GENETIC EVALUATION OF GROWTH AND PRODUCTION TRAITS IN IWI LAYER LINE USING ANIMAL MODEL

BY

BEERAM SPANDANA

ID No. RVM/2018-14

THESIS SUBMITTED TO

P.V. NARSIMHA RAO TELANGANA VETERINARY UNIVERSITY

IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE OF

MASTER OF VETERINARY SCIENCE

(ANIMAL GENETICS AND BREEDING)

IN THE FACULTY OF VETERINARY SCIENCE

DEPARTMENT OF ANIMAL GENETICS AND BREEDING

COLLEGE OF VETERINARY SCIENCE

P.V. NARSIMHA RAO TELANGANA VETERINARY UNIVERSITY

RAJENDRANAGAR, HYDERABAD-500 030

MARCH, 2022

\

CERTIFICATE

This is to certify that **Mrs. BEERAM SPANDANA (RVM/2018-14)** has satisfactorily prosecuted the course of research and that the thesis entitled **"GENETIC EVALUATION OF GROWTH AND PRODUCTION TRAITS IN IWI LAYER LINE USING ANIMAL MODEL"** submitted is the result of original work done and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part there of has not been previously submitted by him for a degree of any University.

Date: 26·3·2022

Place: Hyderabad

(Dr. D.SAKARAM)

Chairman of the Advisory committee

CERTIFICATE

This is to certify that the thesis entitled **"GENETIC EVALUATION OF GROWTH AND PRODUCTION TRAITS IN IWI LAYER LINE USING ANIMAL MODEL"** submitted in partial fulfillment of the requirements for the degree of **Master of Veterinary Science** of **P. V. Narsimha Rao Telangana Veterinary University** is a record of *bona fide* research work carried out by **Mrs. BEERAM SPANDANA (RVM/2018-14)** under our guidance and supervision. The subject of thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part has been fully acknowledged. All assistance and help received during the course of investigations have been duly acknowledged by the author.

The final *Viva Voce* examination was held on 26-3-2022 and the thesis is approved by the student advisory committee.

Dr. D. SAKARAM Professor & Head Dept. of Animal Genetics and Breeding, College of Veterinary Science, Rajendranagar, Hyderabad-30	Chairperson	(signed)
Dr. S. SAI REDDY Assoc. Professor Officer in charge & Head Poultry Research Station, Rjendranagar, Hyderabad-30.	Member	(signed)
Dr. N. RAJANNA Professor &Head Dept. of LPM College of Veterinary Science, Mamnoor, Warangal.	Member	(signed)
Dr. L. LESLIE LEO PRINCE Principal Scientist ICAR-DPR Rajendranagar, Hyderabad-30	Member	(signed)

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

%	: Percent
-ve	: Negative
>	: Greater than
<	: Less than
≤	: Less than or equal to
g	: Grams
h^2	: Heritability
h^2_S	: Heritability from sire component of variance
h^2_D	: Heritability from dam component of variance
h^2_{S+D}	: Heritability from sire + dam component of variance
d	: days
no.	: number
Gen.	: Generation
r_g	: Genetic correlation
r_p	: Phenotypic correlation
r_e	: Environmental correlation

DECLARATION

I, **BEERAM SPANADANA (RVM/2018-14)** hereby declare that the thesis entitled **"GENETIC EVALUATION OF GROWTH AND PRODUCTION TRAITS IN IWI LAYER LINE USING ANIMAL MODEL"** submitted to P.V. Narsimha RaoTelangana Veterinary University for the degree of **MASTER OF VETERINARY SCIENCE** is a result of original research work done by me. It is further declared that the thesis or any part thereof has not been submitted for any other degree or diploma.

Date: 26-3-2022

(BEERAM SPANDANA)

Place: Hyderabad

ACKNOWLEDGEMENTS

Because this may be my only opportunity to thank these individuals in writing, I may be a bit more verbose in my thanks than necessary.

I would like to express my deepest appreciation to all those who provided me the possibility to complete my research work and I extend my thanks to the ***P.V. Narsimha Rao Telangana Veterinary University*** *for providing necessary guidance and required facilities for the successful completion of my work.*

By the grace of the almighty, I was able to put all my humble efforts to fulfill the task assigned to me by the learned members of the Advisory Committee. I deem it as my privilege in expressing my fidelity to my major Advisor and Chairman of Advisory Committee, ***Dr. D.Sakaram,*** *Professor and Head, Department of Animal Genetics and Breeding, College of Veterinary Science, Rajendranagar, Hyderabad for his learned counsel, unstinted attention, arduous and meticulous guidance and constructive criticism to embellish the study, and who enabled me to do the best of my ability in the compilation of this thesis.*

