wks: weeks, bwt: bodyweight, SL: shank length

capacity ($P < 0.05$) and tenderness of breast muscles determined by myofibrillar fragmentation index ($P < 0.05$) and shear force ($P < 0.01$) were significantly higher in breast muscles than thigh muscles. The color of thigh muscles (redness and yellowness) was significantly higher than breast muscles.

Table 7 Carcass characteristics of Ghagus male birds at two different age (sixth and second generations)

Characteristics (%)	24 weeks	20 weeks	P value
Dressing (without skin)	70.2 ± 0.79^a	66.7 ± 0.41^b	0.0001
Dressing (with skin)	76.0 ± 0.61	-	-
Breast	16.3 ± 0.27^a	15.3 ± 0.40^b	0.05
Neck and back	17.6 ± 0.31	16.6 ± 0.91	NS
Legs	23.4 ± 0.39^a	21.6 ± 0.29^b	0.001
Wings	9.1 ± 0.15^a	7.34 ± 0.33^b	0.0001
Giblets	4.41 ± 0.18	4.62 ± 0.18	NS
Liver	1.58 ± 0.08^b	1.99 ± 0.13^a	0.01
Heart	0.49 ± 0.02^a	0.38 ± 0.01^b	0.0001
Gizzard	2.34 ± 0.11	2.25 ± 0.08	NS
Testes	0.64 ± 0.09^a	0.08 ± 0.02^b	0.0001
Spleen	0.12 ± 0.02	0.19 ± 0.05	NS
Feathers	5.13 ± 0.75	-	-
Skin	5.84 ± 0.37	-	-

NS: nonsignificant

Table 8 Meat quality characteristics of Ghagus male birds at 24 weeks (sixth generation)

Meat quality characteristics	Mean ± S.E		P value
	Breast	Thigh	
Water holding capacity (ml/100 g)	32.7 ± 3.33[a]	24.3 ± 3.19[b]	0.05
Shear force—raw chicken (N)	10.5 ± 1.35[b]	23.9 ± 3.75[a]	0.01
Shear force—cooked chicken (N)	6.6 ± 0.49	5.99 ± 0.48	NS
Myofibrillar fragmentation index (%)	93.7 ± 1.82[a]	87.2 ± 2.79[b]	0.05
pH	6.1 ± 0.04	6.2 ± 0.05	NS
Moisture (%)	73.7 ± 0.49	74.1 ± 0.79	NS
Protein (%)	22.9 ± 0.60	22.6 ± 0.87	NS
Fat (%)	1.4 ± 0.15	1.3 ± 0.11	NS
Salt-soluble proteins (g/100 g)	6.9 ± 0.29	7.0 ± 0.09	NS
Heme iron (ppm)	49.7 ± 7.61	51.8 ± 5.46	NS
Total meat pigments (ppm)	563.1 ± 86.7	587.6 ± 61.6	NS
*a** (redness)	8.8 ± 0.57[b]	16.1 ± 1.02[a]	0.0001
*b** (yellowness)	10.1 ± 0.79[b]	12.9 ± 0.71[a]	0.005
*L** (lightness)	25.66 ± 2.05	27.14 ± 2.24	NS

NS: nonsignificant

Discussion

Ghagus breed exhibited consistently better fertility (average 89%) and hatchability (91%), and there was no significant change in the fertility and hatchability traits over the generations. Higher fertility and hatchability are desirable from economic as well as improvement points of view for production of a greater number of chicks. The fertility and hatchability of the Ghagus breed were better than those reported in other indigenous breeds such as Aseel, Kadaknath, and Nicobari (Chatterjee et al. 2007; Rajkumar et al. 2017; Haunshi et al. 2012).

The trend of growth and production performance of the Ghagus breed revealed that the performance was improving over the generations for bodyweight at both juvenile and adult stages in both cocks and hens. Growth traits of birds were recorded at same age and on same sex in each generation. Therefore, the improvement observed in bodyweight was mostly due to unintentional as well as intentional selection practiced during the latest 4 generations. The growth traits of Ghagus were similar to those of Aseel breed (Haunshi et al. 2012; Rajkumar et al. 2017). However, the egg production (40 weeks) was lesser as compared to other breeds such as Nicobari and Kadaknath. The lesser egg production observed in this breed was mostly due to the occurrence of higher broodiness behavior during peak egg production period (Naveen et al. 2021). The age at first egg (AFE) declined gradually, while egg production increased over the generations. This decline was mostly due to the increase in bodyweight as AFE and bodyweight are negatively correlated. The AFE is a highly variable trait as it is influenced by the rearing environment, feeding, season, etc. Overall, AFE was lesser than that reported in other indigenous breeds of chicken such as Nicobari (Chatterjee and Yadav 2008), Aseel (Rajkumar et al. 2017), and Kadaknath (Haunshi et al. 2012). Egg weights recorded at different ages have increased particularly in recent generations, and this increase was mostly due to increase in bodyweight as they are positively correlated. The egg weights of Ghagus were higher than those of Kadaknath and Nicobari breeds but comparable to that of the Aseel breed (Haunshi et al. 2011; 2021; Dalal et al. 2022). The 72-week egg production recorded in the eighth generation was almost similar to that observed during the fifth generation.

