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Performance of different strains of white leghorn layers

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Abstract

An essential tool for the formulation and assessment of selection programmes is the estimation of genetic parameters for performance traits. According to the findings of several studies, it is essential to identify and make use of birds with higher genetic potential. In order to estimate the least square mean and standard error, heritability, and genetic and phenotypic correlations for a variety of traits, including body weight at 20 weeks (BW_{20}) and 40 weeks (BW_{40}) and age at first egg (AFE), total eggs produced up to 40 weeks of age (EN_{40}), egg weight at 40 weeks (EW_{40}), and total egg mass produced up to 40 weeks of age (EM_{40}). Some researchers reported a high value, but others reported a heritability value that was between low and moderate. The inconsistent results may be due to variations in the strains, lines, and makeup of birds utilised in the estimation procedures as well as variations in the techniques and software used to estimate genetic parameters. Planning effective breeding programmes in animal husbandry requires an understanding of genetic and phenotypic characteristics. Animal geneticists can decide whether or not a specific characteristic can be enhanced by selection, by changing management practises, or by both methods based on their heritability estimates. Egg production efficiency has increased as a result of successful selection for performance traits. Since farmers are incharge of poultry farms, which has a tiny, scattered population and minimal pedigree history, the performance testing, selection, and breeding programmes have not been carried out throughout time. Because of changes in management, a growth in the number of flocks, and an increase in flock size, estimation of phenotypic and genetic performance over time is required. For reliable genetic evaluation and the development of breeding objectives, more precise estimates of genetic parameters are needed, particularly heritability, phenotypic and genetic correlations between economic traits.

Keywords: White leghorn layers, genetic parameters, AFE

Introduction

Poultry is one of the agricultural sectors in India that is expanding most rapidly, holding a significant position with an annual growth rate of more than 14%, contributing million tonnes or 3.6% of the world's egg production, with an annual growth rate of 6-7% (Anonyms, 2020) [2]. Poultry industry contributes about Rs. 125 trillion accounting for about 1% of the national GDP and 14% of the livestock GDP. India accounts for about 7% of global egg production and stands 3rd in egg production while ranks 5th in case of poultry production (FAOSTAT, 2022) [15]. The population of poultry in India was 851.81 million with an increase of 16.8% over the previous census. Total backyard poultry was 317.07 million in 2019 with an increase of 45.78%, whereas, total commercial poultry was 534.74 million in 2019 with an increase of 4.5% (20th Livestock Census, 2019). In India, egg production is around 129.60 billion during 2021-22 and the egg production has shown positive growth as 6.19% during 2021-22. Per-capita availability of egg was 95 eggs/year/person (BAHS, 2022-23), against the recommendations of 182 eggs/year/person by Indian Council of Medical Research (ICMR). However, there is a significant supply-demand gap in India that might be closed by genetic improvement in layer birds production through selection. A well-known method for raising both genetic potential and productivity is selective breeding (Sharma and Chatterjee, 2006) [32].

India is home to 19 registered breeds of chicken (NBAGR, 2023) [24] and almost all breeds are dual purpose and has less production as compared to commercial layers. The synthetic strain of White Leghorn has undergone long-term selection for many generations on the basis of egg production and is being maintained at different poultry farms for development of egg type strain which is suited to agro-climatic conditions of different geographical areas. White Leghorn chicken strain plays a vital role in achieving higher growth rate in egg production. As per fresh knowledge and demands have emerged, the selection and breeding strategy for poultry has evolved. In poultry breeding, the idea of two, three or four-way crossings helps to produce high-yielding contemporary strains of layer and broiler chickens. The need for the creation of specialized sire and dam lines was drive by the negative correlations between production and reproduction traits (Chambers, 1990; Fairfull and Gowe, 1990) [9, 13]. A well-known method for improving both genetic potential and productivity is selective breeding (Falconer and Mackay, 1996) [14]. Access to genetic diversity and techniques for utilising it, are necessary for genetic improvement. According to Thiruvenkadan *et al*. (2010) [35], a significant number of economic traits of egg-type chicken have been taken to carry selection procedure, making improvement in poultry production (Chatterjee and Bhattacharya, 2008) [10].

To evaluate the population under selection in each generation, estimation of genetic parameters like heritability, genetic correlations, and phenotypic correlations is essential. Not only the genetic parameters of a population used to predict response, but they are also the foundation for future breeding and selection strategies. Estimates of the heritability of the traits for which a particular individual is chosen would determine the rate of genetic progress (Saxena and Kolluri, 2018) [31]. Genetic makeup varies from population to population, and no two populations can have the same environment. As a result, estimates of heritability for the same traits will inevitably vary between groups and generations. Therefore, it would be desirable to calculate the heritability of different economic traits in the population where the breeding programme will be implemented. More than one economic trait influences the economic value of poultry-based products, and the market forecasts simultaneous improvement in most of them. Given that numerous poultry production traits are known to be correlated with one another, these correlations may be advantageous or disadvantageous. It is of the utmost importance to understand how the development of a particular trait affects the development of another.

White Leghorn chicken and its strains

The development of location-specific chicken varieties, their maintenance, enhancement, and characterization are the primary goals of the development of different strains of White leghorn chicken strain. The use of elite layer germplasm, as well as the creation of best practices at village level is very important for disseminating the new technologies to the poultry farmers. At the ICAR - Directorate on Poultry Research, Hyderabad, two pedigreed random bred control populations - one for layers and the other for broilers, were kept. To track the genetic response and development, samples of hatching eggs from these populations are being delivered to several AICRP centers for poultry breeding. White Leghorn lines (IWN, IWP, IWF, and IWD) strains have been examined by the Anand Centre, and these strains are currently being kept and will continue to be maintained. The ICAR-DPR in Hyderabad is keeping and managing IWH, IWI, IWD, IWF, and IWK strains. IWD and IWK in Anand and M-1 and M-2 in Jabalpur are the strains that are being developed at various AICRP facilities. Since IWN and IWP have been considered to be the most promising lines and are kept for use.