I would like to express my sincere gratitude to ***Dr .L. Leslie Leo Prince,*** *Principal Scientist, ICAR-DPR, Rajendranagar, Hyderabad for guiding throughout the research, patience and motivation. His guidance helped me alwaysduring research.*

It gives me immense pleasure in extending my deep sense of gratitude to ***Dr. S. Sai Reddy,*** *Associate Professor and Head, Department of Animal Genetics and Breeding, College of Veterinary Science, Mamnoor, Warangal for his timely suggestions, motivation, constant encouragement and unfailing support throughout my PG study and through theprocess of researching.*

I am pleased to place my profound etiquette to ***Dr. N. Rajanna,*** *Professor, Department of Livestock Production and Management, College of Veterinary Science, Rajendranagar for his sumptuous suggestions, timely help and constant encouragement.*

I am very thankful to ***Dr. P.Jayalakshmi,*** *Professor, Department of Animal Genetics and Breeding, College of Veterinary Science, Rajendranagar, for constant help, valuable suggestions and guidance during my entire research.*

I wish to express my gratitude to ***Dr. B. Sridevi,*** *Assistant Professor for their valuable suggestions and encouragement during this study.*

I wish to express my gratitude to ***Dr. Sai Prasanna,*** *Assistant Professor for their valuable suggestions and encouragement during this study.*

I am grateful and express thanks to the honorable members of the Ethical Review Committee for giving kind approval to my research protocol.

I thank my seniors ***Dr. Rajith Reddy, Dr.Paramesh Dr.Tejasree, Dr.Narmada, Dr.Pragnya*** *and* ***Dr.Naresh Reddy,*** *my dear friends* ***Dr. Sriteja, Dr.Rachana, Dr. Jyothsna, Dr. Sandeep and my juniors Dr.Nagasree, Dr. Vasanthi and Dr. Suvarna*** *for their guidance and help during my work.*

I also express my sincere thanks to the ***Staff of Library*** *L. Atachamamba, Assistant Professor,* ***PG Academic section staff*** *Vijaya kumari and* ***Non-Teaching staff*** *of my department who assisted in carrying out my research trial smoothly in the laboratory, field and academics.*

It gives me immense pleasure to express my love and deep sense of honour to my beloved Husband ***Dr.Varna Sathosh Reddy*** *for his encouragement, co-operation and deep understanding and for helping me to reach the destiny.*

I would like to express my love to cute daughter ***Varna Niheera Reddy*** *for all the luck she brought to me.*

I would like to thank my parents Sri ***Beeram Srinivas Reddy*** *and Smt.****Rajithamma****, my brother* ***Sanjay Reddy****, my aunt Smt.* ***Renuka*** *and my brother in law* ***Varna Rakesh Reddy****, reflection of God Almighty for giving me endless love and unwavering support always and I thank all my well- wishers and request their pardon for not mentioning them here.*

(BEERAM SPANDANA)

Name of the author	:	**BEERAM SPANDANA**
Title of the thesis	:	**GENETIC EVALUATION OF GROWTH AND PRODUCTION TRAITS IN IWI LAYER LINE USING ANIMAL MODEL**
Degree to which it is submitted	:	**MASTER OF VETERINARY SCIENCE**
Faculty	:	**VETERINARY SCIENCE**
Department	:	**ANIMAL GENETICS AND BREEDING**
Major advisor	:	**Dr. D. SAKARAM**
University	:	**P.V. NARSIMHA RAO TELANGANA VETERINARY UNIVERSITY**
Year	:	**2022**

ABSTRACT

The study was carried out to analyse the performance data of four generations of IWI layer line of White Leghorn and it was found that the significant generation differences were observed in all the traits under study *viz*., body weight at 0 day, 4, 8, 16, 20 and 40 weeks of age, age at sexual maturity, egg production up to 40, 52 and 64 weeks of age and egg weights at 28, 40, 52 and 64 weeks of age. The overall Least Square Means computed were 33.74±0.06, 974.38±3.95, 1114.55±3.50 and 1372.76±5.19 grams respectively for body weights at 0 day, 16, 20 and 40 weeks of age. The mean for age at sexual maturity was 143.69±0.263 days. The means for egg production up to 40, 52 and 64 weeks were 115.02±0.61, 186±0.98 and 250.25±1.20 eggs respectively. The mean egg weights at 28, 40, 52 and 64 weeks of age were 46.34±0.10, 50.98±0.12, 53.17±0.15 and 55.21± 0.18 grams respectively.