The findings of higher estimates of heritability for growth traits observed in two different generations indicated that there is enough genetic variation in the Ghagus population and that this breed could be further improved for the bodyweight at the juvenile stage. The higher estimates of heritability were also observed in other indigenous breeds such as Aseel and Kadaknath (Haunshi et al. 2012, 2021; Dalal et al. 2022). The higher genetic correlation observed between bodyweight and shank length would lead to improvement in shank length as indirect response to selection for higher bodyweight, and this would be helpful for faster movement of birds to escape from predators in the free-range or backyard systems of rearing. The findings of positive correlations of growth traits with 40-week egg production are due to the fact that the higher the bodyweight during the growing stage, the lower will be the AFE. The lower AFE leads to increase in egg numbers. Previous studies also reported the positive correlations between bodyweights (juvenile or grower) and egg production. The correlations of juvenile bodyweight with 40-week egg production in Ethiopian Horro chickens (Dana et al. 2011), bodyweight (4 and 16 weeks) with 40- and 56-week egg production in two lines of White Leghorn (Reddy et al. 2001), bodyweight (12 and 16 weeks) with 40-week egg production in Aseel (Dalal et al. 2022), and between juvenile growth traits and egg production in *Vanashree* (Haunshi et al. 2021) were positive. It was reported that early growth was negatively correlated with AFE in the Thai native chickens and that lesser AFE will lead to enhancement of both growth and egg production (Tongsiri et al. 2020). The correlation observed between shank length and egg production was an indirect correlation as bodyweights and shank lengths are highly correlated genetically. This phenomenon of positive correlation observed between bodyweights and egg production may not be true in all the chicken breeds or lines, but it may mostly be seen in slow growing birds like IC with lesser to moderate egg production potential. Therefore, this positive association between bodyweights and egg numbers could be exploited for the improvement of IC for both growth and egg production simultaneously.

Slaughter study at 20 weeks revealed that dressing percentage was somewhat lesser. A study of cut-up parts revealed a higher proportion of legs followed by neck and back, breast, wings, and finally giblets. The trend was similar for carcass traits at 24 weeks of age. However, the dressing percentage and cut-up parts percentage were higher at 24 weeks. This shows that musculoskeletal growth of IC continues to occur even after 20 weeks of age and hence the ideal marketing age of IC could be higher than 20 weeks. The Ghagus birds had lean meat with lesser abdominal fat. Most of the carcass traits of Ghagus were comparable to those of the Aseel (Rajkumar et al. 2016). Redness and yellowness of breast and thigh muscles of the Ghagus breed were higher than the Aseel breed (Devatkal et al. 2018). However, the lightness of the respective muscles of the Ghagus breed was lower than that of the Aseel breed (Rajkumar et al. 2016; Devatkal et al. 2018). The higher redness of meat indicates the higher myoglobin content (Wideman et al. 2016). Slow-growing IC breeds tend to have more redness as compared to broiler meat, and hence, meat of IC appears more appealing to the consumers (Rajkumar et al. 2016; Devatkal et al. 2018). Protein content was higher, while fat content was lesser than the Aseel breed with comparable moisture content (Rajkumar et al. 2017; Devatkal et al. 2018). Higher myofibrillar fragmentation index indicates the tenderness of muscles, and it was significantly higher in breast muscles. This parameter is strongly associated (negatively) with the shear force value. Other meat quality characteristics (pH, water holding capacity, and shear force value) were comparable to those of Aseel chickens (Devatkal et al. 2018). Overall, the meat quality characteristics of Ghagus were on par with the other indigenous chickens.

The study described the performance of Ghagus, an indigenous chicken breed of India with respect to growth, production, reproduction performance over nine generations. The growth and production performance of Ghagus can be improved through selective breeding as there is sufficient genetic variability in the population. The reproduction performance of Ghagus is better as it has shown consistently better fertility and hatchability over the generations. The slaughter and meat quality study revealed that this breed has lean meat, high protein with attractive meat color (redness and yellowness). Therefore, there is a scope for further improvement of Ghagus as a meat type chicken breed for rearing at the backyard, free-range, and intensive or semi-intensive production systems to meet the ever-increasing demand for indigenous chickens' meat in the country.

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Author contribution All the authors have contributed in conceptualization and design of the study. Santosh Haunshi executed the work and wrote the first draft of the paper. Ullengala Rajkumar helped in collection of data on growth and production traits. Leslie Leo Prince helped in collection of data on reproduction traits, statistical analysis, and interpretation of the results. Kandeepan Gurunathan and Suresh Devatkal collected the data on carcass and meat quality traits. TRK helped in healthcare of experimental birds. RNC edited the manuscript. All authors read and approved the final draft of the manuscript.

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Data availability The data of the study are available from the corresponding author.

Declarations

Disclosure Authors have no conflict of interest to declare.

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