Review

In many selection programmes to create high yielding breeds, genetic improvement of a variety of traits in layers is essential. To create efficient breeding plans for enhancing the economic qualities through selection, it is necessary to have a fundamental understanding of genetic parameters including heritability, genetic correlation, and phenotypic correlation. Changes in heritability estimates make it simple to quantify the genetic change brought about by selection. It's necessary to understand how changing one character affects other characters which are undergoing change at the same time. Since these estimates differ from population to population and over time, it is preferable to acquire the estimates of genetic and phenotypic parameters for each population, every generation, and for various strains or lines.

Mean values, heritability estimates, genetic and phenotypic correlations of various traits

The level of performance of a population must be known before deciding the selection programme to set and achieve the goal. The changes in phenotypic means of a selected trait are first observable effect of selection. The simplest way to observe the physical change in trait after selection is measured in the form of observed changes in means. The averages of the traits give an idea about the variations existing in the poultry population and the performance level of a population must be known before deciding the selection programme to achieve the goal.

One of the most essential elements of a metric character is heritability. It expresses the percentage of the overall variance that can be attributed to the average effect of genes, which decides how similar two relatives are. However, the predictive role that heritability plays in the genetic analysis of metric features expresses the accuracy of the phenotypic value as a guide to the breeding value. Individual's phenotypic values are the only ones that can be accurately evaluated, but the breeding value determines how much of an impact they have on subsequent generations. It is most often used to describe the amount of superiority of parents above their counterparts for a given trait, which on an average is passed onto the offspring. Heritability estimates are essential to plan breeding system, to predict response to selection and genetic evaluation of selection programmes. A high estimates of heritability indicates the existence of sufficient amount of additive genetic variance which can be exploited through individual selection, where as a low estimates may suggest the use of some form of family selection or progeny testing or both. Heritability estimates are of value because they are estimates of the proportion of phenotypic variances that is additively genetic and thus serve as an indication of the rate of improvement that might be realized by selection. The heritability estimates are necessary to the breeder for planning the selection programme, predicting the response to selection and for genetic evaluation of selection programmes.

The phenotypic correlation is a relationship between two characters that can be observed directly, whereas the genetic correlation is an association between the breeding values of two characters (Falconer and Mackay, 1996) [14]. The direction and magnitude of the correlations between the traits are usefully revealed by the genetic and phenotypic correlation between different economic traits. This information is very crucial for selection and breeding programmes because it can help breeders and farmers make better selection. The phenotypic correlation results from the combination of the genetic and environmental factors of correlation. When both characters have low heritability, environmental correlation plays a major role in determining the phenotypic correlation; however, when both characters have high heritability, genetic correlation takes preference (Falconer and Mackay, 1996) [14].

1. Body Weight (BW_{20})

A pullet's body weight is a measure of its cumulative growth as well as an indicator of its genetic make-up and capacity for environmental adaptation. The effective growth is a requirement for the bird's future performance. It is directly related to the production of eggs, the weight of the eggs, reproduction, livability, and feed efficiency. The ideal body weight for egg production is difficult to determine, however the trait used to choose the pullet for more egg production is body weight at the time of hatching. Therefore, it is necessary that the pullets reach its ideal body weight during the initial stage of growth.

Mean value of body weight at 20 weeks of age ranged from 884.61 g (Karuppasamy *et al.*, 2018) [18] to 1412.25 g (Tomar *et al.*, 2015) [37].

Heritability of BW_{20} ranged from 0.16±0.08 (Jayalaxmi *et al.*, (2010) [17] in IWK strain to 0.98±0.23 (Ahmad and Singh, 2007 and Barot *et al.*, 2008) [3, 6] in layer strain and IWP strain.

The genetic correlation of BW_{20} with BW_{40}, AFE, EN_{40}, EW_{40} and EM_{40} ranged from 0.62±0.23 (Jayalaxmi *et al.*, 2010) [17] in IWK to 0.96±0.07 (Qadari *et al*., 2013) [28] in IWP strain, -0.54±0.27 (Barot *et al*., 2008) [6] in IWP to 0.42±0.25 (Barot *et al*., 2008) [6] in IWP, -0.56±0.25 (Barot *et al*., 2008) [6] in IWP to 0.59±0.13 (Bais *et al*., 2008) [5] in IWI, 0.02±0.35 (Qadari *et al*., 2013) [28] in IWP to 0.82±0.12 (Barot *et al*., 2008) [6] in IWP and -0.26±0.28 (Qadari *et al*., 2013) [28] in IWP to 0.16±0.07 (Tomar *et al.*, 2014) [36] in WLH, respectively, whereas, the phenotypic correlation ranged from 0.27 (Jayalaxmi *et al.*, 2010) [17] in IWK to 0.77±0.01 (Tomar *et al.*, 2014) [36] in WLH, -0.31±0.02 (Manjeet *et al.*, 2018) [22] in WLH to 0.09 (Qadari *et al*., 2013) [28] in IWP, -0.11±0.05 (Barot *et al*., 2008) [6] in IWP to 0.27±0.05 (Barot *et al*., 2008) [6] in IWP, 0.07±0.05 (Barot *et al*., 2008) [6] in IWP to 0.34±0.05 (Barot *et al.*, 2008; Chaudhary *et al.*, 2009) [6, 11] in IWP, IWP and WLH strain and 0.01 (Qadari *et al*., 2013) [28] in IWP to 0.16±0.02 (Tomar *et al.*, 2014) [36] WLH, respectively.