Variance and covariance components were estimated by average information restricted maximum likelihood (AIREML) fitting an animal model. Low to moderate heritability values were observed for body weight traits. Age at sexual maturity was also found to be moderately heritable. The heritability estimates for egg production up to 40, 52 and 64 weeks of age were 0.15±0.03, 0.16±0.07 and 0.15±0.04 respectively. Egg weights at early ages showed low heritability values whereas moderate heritability values were observed for egg weights at later ages.

Body weight traits under study showed a moderate to high positive genetic and phenotypic correlation with each other. Age at sexual maturity showed a negative correlation of varying magnitude with egg production and egg weight traits. Egg production traits as well as egg weight traits showed a positive correlation of high magnitude among themselves whereas a negative association was observed between egg production and egg weights at different ages.

The graph plotted with average breeding values against generation was increasing linearly for body weights at 8, 16 weeks of age and the egg production traits under study. Egg weight at 28 and 40 weeks of age decreased with fluctuations over generations.

INTRODUCTION

CHAPTER I

INTRODUCTION

The poultry sector in India has undergone a paradigm shift in structure and operation. A significant feature of India's poultry industry is its transformation from a mere backyard activity into a major commercial activity in just about four decades. Poultry farming occupies a pivotal position in bringing about rapid economic growth and is the fastest growing subsector in Indian agriculture.

Today the farmer needs birds which lay more eggs with optimum egg size and the least feed consumption. The Layer industry in India witnessed a phenomenal growth in last two decades due the challenging performance of White Leghorn breed. White Leghorn is the main promising breed of layer industry well known for its egg production and is the only breed contributing more than 90 per cent to the Indian layer industry. The genetic improvement in White Leghorn is paving the way for exploiting the production potential of this breed.

Selective breeding is a well-known tool for increasing genetic potential as well as productivity. Selection changes the genetic structure of population by changing gene and genotypic frequencies and hence, the genetic parameters are also liable to change in every generation (Falconer and Mackay, 1996). The genetic parameters of a population are required not only for prediction of responses, but also used as a base for the future selection and breeding strategies. Genetic improvement in egg production, egg weight, age at sexual maturity and body weights are important breeding goals for commercial chicken layers. Accurate estimates of genetic parameters (heritability, genetic and phenotypic correlations) for these traits are essential for estimating breeding values and optimizing prediction of genetic response to selection. Genetic and phenotypic parameters are the main tools for choosing a selection method and its accuracy in improving a trait.

An animal model is one in which there are one or more observations per animal, and all factors affecting those observations are described including an animal additive genetic effect. Traditionally, heritability has been estimated by correlations of close kin, e.g. parent-offspring regressions (Provine, 2001). However, an animal model takes into account all relationships in a pedigree and is therefore expected to provide estimates of quantitative genetic parameters with higher precision than estimates restricted to the similarity between close kin. It is also less likely to be biased by complicating factors such as non-genetic factors, inbreeding, selection and shared environment (Kruuk and Hadfield, 2007). Moreover, the animal model is expected to be statistically more robust to unbalanced data sets compared to parent-offspring models. The key feature of the animal model is that it includes individual additive genetic effects, or breeding values. These additive genetic effects and critically their variances are estimable given relatedness data, which can be derived from pedigree data or more recently, from genomic estimates of relatedness (Sillanpaa, 2011).

The use of restricted maximum likelihood (REML) under an animal model for estimation of genetic variances and covariance allows separation of genetic effects from random environmental and other nuisance effects and can be easily extended to estimation of other effects such as maternal genetic and common litter effects. Average information restricted maximum likelihood (AIREML) is a powerful approach which uses REML algorithm, very flexible, allows all possible (co)variance components to be fitted in the model, results in unbiased estimates of (co)variance components and breeding values of selected candidates. The inclusion of maternal effects in the model further reduces the bias in estimation of genetic parameters. Simple direct additive genetic animal model may result in overestimation of direct heritability by overlooking maternal effects.

Continuous evaluation of popular layer lines of White Leghorn in terms of production, physiology and immunity is required for further genetic improvement. AICRP on poultry breeding played a significant role in development of egg type chicken germplasm (White Leghorn) in the country. IWH, IWI, IWK and layer control (LC) lines evolved under AICRP on poultry breeding and are being maintained at ICAR-Directorate of Poultry Research, Hyderabad. IWH and IWI lines were subjected to selection for higher egg production and used for production of commercial layer cross named ‘Krishilayer’ while, IWI line in combination with PD–3 line was used for production of another egg type cross named ‘Swetasree’ for backyard poultry production. (Santosh *et al.*, 2016). Hence the present study on IWI line is undertaken with following objectives

Objectives:

1) To evaluate growth and production performance in IWI line.

2) To estimate the genetic parameters of growth and production trait.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

The White leghorn, Minorca and Ancona are the egg producing type of poultry therefore belongs to the category of layer breeds. They are good egg producers and not broody in nature. The single comb White Leghorn is used for the purpose of egg production commercially. They have white egg shells and yellow skin. Breeding and feed management practices have been improved through education, training, competition and expansion. To maintain the growth rate of commercial layer (6-8%), layer breeder has to maintain this growth rate. Continuous evaluation of popular layer lines of White Leghorn in terms of production, reproduction, egg quality, physiology and immunity is required for further genetic improvement. Accurate estimates of genetic parameters are required for estimation of breeding values and genetic gains in traits of economic importance. Various traits of economic importance in layers include egg production, egg weight, body weight, hatchability, fertility and livability.

2.1 MEAN PERFORMANCE

2.1.1 Age at Sexual Maturity

The average age at sexual maturity in various strains/lines of White Leghorn reported by authors in the literature from 1985 to 2019 were presented in Table 2.1.

The values for the trait ranged from 136.85 (Chandan *et al.,* 2019a) to 203.029±0.330 days (Rahman *et al.,* 2003).

2.1.2 Body Weights

The mean body weights at 0 day, 16, 20 and 40 weeks of age in White Leghorns were presented in chronological order in Table 2.2.

The mean body weights at 0 day were 36.41± 6.34g (Chandan *et al.,* 2019a) and 32.57±4.76g (Chandan *et al.,* 2019b). Means for body weight at 16, 20 and 40 weeks of age stretched from 907.38±4.73g (Jaya Laxmi, 2008) to 1258.80±3.09g (Paleja *et al.,* 2008), 958.72±20.87g (Bhushan and Verma, 1986) to 1617±0.123g

(Rahman *et al.,* 2003) and 1338.87±6.91g (Vasu *et al*., 2004a) to 1873±0.008g (Rahman *et al.,* 2003) respectively.

2.1.3 Egg Production

The means for egg production up to 40, 52 and 64 weeks of age in White Leghorns as reported in the literature was presented in table 2.3.

The average egg production upto 40 weeks of age extended from 70.39±0.715 (Rahman *et al.,* 2003) to 121.21±0.02 (Veeramani *et al.*, 2008). Whereas the values at 52 weeks age were 169.73±24.10 (Chandan *et al.*,2019a) and 189.75±21.76 (Chandan *et al.,* 2019b) in different strains of White Leghorns. Similarly means for egg production up to 64 weeks of age extended from 182.53±2.50 (Vasu *et al*., 2004) to 257.71±0.51 (Paleja *et al.,* 2008).

2.1.4 Egg Weight

The mean egg weights at 28, 40, 52 and 64 weeks of age in White Leghorns were shown in the Table 2.4.

At 28 and 40 weeks of age the mean egg weight varied from 44.86±3.37g (Chandan *et al.*, 2019b) to 51.12±2.89g (Churchil *et al.*, 2019), 49.26±5.60 g in IWH strain (Chatterjee *et al.*, 2008) to 55.45±0.36 g in IWF strain (Devi and Mahipal Reddy, 2005) respectively. Similarly means for egg weight at 52 weeks varied from 52.21±0.12g to 55.56±0.18g (Jaya Laxmi, 2008) in I and K strains respectively and at 64 weeks of age varied from 50.45±0.17g in I strain (Vasu *et al*., 2004a) to 60.38±4.31g in P strain (Churchil *et al.,* 2019).

Table 2.1 Means of age at sexual maturity (days) in White Leghorn

Age at sexual maturity	Author(s)
166.17±0.46	Nayak and Mishra (1985)
166.65	Thakur *et al.* (1989)
166.52±0.86	Mishra *et al.* (1992)
166.60±0.30	Singh *et al.* (1992)
174.90±0.55	Yadav *et al.* (1992)
163.70±1.24	Brah *et al.* (1996a)
162.90±0.18	Brah *et al.* (1996b)
153.0±0.24	Chaudary *et al.* (1996)
150.65±0.45(D) 152.95±0.38(F) 149.42±1.06(K)	Devi *et al.* (1998)
164.01±0.25	Sharma and Krishna (1998)
157.20	Ledur *et al.* (2000)
155.38±0.25	Singh *et al.* (2000)
138.31±3.44	Reddy *et al.* (2001)
159.95±0.38	Devi (2002)
203.029±0.330	Rahman *et al.* (2003)
161.87±0.70	Sethi *et al.* (2003)
201.19±2.01(inbred) 173.03±0.238(control)	Sharma *et al.* (2003)
148.24±0.27(D) 155.21±0.33(F)	Kumar *et al.* (2004)
153.98±0.54(I) 158.10±0.87(C)	Vasu *et al.* (2004)
150±0.72(D) 153±0.55(F)	Devi and Mahipal Reddy (2005)
159.32±2.79(H) 159.32±2.61(I) 146.13±1.77(K) 158.36±2.20(C)	Chatterjee *et al.* (2008)
141.71±0.41 (H) 148.20±0.43 (I) 143.45±0.43 (K) 148.49±0.51 (C)	Jaya Laxmi (2008)
140.34±0.23	Paleja *et al.* (2008)
137.55±0.04	Veeramani *et al.* (2008)
150.51±0.34	Laxmi *et al.* (2009)
149.77±0.21	Tomar *et al.* (2015)
136.85±10.32	Chandan *et al.* (2019a)
139.27±8.63	Chandan *et al.* (2019b)
154.24±10.81 (N)152.65±12.09(P)	Churchil *et al.* (2019)