2. Body Weight (BW_{40})

The body weight at 40 weeks (BW_{40}) of a bird is an important trait, and it indicates its genetic constitution concerning the specific environment and its adaptability to that environment. It depends mainly on the hatching weight of chicks. Generally, heavier breeds of chicken have faster growth rates up to the marketing age in comparison to lighter chicken breeds. Within a particular chicken breed, BW_{40} in flocks may depend on many factors such as the genetic merit of breeder flocks, brooding conditions, the occurrence of diseases and feed quality.

Mean value of body weight at 40 weeks of age ranged from 1290.74 g (Sreenivas *et al*., 2012) [33] to 1688.79 g (Savaliya *et al.*, 2014) [30].

Heritability of BW_{40} ranged from 0.14±0.06 (Savaliya *et al.*, (2014) [30] in IWP strain to 0.74±0.20 (Ahmad and Singh, 2007 and Barot *et al.*, 2008) [3, 6] in layer strain and IWP strain.

The genetic correlation of BW_{40} with AFE, EN_{40}, EW_{40} and EM_{40} ranged from -0.23±0.84 (Jayalaxmi *et al.*, 2010) [17] in IWK to 0.59±0.18 (Barot *et al*., 2008) [6] in IWP, -0.66±0.18 (Savaliya *et al.*, 2014) in IWN to 0.19±0.22 (Qadari *et al.*, 2013) [28] in IWN, -0.14±0.19 (Veeramani *et al.*, 2008) [38] in WLH to 0.68±0.14 (Barot *et al*., 2008) [6] in IWP strain and -0.339±0.266 (Qadari *et al*., 2013) [28] in IWP to 0.21±0.23 (Qadari *et al*., 2013) [28] in IWN, respectively, whereas, the phenotypic correlation ranged from -0.26±0.02 (Manjeet *et al.*, 2018) [22] in WLH to 0.27±0.05 (Barot *et al*., 2008) [6] in IWP, -0.33±0.21 (Anees *et al.*, 2010) [4] in IWN to 0.05±0.02 (Veeramani *et al.*, 2012) [38] in IWP, 0.01 (Sreenivas *et al*., 2012) [33] in IWH to 0.45±0.04 (Barot *et al.*, 2008; Anees *et al.*, 2010) [6, 4] in IWP and IWN strain and -0.10 (Qadari *et al*., 2013) [28] in IWP to 0.21±0.02 (Manjeet *et al.*, 2018) [22] in WLH., respectively.

3. Age at First Egg (AFE)

Age at first egg reflects sexual maturity, a crucial feature in breeding programmes for layer birds. The type of breed, strain, nutritional state, management procedures, etc., all play an important role. Starting to lay eggs at the right age results in higher productivity in terms of egg number and egg weight. It's a significant economic feature that varies greatly as a result of both genetic and non-genetic factors.

The average age at first egg varied from 133.94 (Karuppasamy *et al.*, 2018) [18] to 178.15 days (Godara *et al.*, 2007) [16] in different White Leghorn chicken populations.

Heritability of AFE ranged from 0.01±0.10 (Sreenivas *et al*., 2012) [33] in IWK to 0.72±0.21 (Barot *et al*., 2008) [6] in IWP strain.

The genetic correlation of AFE with EN_{40}, EW_{40} and EM_{40} ranged from -1.01±0.15 (Qadari *et al*., 2013) [28] in IWN to -0.27±0.02 (Anees *et al*. 2010) [4] in IWN strain, -0.19±0.11 (Churchil *et al.*, 2019) [12] in IWN to 0.96±0.43 (Patil *et al.*, 2018) [27] in IWP and -1.02±0.18 (Qadari *et al*., 2013) [28] in IWN to -0.28±0.19 (Manjeet *et al.*, 2018) [22] in WLH, respectively, whereas, the corresponding phenotypic correlation ranged from -0.67±0.02 (Churchil *et al.*, 2019) [12] in IWN to 0.41±0.01 (Tomar, 2014) [36] in WLH, 0.03±0.01 (Godara *et al.*, 2007) [16] in WLH to 0.53±0.02 (Churchil *et al.*, 2019) [12] in IWN and -0.50 (Qadari *et al.*, 2013) [28] in IWN to -0.28±0.02 (Manjeet *et al.*, 2018) [22] in WLH., respectively.

4. Egg Number (EN_{40})

The most significant economic characteristic is egg production. According to studies, 80 percent of the variation in economic returns can be attributed to egg production. The number of eggs is given the most weightage in many breeding and selection procedures. It can be expressed in terms of the number of eggs produced over a specific time period or up to a certain age. Although annual egg production is the primary indicator used to assess a bird's production potential.

The egg number produced up-to 40 weeks of age varied from 74.14 (Tomar *et al.*, 2015) [37] to 129.90 (Karuppasamy *et al.*, 2018) [18] in different White Leghorn chicken populations.

Heritability of EN_{40} ranged from 0.02±0.03 (Savaliya *et al.*, 2014) [30] in IWP strain to 0.83±0.21 (Barot *et al.*, 2008) [6] in IWP strain.

The genetic correlation of EN_{40} with EW_{40} and EM_{40} ranged from -0.81±0.21 (Barot *et al.*, 2008; Sreenivas *et al.*, 2012) [6, 33] in IWP and IWK to 0.35±0.50 (Jayalaxmi *et al.*, 2010) [17] in IWK strain and 0.45±0.01 (Tomar *et al.*, 2014) [36] in WLH to 0.97±0.03 (Qadari *et al.*, 2013) [28] in IWN and IWP, respectively, whereas, the corresponding phenotypic correlation ranged from -0.49±0.20 (Anees *et al.*, 2010) [4] in IWN to 0.03 (Sreenivas *et al*., 2012) [33] in IWH and -0.92 (Qadari *et al*., 2013) [28] in IWN to 0.94±0.01 (Tomar, 2014) [36] in WLH.