Alphabets within parenthesis indicate strains

Table 2.2 Means of body weight (grams) at various ages in White Leghorn

Body weight (grams) at				Author(s)
0 day of age	16 weeks of age	20 weeks of age	40 weeks of age	
		1279.0±0.003		Nayak and Mishra (1985)
		958.72±20.87		Bharath Bhushan and Verma (1986)
		1191.16±8.44		Mishra *et al.* (1992)
		992.00±2.20	1404.00±3.40	Singh *et al*. (1992)
		1117.70±8.49	1519.20±11.71	Brah *et al.* (1996a)
		1014.30±1.44	1348.10±1.89	Brah *et al.* (1996b)
		1105.00±2.10	1445.00±3.92	Chaudary *et al*. (1996)
		1454.00±3.00	1751.00±3.00	Sharma and Krishna (1998)
	997.22±122.08 (H) 1029.49±61.14 (I)		1442.99±174.50(H) 1464.07±180.63(I)	Reddy *et al*. (2001)
		1220.52±0.21	1630.25±0.58	Devi (2002)
		1617±0.123	1873±0.008	Rahman *et al.* (2003)
		1039.79±10.49		Sethi *et al.* (2003)
			1338.87±6.91(I) 1413.96±7.97 (C)	Vasu *et al*. (2004)
		1348±13.14 (D) 1271±12.58 (F)	1394±11.2(D) 1380±12.3(F)	Devi and Mahipal Reddy (2005)
		1059.83±0.27 (H)	1443.12±0.32 (H)	

Body weight (grams) at				Author(s)
0 day of age	16 weeks of age	20 weeks of age	40 weeks of age	
		1054.77±0.22 (I) 1029.23±0.26 (K) 1034.34±0.26 (C)	1443.52±0.28(I) 1510.93±0.32 (K) 1505.85±0.60 (C)	Chatterjee *et al.* (2008)
	955.20±5.95 (H) 907.38±4.73 (I) 909.57±5.56 (K) 907.46±4.92 (C)	1168.68±5.88 (H) 1131.72±5.54 (I) 1143.83±6.64 (K) 1155.56±5.99 (C)	1407.73±7.66 (H) 1422.88±6.93 (I) 1410.95±8.12 (K) 1484.59±7.39 (C)	Jaya Laxmi (2008)
	1258.80±3.09		1510.80±5.27	Paleja *et al.* (2008)
	1131± 0.8		1651±1.0	Veeramani *et al.* (2008)
		1171.48±4.00	1381.87±6.62	Laxmi *et al.* (2009)
		1336.82±3.36	1568.64±3.68	Tomar *et al.* (2015)
36.41± 6.34	1017.15± 137.97	1168.74±134.62	1389.89±173.59	Chandan *et al.* (2019a)
32.57±4.76	949.38±160.51	1120.51±135.39	1421.07±165.58	Chandan *et al.* (2019b)
	1064.48±106.32(N) 1024.67±222.93(P)		1560.47±161.63(N) 1587.34±165.26(P)	Churchil *et al.* (2019)