Egg Weight (EW_{40})

In layer type chickens, egg weight is also a significant economic trait because it has a direct impact on egg marketability. Throughout the laying stage, desired egg weight is important. Therefore, egg weight is an integral trait in the selection of layer chickens. The egg weight laid by pullets is affected by a number of genetic and non-genetic factors. Breed/strain, dwarf gene, inbreeding, etc. are all genetic factors. Nutrition, ambient temperature, egg number in the clutch, management system, medications and chemicals, disease state, any break in laying such winter pause, broodiness, moulting, etc. are non-genetic factors that may affect egg weight (Niranjan *et al.*, 1994) [25]. The data on egg weights at various ages in various populations of layer chickens as reported by several research workers are presented in table 1.

Egg weight (g) at different ages ranged from 47.86 (Paleja *et al*., 2008) [26] to 59.86g (Rosa *et al*., 2018) [29] at 40 weeks of age.

Heritability of EW_{40} ranged from 0.07±0.03 (Anees *et al.*, 2010; Savaliya *et al.*, 2014) [4, 30] in IWN and IWP strain to 0.86±0.23 ((Ahmad and Singh, 2007 and Barot *et al.*, 2008) [3, 6] in layer strain and IWP strain.

The genetic correlation of EW_{40} with EM_{40} ranged from -0.43±0.37 (Qadari *et al*., 2013) [28] in IWP to 0.48±0.21 (Patil *et al.*, 2018) [27] in IWN strain respectively, whereas, the corresponding phenotypic correlation ranged from 0.16±0.02 (Tomar *et al.*, 2014) [36] in WLH to 0.53 (Patil *et al.*, 2018) [27] in IWN.

Egg Mass (EM_{40})

Both egg number and egg weight have an impact on the price and marketability of eggs. Therefore, in terms of economic activity, egg weight and egg number are equally significant. Since both of these traits are negatively correlated, it is challenging to improve both of them at the same time. To overcome this, the egg mass is taken into account, which is defined as the amount of egg material generated by the bird taking both egg weight and egg number into consideration. The data on the total egg mass produced in different WLH - layer chicken populations up to 40 weeks of age, as reported by several research workers, are shown in the table 1.

The amount of total egg mass (kg) produced upto 40 weeks of age in White Leghorn varied from 1.41 (Patil *et al.*, 2018) [27] to 6.07 kg (Paleja *et al.*, 2008) [26].

Heritability of EM_{40} ranged from 0.07±0.07 (Patil *et al.*, 2018) [27] in IWP strain to 0.39±0.12 (Qadari *et al*., 2013) [28] in IWN strain, respectively. All these estimates show that these range from low to medium high for all performance traits. While, Thangaraju and Ulaganathan (1990) [34] reported higher estimates of heritability for egg mass i.e. 0.80±0.183 in Forsgate strain and 0.68±0.166 in Meyer strain. Paleja *et al*., (2008) [26] reported heritability estimates for egg mass which ranged from 0.12±0.06 to 0.26±0.06.

Table 1: Averages of different performance traits with standard error in egg type chicken

BW_{20}(g)	BW_{40}(g)	AFE(d)	EN_{40}	EW_{40}(g)	EM_{40}(kg)	S/L/G	Author(s)
1174.00±11.55	-	151.90±0.51	84.50±0.76	54.68±0.15		H	Malik *et al.* (2005) [20]
1081.00±10.00	-	152.20±1.28	83.46±1.79	54.71±0.24		H×C	
1238.76	1510.55	150.39	90.31	54.67		Strain C	Narwal *et al.* (2005) [23]
-	-	147.13±0.37	108.56±0.52	-		-	Ahmad and Singh (2007) [3]
1093.27±3.66 to 1319.08±4.69	-	151.60±0.65to 178.15±0.53	63.96±0.65to 93.74±0.57	49.23±0.10to 52.53±0.13		Over5 Gen.	Godara *et al.* (2007) [16]
1040.50±2.24 to 1202.15±4.25	1326.57±11.43 to 1456.67±6.92	135.94±0.61to 157.45±0.31	88.67±0.67to 104.87±0.86	50.23±0.13to 52.82±0.11		IWH	Bais *et al.* (2008) [5]
1097.75±3.05 to 1189.42±5.56	1447.65±7.35 to 1555.22±8.78	148.42±0.50to 160.97±0.35	83.95±0.64to 94.61±0.80	50.12±0.18to 54.78±0.15		IWI	
1133.36±9.64 to 1214.75±11.32	1421.86±14.70 to 1514.09±14.64	150.00 to 159.52	93.58±0.93to 107.04±0.73	49.22±0.32to 53.27±0.35		WLH	Barot *et al.* (2008) [6]
	1651±1.00	137.55±0.04	121.21±0.02	54.01±0.02		IWP	Veeramani *et al.* (2008) [38]
1258.80±3.09	1450.44 to 1579.24	140.34 to 150.46	114.72 to 126.88	47.86 to 51.65	5.170 to 6.065	IWN	Paleja *et al.* (2008) [26]
1143.83±6.64	1410.95±8.12	143.45±0.43	102.39±0.73	54.23±0.17		IWK	Jayalaxmi *et al.* (2010) [17]
1168.68±5.88	1407.73±7.66	141.71±0.41	108.77±0.65	50.54±0.14		IWH	
	1563±0.9	151.38±0.09	102.81±0.09	54.04±0.02		IWN	Anees *et al.* (2010) [4]
-	1311.32±7.09	143.49±0.56	106.15±0.49	50.22±0.18		IWH	Sreenivas *et al.* (2012) [33]
-	1322.13±7.74	148.18±0.61	100.21±0.53	49.89±0.18		IWI	
-	1290.74±7.21	155.63±0.57	94.08±0.50	53.13±0.17		IWK	
-	1584±0.007	143.85±0.04	115.99±0.03	54.26±0.02		IWN	Veeramani *et al.* (2012) [38]
-	1651±0.02	137.55±0.04	121.21±0.02	54.01±0.02		IWP	
1249.18±4.41	1415.15±5.27	134.56±0.43	118.94±0.54	50.35±0.09	5.462±0.028	IWN	Qadari *et al.* (2013) [28]
1280.02±4.04	1486.23±5.18	137.90±0.42	114.97±0.58	52.47±0.10	5.447±0.032	IWP	
	1656.03±4.03	145.26±0.23	119.28±0.39	52.21±0.07		IWN strain	Savaliya *et al.* (2014) [30]
	1688.79±4.68	144.91±0.25	116.63±0.43	53.10±0.07		IWP strain	
1336.82±3.36	1568.64±3.68	149.77±0.21	80.85±0.32	50.87±0.07		Synthetic White Leghorn	Tomar *et al.* (2014) [36]

1246.52 to 1412.25	1485.65 to 1669.39	143.37 to 154.19	74.14 to 90.09	48.98 to 51.77	4.103±0.016	Synthetic White Leghorn	Tomar *et al.* (2015) [37]
884.61±10.52	1335.70±18.32	133.94±1.60	129.90±1.50	51.09±0.48		IWH	Karuppasamy *et al.* (2018) [18]
1196.81				59.86		WLH	Rosa *et al.* (2018) [29]
		141.73±0.47	123.64±0.58	48.26±0.17	1.487±0.010	IWN	Patil *et al.* (2018) [27]
		146.66±0.42	116.78±0.48	49.75±0.13	1.413±0.012	IWP	
	1560.47	154.24	110.67	54.54		IWN	Churchil *et al.* (2019) [12]
	1587.34	152.65	105.64	55.04		IWP	

Table 2: Heritability estimates for different performance traits in egg type chickens

H_2	BW20	BW40	AFE	EN40	EW40	EM_{40}	S/L/G	Author (s)
H_2	0.43±0.16 to 0.98±0.23	0.49±0.17 to 0.74±0.20	0.16±0.14	0.29±0.15	0.11±0.24 to 0.86±0.23		Over5 Gener.	Ahmad and Singh (2007) [3]
H_2	0.19±0.27 to 0.31±0.11	-	0.26±0.10 to 0.37±0.12	0.18±0.05 to 0.39±0.13	0.22±0.06 to 0.39±0.13		Over5 Gener.	Godara *et al.* (2007) [16]
H_2	-	-	0.07±0.03	-	-		IWH	Bais *et al.* (2008) [5]
H_2	-	-	0.12±0.04	-	-		IWI	
H_2	0.23±0.52	0.28±0.06	0.21±0.05	-	0.22±0.06		IWH	
H_2	0.35±0.08	0.36±0.08	0.32±0.07	-	0.14±0.07		IWI	
H_2	0.45±0.17	0.49±0.17	0.48±0.17	0.25±0.13	-		IWP (S_5)	Barot *et al.* (2008) [6]
H_2	0.68±0.20	0.62±0.19	0.72±0.21	0.21±0.12	0.86±0.23		IWP (S_6)	
H_2	0.98±0.23	0.74±0.20	0.35±0.15	0.36±0.15	0.71±0.20		IWP (S_7)	
H_2	0.68±0.19	0.72±0.20	0.33±0.14	0.35±0.15	0.63±0.19		IWP (S_8)	
H_2	0.43±0.16	0.57±0.18	0.48±0.17	0.83±0.21	0.55±0.18		IWP (S_9)	
H_2	0.44±0.12	0.57±0.13	0.42±0.11	0.23±0.08	0.49±0.12	0.18±0.08	IWN(S_3)	Paleja *et al.* (2008) [26]
H_2	0.23±0.08	0.72±0.15	0.47±0.11	0.13±0.06	0.68±0.14	0.12±0.06	IWN(S_4)	
H_2	0.39±0.08	0.66±0.12	0.15±0.05	0.43±0.09	0.43±0.09	0.27±0.07	IWN(S_5)	
H_2	0.34±0.09	0.44±0.10	0.37±0.09	0.28±0.08	0.25±0.07	0.17±0.06	IWN(S_6)	
H_2		0.45±0.12	0.32±0.09	0.26±0.07	0.48±0.13		IWP	Veeramani *et al.* (2008) [38]
H_2	0.78±0.15	0.23±0.08		0.62±0.16	0.42±0.10		Layer type chicken	Yahaya *et al.* (2009) [40]
H_2	0.31±0.09	0.36±0.09	0.18±0.08	0.09±0.07	0.42±0.09		IWH	Jayalaxmi *et al.* (2010) [17]
H_2	0.16±0.08	0.44±0.11	0.20±0.06	0.06±0.07	0.37±0.10		IWK	
H_2		0.65±0.16	0.20±0.06	0.35±0.09	0.07±0.03		IWN	Anees *et al.* (2010) [4]
H_2	-	0.25±0.15	0.14±0.11	0.05±0.10	0.11±0.02		IWH	Sreenivas *et al.* (2012) [33]
H_2	-	0.33±0.18	0.02±0.10	0.11±0.07	0.22±0.15		IWI	
H_2	-	0.41±0.21	0.01±0.10	0.13±0.07	0.12±0.03		IWK	
H_2	-	0.41±0.11	0.28±0.08	0.29±0.09	0.27±0.08		IWN	Veeramani *et al.* (2012) [38]
H_2	-	0.45±0.12	0.32±0.09	0.26±0.07	0.48±0.13		IWP	
H_2	-	0.31±0.12	0.48±0.13	0.54±0.14	0.19±0.09	0.39±0.12	IWN strain	Qadari *et al.* (2013) [29]
H_2	0.31±0.11	0.45±0.10	0.24±0.09	0.23±0.09	0.09±0.06	0.16±0.08	IWP strain	
H_2	-	0.32±0.08	0.21±0.07	0.18±0.06	0.09±0.05		IWN strain	Savaliya *et al.* (2014) [30]
H_2	-	0.14±0.06	0.10±0.06	0.02±0.03	0.07±0.05		IWP strain	
H_2	0.49±0.08	0.36±0.08	0.36±0.08	0.31±0.08	0.49±0.08	0.25±0.07	WLH	Tomar *et al.* (2014) [36]
H_2	0.45±0.13	0.42±0.12	0.28±0.08		0.43±0.12	0.32±0.11	Synthetic WLH	Manjeet *et al.* (2018) [22]
					0.42		WLH	Rosa *et al.* (2018) [29]
H_2			0.46±0.13	0.29±0.11		0.24±0.10	IWN	Patil *et al.* (2018) [27]
H_2			0.18±0.09	0.12±0.08		0.07±0.07	IWP	
H_2		0.39±0.05	0.35±0.05	0.28±0.05			IWN	Churchil *et al.* (2019) [12]
H_2		0.29±0.05	0.09±0.03	0.24±0.04			IWP	