Alphabets within parenthesis indicate strains

Table 2.3 Means for egg production (number) in White Leghorn

Egg production upto (number)			Author(s)
40 weeks age	52 weeks age	64 weeks age	
79.08±0.48			Singh and Mohanty (1985)
75.77±0.46			Nayak and Mishra (1985)
80.65			Thakur *et al.* (1989)
104.60±0.50			Thangaraju and Ulaganathan (1990a)
89.60±0.40			Singh *et al.* (1992)
91.60±1.44			Brah *et al.* (1996a)
88.50±0.27			Brah *et al.* (1996b)
93.50±0.47			Chaudary *et al.* (1996)
112.53±0.41(D) 110.31±0.40(F) 113.30±0.59(K)		226.36±1.14(D) 234.00±1.51(F) 235.44±1.77(K)	Devi *et al.* (1998)
87.39±0.25			Sharma and Krishna (1998)
118.64±0.68			Singh *et al.* (2000)
110.67±21.58			Reddy *et al.* (2001)
70.39±0.715			Rahman *et al.* (2003)
73.91±0.57			Sethi *et al.* (2003)
109.81±0.28(D) 97.34±0.33(F)		233.08±0.67(D) 234.72±052(F)	Kumar *et al.* (2004)
		202.75±1.99(I) 182.53±2.50(C)	Vasu *et al.* (2004)
111±0.82(D) 114±0.82(F)			Devi and Mahipal Reddy (2005)
100.83±0.05(H) 97.30±4.50(I) 98.38±4.10(K) 88.84±5.32(C)			Chatterjee *et al.* (2008)
108.77 0.65 (H) 105.59 0.55 (I) 102.39 0.73 (K) 97.14 0.71 (C)		204.05 1.31 (H) 207.39 1.24 (I) 194.08 1.35 (K) 189.623 1.23 (C)	Jaya Laxmi (2008)

Egg production upto (number)			Author(s)
40 weeks age	52 weeks age	64 weeks age	
119.24±0.27		257.71±0.51	Paleja *et al.* (2008)
121.21±0.02		246.40±0.04	Veeramani *et al.* (2008)
98.74±0.70		214.58±1.56	Laxmi *et al.* (2009)
80.85±0.32			Tomar *et al.* (2015)
103.92±17.66	169.73±24.10	232.00±26.85	Chandan *et al.* (2019a)
118.02±17.73	189.75±21.76	254.31±29.00	Chandan *et al.* (2019b)
110.67±18.37(N) 105.64±28.37(P)		248.27±39.39(N) 234.46±59.39(P)	Churchil *et al.* (2019)

Alphabets within parenthesis indicate strains

Table 2.4 Means for egg weight (g) in White Leghorn

Egg weight (g) at				Author(s)
28 weeks age	40 weeks age	52 weeks age	64 weeks age	
	52.36±0.10			Nayak and Mishra (1985)
	51.40±0.24			Brah *et al.* (1996a)
	52.10±0.05			Brah *et al.* (1996b)
	51.80±0.08			Chaudary *et al.* (1996)
	54.50±0.11			Brah *et al.* (1998)
			59.56±0.31(D) 53.84±0.16(F) 58.14±0.34(K)	Devi *et al.* (1998)
	55.4			Sabri *et al.* (1999)
	52.38			Prabhakaran *et al.* (2000)
			58.75±0.29(D) 55.78±0.25(F) 59.54±0.29(K)	Jaya Laxmi *et al.* (2001)
	53.76±0.161			Rahman *et al.* (2003)
45.36±0.11(I) 45.98±0.15(C)	49.57±0.14(I) 50.45±0.19(C)		50.45±0.17(I) 50.62±0.19(C)	Vasu *et al.* (2004)
50.0±0.34(D) 50.4±0.35(F)	55.1±0.29(D) 55.45±0.36(F)			Devi and Mahipal Reddy (2005)
45.94±5.65(H) 47.15±4.94(I) 49.61±7.16(K) 47.05±6.12(C)	49.26±5.60(H) 49.75±5.38(I) 53.79±7.29(K) 49.91±7.64(C)			Chatterjee *et al.* (2008)
46.54±0.15(H) 46.59±0.11 (I) 49.07±0.15(K) 46.41±0.15(C)	50.54±0.14(H) 50.78±0.12(I) 54.23±0.17(K) 51.50±0.15(C)	52.39±0.14(H) 52.21±0.12(I) 55.56±0.18(K) 52.64±0.16(C)	54.23±0.13(H) 54.43±0.13(I) 58.36±0.18(K) 55.06±0.14(C)	Jaya Laxmi (2008)

Egg weight (g) at				Author(s)
28 weeks age	40 weeks age	52 weeks age	64 weeks age	
	50.15±0.08			Paleja *et al.* (2008)
50.42±0.01	54.01±0.02			Veeramani *et al.* (2008)
47.77±0.11	51.53±0.24	54.40±0.24	56.57±0.15	Laxmi *et al.* (2009)
	50.87±0.07			Tomar *et al.* (2015)
45.80±3.67	52.20±3.68	54.82±4.74	57.48±4.33	Chandan *et al.* (2019a)
44.86±3.37	50.76±3.95	54.21±4.15	56.07±4.49	Chandan *et al.* (2019b)
51.12±2.89(N) 50.37±3.34(P)	54.54±3.41(N) 55.04±3.89(P)		59.46±3.83(N) 60.38±4.31(P)	Churchil *et al.* (2019)

Alphabets within parenthesis indicate strains

2.2 HERITABILITIES

2.2.1 Age at Sexual Maturity

Heritability estimates of age at sexual maturity in White Leghorns as reported in literature were summarized in Table 2.5.