Table 3: Genetic and phenotypic correlations among various performance traits

S/L/Generation	Genetic Correlation (rg)	Phenotypic Correlation (rp)	Author(s)
(BW_{20} * BW_{40})			
IWK	0.62±0.23	0.27	Jayalaxmi *et al*. (2010) [17]
IWP	0.96±0.07	0.48	Qadari *et al*. (2013) [28]
White Leghorn	0.76±0.01	0.77±0.01	Tomar *et al*. (2014) [36]
(BW_{20} * AFE)			
WLH	0.10±0.12	0.01±0.01	Godara *et al*. (2007) [16]
IWP Gen.S5	0.11±0.29	-0.18±0.05	Barot *et al*. (2008) [6]
S6	-0.04±0.25	-0.19±0.05	
S7	-0.12±0.26	-0.15±0.05	
S8	0.42±0.25	0.07±0.05	
S9	-0.54±0.27	-0.26±0.05	
IWK	-0.21±1.14	-	Jayalaxmi *et al*. (2010) [17]
IWN	-	-0.01	Qadari *et al*. (2013) [38]
IWP	0.28±0.25	0.09	
White Leghorn	-0.33±0.06	-0.16±0.02	Tomar *et al*. (2014) [36]
WLH	-0.46±0.17	-0.31±.02	Manjeet *et al*. (2018) [22]
(BW_{20} * EN)			
WLH	0.22±0.12	0.11±0.01	Godara *et al*. (2007) [16]
Gen.S5	-0.41±0.30	0.26±0.05	Barot *et al*. (2008) [6]
S6	0.20±0.31	0.27±0.05	
S7	-0.24±0.24	0.11±0.05	
S8	-0.56±0.25	-0.11±0.05	
S9	0.14±0.24	0.22±0.05	
IWH	-0.03±0.17	-	Bais *et al*. (2008) [5]
IWI	0.59±0.13	-	
WLH	0.51	0.02	Yahaya *et al*. (2009) [40]
IWK	0.10±0.60	0.18	Jayalaxmi *et al*. (2010) [17]
IWP	-0.26±0.25	0.01	Qadari *et al*. (2013) [28]
IWN	-	0.07	
White Leghorn	0.07±0.07	0.09±0.02	Tomar *et al*. (2014) [36]
(BW_{20} * EW)			
Gen.S5	0.49±0.19	0.34±0.05	Barot *et al*. (2008) [6]
S6	0.82±0.12	0.29±0.05	
S7	0.44±0.19	0.27±0.05	
S8	0.72±0.14	0.33±0.04	
S9	0.26±0.27	0.07±0.05	
WLH	0.65±0.06	0.34±0.03	Chaudhary *et al*. (2009) [11]
IWK	0.19±0.29	0.16	Jayalaxmi *et al*. (2010) [17]
IWN	-	0.12	Qadari *et al*. (2013) [28]
IWP	0.02±0.35	0.13	
White Leghorn	0.38±0.06	0.18±0.02	Tomar *et al*. (2014) [36]
WLH	0.09±0.18	0.11±0.02	Manjeet *et al*. (2018) [22]
(BW_{20} * EM)			
IWN	-	0.11	Qadari *et al*. (2013) [28]
IWP	-0.26±0.28	0.01	
WLH	0.16±0.07	0.16±0.02	Tomar *et al*. (2014) [36]
WLH	0.01±0.19	0.08±.02	Manjeet *et al*. (2018) [22]
(BW_{40} * AFE)			
Gen.S5	0.50±0.23	0.17±0.05	Barot *et al*. (2008) [6]
S6	0.59±0.18	0.27±0.05	
S7	0.04±0.27	0.23±0.05	
S8	0.39±0.24	0.15±0.05	
S9	0.28±0.25	0.10±0.05	
WLH	0.10±0.19	0.03±0.02	Veeramani *et al*. (2008) [38]
IWK	-0.23±0.84	0.03	Jayalaxmi *et al*. (2010) [17]
IWN	-0.04±0.02	0.14±0.19	Anees *et al*. (2010) [4]
IWI	0.54±0.27	0.07	Sreenivas *et al*. (2012) [33]
IWK	0.33±0.16	0.00	
IWN	0.34±0.10	0.12±0.02	Veeramani *et al*. (2012) [38]
IWP	0.09±0.13	0.03±0.02	
IWN	-0.15±0.22	0.09	Qadari *et al*. (2013) [28]
IWP	0.49±0.20	0.21	
IWN	0.48±0.18	0.09	Savaliya *et al*. (2014) [30]

IWP	0.48±0.18	0.02	
White Leghorn	-0.12±0.07	-0.06±0.02	Tomar *et al.* (2014) [36]
WLH	-0.17±0.18	-0.26±0.02	Manjeet *et al.* (2018) [22]
IWN	-0.01±0.01	-0.11±0.02	Churchil *et al.* (2019) [12]
IWP	0.27±0.17	0.07±0.02	
(BW_{40} * EN)			
IWH	-0.16±0.15	-	Bais *et al.* (2008) [5]
IWI	-0.36±0.08	-	
Over5 Gener.	-0.19±0.27 to -0.63±0.24	-0.02±0.05 to-0.19±0.05	Barot *et al.* (2008) [6]
WLH	-0.08±0.20	-0.05±0.02	Veeramani *et al.* (2008) [38]
WLH	0.68	0.20	Yahaya *et al.* (2009) [40]
WLH	-0.56±0.09	0.04±0.03	Chaudhary *et al.* (2009) [11]
IWN	-0.14±0.02	-0.33±0.21	Anees *et al.* (2010) [4]
IWK	-0.50	-0.06	Jayalaxmi *et al.* (2010) [17]
IWH	-	0.03	Sreenivas *et al.* (2012) [33]
IWI	-0.09±0.41	0.03	
IWK	-0.22±0.48	-0.01	
IWN	-0.12±0.11	0.03±0.02	Veeramani *et al.* (2012) [38]
IWP	-0.14±0.13	0.05±0.02	
IWN	0.19±0.22	0.03	Qadari *et al.* (2013) [28]
IWP	-0.32±0.24	-0.10	
White Leghorn	-0.27±0.06	0.02±0.02	Tomar *et al.* (2014) [36]
IWN	-0.66±0.18	-0.10	Savaliya *et al.* (2014) [30]
IWP	-0.28±0.73	-0.02	
IWN	-0.05±0.12	-0.11±0.02	Churchil *et al.* (2019) [12]
IWP	-0.05±0.13	-0.05±0.02	
(BW_{40} * EW)			
Gen.S5	0.68±0.14	0.45±0.04	Barot *et al.* (2008) [6]
S6	0.41±0.22	0.34±0.05	
S7	0.46±0.19	0.26±0.05	
S8	0.46±0.19	0.31±0.04	
S9	0.50±0.21	0.25±0.05	
WLH	-0.14±0.19	0.08±0.02	Veeramani *et al.* (2008) [39]
IWN	0.23±0.02	0.45±0.15	Anees *et al.* (2010) [4]
IWK	0.45±0.19	0.21	Jayalaxmi *et al.* (2010) [17]
IWH	0.49±0.32	0.01	Sreenivas *et al.* (2012) [33]
IWI	0.63±0.20	0.09	
IWK	0.47±0.66	0.14	
IWN	0.27±0.11	0.22±0.02	Veeramani *et al.* (2012) [38]
IWP	-0.01±0.12	0.08±0.02	
IWN	0.01±0.28	0.26	Qadari *et al.* (2013) [28]
IWP	0.06±0.32	0.16	
White Leghorn	0.51±0.05	0.24±0.02	Tomar *et al.* (2014) [36]
IWN	0.36±0.24	0.09	Savaliya *et al.* (2014) [30]
IWP	0.18±0.37	0.07	
WLH	0.40±0.15	0.16±0.02	Manjeet *et al.* (2018) [22]
IWN	0.37±0.10	0.31±0.02	Churchil *et al.* (2019) [12]
IWP	0.43±0.10	0.14±0.02	
(BW_{40} * EM)			
IWN	0.21±0.23	0.13	Qadari *et al.* (2013) [28]
IWP	-0.34±0.27	-0.10	
WLH	0.12±0.07	0.08±0.02	Tomar *et al.* (2014) [36]
WLH	0.14±0.18	0.21±0.02	Manjeet *et al.* (2018) [22]
(AFE * EN)			
WLH	-0.28±0.12	-0.24±0.01	Godara *et al.* (2007) [16]
WLH	-1.05±0.05	-0.62±0.03	Ahmad and Singh (2007) [3]
IWH	-0.86±0.07	-	Bais *et al.* (2008) [5]
Gen.S5	-0.65±0.39	-0.48±0.04	Barot *et al.* (2008) [6]
S6	-0.32±0.34	-0.45±0.04	
S7	-0.46±0.34	-0.42±0.04	
S8	-0.62±0.38	-0.56±0.04	
S9	-0.85±0.23	-0.57±0.04	
IWN	-0.81±0.07	-0.41±0.02	Veeramani *et al.* (2008) [39]
IWN	-0.27±0.02	-0.51±0.20	Anees *et al.* (2010) [4]
IWK	-0.73±2.23	-0.14	Jayalaxmi *et al.* (2010) [17]
IWH	-0.65±0.51	-0.22	Sreenivas *et al.* (2012) [33]