The heritability of age at sexual maturity extended from as low as 0.01±0.09 in H strain (Reddy *et al.*, 2001) to as high as 0.94±0.21 (Thangaraju and Ulaganathan, 1990a).

2.2.2 Body Weights

Heritability estimates of body weights at different ages in White Leghorns as reported in literature are summarized in Table 2.6.

The heritability of 0 day body weight as reported by Chandan *et al.* (2019a) and Chandan *et al.* (2019b) were 0.81±0.072 in K strain and 0.835±0.079 in H strain of White Leghorn respectively. Whereas the value at 16 weeks varied widely from as low as 0.009±0.04 in I strain (Reddy *et al.*, 2001) to 0.51±0.13 (Veeramani *et al.*,

2008) based on the sire component of variance. Similarly heritability of 20 and 40 week body weight varied from 0.05±0.18 (Chatterjee *et al.*, 2008) to 0.80±0.78 (Chaubal *et al.*, 1994) and from 0.02±0.17 (Chatterjee *et al.*, 2008) to 0.79±0.78 (Chaubal *et al.*, 1994) respectively.

2.2.3 Egg Production

Heritability estimates of egg production up to various ages in White Leghorns as reported in literature were presented in table 2.7.

The heritability of egg production up to 40 weeks of age extended from 0.01±0.05 (Reddy *et al*., 2001) to 0.64±0.15 (Thangaraju and Ulaganathan, 1990a).

Table 2.5 Heritability estimates of age at sexual maturity in White Leghorn

.	**Age at sexual maturity**	**Author(s)**
h^2_S	0.94±0.21	Thangaraju and Ulaganathan (1990a)
h^2_S	0.53±0.23	Mishra *et al.* (1992)
h^2_{S+D}	0.19±0.10	Yadav *et al.* (1992)
h^2_S h^2_D h^2_{S+D}	0.61±0.51 0.05±0.40 0.39±0.23	Chaubal *et al.* (1994)
h^2_S	0.09±0.08	Brah *et al.* (1996a)
h^2_S	0.35±0.05	Chaudary*et al*. (1996)
h^2_S h^2_D h^2_{S+D}	021±0.05 0.32±0.06 0.29±0.03	Bais *et al.* (1997)
h^2_{S+D}	0.13±0.14	Devi *et al*. (1998)
h^2_S	0.42±0.01	Chatterjee *et al.* (2000)
h^2_S	0.437±0.10	Singh *et al.* (2000)
 h^2_S h^2_S	Strain H 0.01±0.09 Strain I 0.02±0.04	Reddy *et al*. (2001)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}	Generation 1 0.26±0.08 0.24±0.18 0.25±0.08 Generation 2 0.18±0.10 0.20±0.18 0.18±0.07	Singh *et al.* (2001)
h^2_S	0.16±0.01	Chatterjee *et al.* (2002)
h^2_{S+D}	0.18±0.13	Sharma *et al.* (2002)
h^2_{S+D}	0.154±0.04	Singh *et al.* (2002)
h^2_S	0.17±0.09	Rahman *et al.* (2003)

.	**Age at sexual maturity**	**Author(s)**
h^2_S h^2_D h^2_{S+D}	0.25±0.08 0.31±0.09 0.28±0.06	Sethi *et al.* (2003)
 h^2_S h^2_S	Inbred 0.57±0.23 Control 0.25±0.24	Sharma *et al.* (2003)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}	Strain D 0.29±0.09 0.27±0.09 0.02±0.06 Strain F 0.27±0.10 0.15±0.14 0.21±0.08	Kumar *et al*. (2004)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}	Strain I 0.18±0.16 0.69±0.22 0.44±0.10 Strain C 0.24±0.19 0.32±0.24 0.28±0.11	Vasu *et al*. (2004)
h^2_S	0.232±0.09	Singh and Singh (2005)
h^2_S	0.43±0.14	Ahmed and Singh (2006)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}	Strain H 0.22±0.13 0.11±0.18 0.16±0.11 Strain I 0.33±0.16 0.38±0.16 036±0.11 Strain K 0.28±0.14 0.14±0.17 0.21±0.11 Strain C 0.19±0.12 0.06±0.15 0.12±0.09	Chatterjee *et al.* (2008)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D	Strain H 0.049± 0.11 0.36± 0.19 0.18± 0.08 Strain I 0.18± 0.10 0.27± 0.19	Jaya Laxmi (2008)