IWI	-	-0.29	
IWK	-0.36±0.34	-0.31	
IWN	-0.81±0.04	-0.47±0.02	Veeramani *et al.* (2012) [38]
IWP	-0.44±0.13	-0.41±0.02	
IWN	-1.01±0.15	-0.59	Qadari *et al.* (2013) [28]
IWP	-0.68±0.33	-0.50	
White Leghorn	-0.33±0.04	0.41±0.01	Tomar *et al.* (2014) [36]
IWN	-0.88±0.21	-0.58	Savaliya *et al.* (2014) [30]
IWP	-0.88±0.21	-0.52	
IWN		-0.472	Patil *et al.* (2018) [27]
IWP	-0.98±0.58	-0.50	
IWN	-0.83±0.12	-0.67±0.02	Churchil *et al.* (2019) [12]
IWP	-0.84±0.20	-0.48±0.02	
(AFE * EW)			
WLH	0.03±0.12	0.03±0.01	Godara *et al.* (2007) [16]
Gen.S5	0.57±0.19	0.07±0.05	Barot *et al.* (2008) [6]
S6	0.05±0.24	0.13±0.05	
S7	0.13±0.27	0.09±-0.05	
S8	0.08±0.27	0.05±0.05	
S9	0.61±0.21	0.15±0.05	
WLH	0.11±0.19	0.03±0.02	Veeramani *et al.* (2008) [38]
IWN	0.09±0.02	0.12±0.21	Anees *et al.* (2010) [4]
IWK	0.42±1.010	0.03	Laxmi *et al.* (2010) [17]
IWH	0.25±0.48	0.03	Sreenivas *et al.* (2012) [33]
IWI	0.31±0.47	0.08	
IWK	0.76±0.18	0.02	
IWN	0.25±0.12	0.12±0.02	Veeramani *et al.* (2012) [38]
IWP	0.10±0.13	0.03±0.02	
IWN	0.35±0.23	0.17	Qadari *et al.* (2013) [28]
IWP	0.56±0.34	0.12	
IWN	0.27±0.28	0.04	Savaliya *et al.* (2014) [30]
IWP	0.27±0.28	0.03	
White Leghorn	0.32±0.06	0.13±0.02	Tomar *et al.* (2014) [36]
WLH	0.50±0.15	0.10±0.02	Manjeet *et al.* (2018) [22]
IWN	-0.09±0.24	0.11	Patil *et al.* (2018) [27]
IWP	0.96±0.43	0.05	
IWN	-0.19±0.11	0.5±0.02	Churchil *et al.* (2019) [12]
IWP	0.21±0.15	0.05±0.02	
(AFE * EM)			
IWN	-1.02±0.17	-0.49	Qadari *et al.* (2013) [28]
IWP	-0.61±0.37	-0.44	
WLH	-0.49±0.05	-0.36±0.02	Tomar *et al.* (2014) [36]
WLH	-0.28±0.19	-0.28±0.02	Manjeet *et al.* (2018) [22]
IWN	–	-0.33	Patil *et al.* (2018) [27]
IWP	-0.42±0.61	-0.39	
(EN * EW)			
WLH	-0.18±0.01	-0.42±0.11	Godara *et al.* (2007) [16]
IWH	0.34±0.20	-	Bais *et al.* (2008) [5]
IWI	-0.62±0.12	-	
Gen.S5	-0.62±0.26	-0.03±0.05	Barot *et al.* (2008) [6]
S6	-0.27±0.30	-0.25±0.05	
S7	-0.32±0.23	-0.06±0.05	
S8	-0.50±0.26	-0.18±0.05	
S9	-0.81±0.20	-0.28±0.05	
WLH	-0.31±0.18	-0.01±0.02	Veeramani *et al.* (2008) [38]
IWN	0.20±0.02	-0.49±0.20	Anees *et al.* (2010) [4]
IWK	0.35±0.50	-0.03	Jayalaxmi *et al.* (2010) [17]
IWH	-0.14±0.49	0.03	Sreenivas *et al.* (2012) [33]
IWI	-0.38±0.49	-0.04	
IWK	-0.81±0.21	-0.13	
IWN	-0.27±0.11	-0.16±0.02	Veeramani *et al.* (2012) [38]
IWP	-0.24±0.13	-0.10±0.02	
IWN	0.19±0.22	0.02	Qadari *et al.* (2013) [28]
IWP	-0.32±0.24	-0.17	
White Leghorn	-0.27±0.06	0.01±0.02	Tomar *et al.* (2014) [36]
IWN	-0.66±0.18	-0.10	Savaliya *et al.* (2014) [30]

IWP	-0.28±0.73	-0.02	
IWN	-0.29±0.26	-0.08	Patil *et al.* (2018) [27]
IWP	-0.52±0.49	0.01	
IWN	-0.45±0.11	-0.18±0.02	Churchil *et al.* (2019) [12]
IWP	-0.02±0.12	-0.07±0.02	
(EN * EM)			
IWN	0.97±0.02	0.92	Qadari *et al.* (2013) [28]
IWP	0.97±0.03	-0.92	
WLH	0.45±0.01	0.94±0.01	Tomar *et al.* (2014) [36]
IWN	0.70±0.14	0.80	Patil *et al.* (2018) [27]
IWP	0.78±0.21	0.82	
(EW * EM)			
IWN	-0.29±0.25	0.30	Qadari *et al.* (2013) [28]
IWP	-0.43±0.37	0.27	
WLH	0.10±0.07	0.16±0.02	Tomar *et al.* (2014) [36]
WLH	0.04±0.20	0.25±0.02	Manjeet *et al.* (2018) [22]
IWN	0.48±0.21	0.53	Patil *et al.* (2018) [27]

Conclusion

The poultry industry in India, particularly the sector focusing on White Leghorn chicken strains, underscores the critical role of genetic improvement through selective breeding. With significant contributions to egg production and economic output, this industry faces challenges such as meeting the demand-supply gap and optimizing genetic potential across various economic traits like body weight, age at first egg, egg number, egg weight, and egg mass. Understanding genetic parameters such as heritability, genetic, and phenotypic correlations is essential for formulating effective breeding strategies. Continued research and development in genetic selection methodologies are crucial for sustaining and enhancing the productivity and profitability of India's poultry sector amidst evolving market demands and environmental conditions.

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