.	**Age at sexual maturity**	**Author(s)**
h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}	0.23± 0.07 Strain K 0.04± 0.17 0.02± 0.07 Control 0.04± 0.09 0.17± 0.17 0.10± 0.07	
h^2_S h^2_D h^2_{S+D}	0.32±0.09 0.12±0.06 0.22±0.05	Veeramani *et al.* (2008)
h^2_S	0.28±0.08	Manjeet *et al.* (2018)
h^2 animal model	0.38±0.09	Chandan *et al.* (2019a)
h^2 animal genetic model	0.33±0.10	Chandan *et al.* (2019b)
h^2	Strain N 0.35±0.05 Strain P 0.09±0.03	Churchil *et al.* (2019)

Table 2.6 Heritability estimates of body weights at different ages in White Leghorn

.	Body weights at				Author(s)
	0 day of age	16 weeks of age	20 weeks of age	40 weeks of age	
h^2_S			0.43±0.11		Thangaraju and Ulaganathan (1990a)
h^2_S h^2_D h^2_{S+D}			0.80±0.78 -ve 0.55±0.32	0.79±0.78 -ve 0.55±0.32	Chaubal *et al.* (1994)
h^2_S			0.63±0.10	0.77±0.10	Brah *et al.* (1996a)
h^2_S				0.69±0.08	Brah *et al.* (1996b)
h^2_S				0.63±0.07	Chaudary *et al.* (1996)
h^2_S h^2_D h^2_{S+D}			0.23±0.05 0.37±0.06 0.33±0.03	0.28±0.06 0.33±0.07 0.31±0.03	Bais *et al.* (1997)
h^2_S			0.39±0.06	0.53±0.08	Sharma and Krishna (1998)
h^2_S h^2_S		Strain H 0.25±0.13 Strain I 0.01±0.04		Strain H 0.19±0.12 Strain I 0.10±0.07	Reddy *et al.* (2001)
h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}			Generation 1 0.36±0.08 0.41±0.09 0.39±0.07 Generation 2 0.19±0.09 0.23±0.11 0.20±0.07		Singh *et al.* (2001)
h^2_{S+D}			0.19±0.13		Sharma *et al.* (2002)
h^2_S			0.36±0.22	0.56±0.47	Devi (2002)
h^2_{S+D}			0.40±0.06		Singh *et al.* (2002)
h^2_S			0.55±0.16	0.37±0.13	Rahman *et al.* (2003)
h^2_S				Strain I 0.06±0.13	Vasu *et al.* (2004)

.	Body weights at				Author(s)
	0 day of age	16 weeks of age	20 weeks of age	40 weeks of age	
h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}				0.62±0.22 0.34±0.09 Strain C 0.53±0.25 0.40±0.23 0.47±0.13	
h^2_S			0.26±0.08	0.23±0.07	Singh and Singh (2005)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}			Strain H 0.11±0.10 0.05±0.18 0.08±0.10 Strain I 0.37±0.16 0.30±0.14 0.33±0.11 Strain K 0.37±0.16 0.17±0.17 0.27±0.12 Strain C 0.37±0.18 0.47±0.18 0.42±0.13	Strain H 0.13±0.11 0.02±0.17 0.08±0.10 Strain I 0.12±0.11 0.25±0.12 0.19±0.09 Strain K 0.21±0.13 0.26±0.18 0.23±0.11 Strain C 0.21± 0.09 0.34±0.11 0.06±0.08	Chatterjee *et al.* (2008)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}		Strain H 0.12±0.11 0.06±0.07 Strain I 0.02±0.07 0.43±0.15 0.22±0.07 Strain K 0.36±0.17 0.09±0.18 0.22±0.09 Control 0.71±0.19 0.36±0.10		Strain H 0.06±0.20 0.66±0.19 0.36±0 .10 Strain I 0.16±0.10 0.23±0.14 0.20±0.07 Strain K 0.48±0.19 0.40±0.19 0.44±0.11	Jaya Laxmi (2008)
h^2_S h^2_D h^2_{S+D}		0.51±0.13 0.31±0.07 0.41±0.07		0.45±0.12 0.39±0.08 0.42±0.07	Veeramani *et al.* (2008)
h^2_S			0.45 ±0.13	0.42 ±0.12	Manjeet *et al.* (2018)
h^2animal model	0.81±0.07	0.34±0.09			Chandan *et al.* (2019a)

.	Body weights at				Author(s)
	0 day of age	16 weeks of age	20 weeks of age	40 weeks of age	
h^2animal model	0.84±0.08	0.25±0.08	0.44±0.14	0.47 ±0.11	Chandan *et al.* (2019b)
h^2		Strain N 0.49±0.05 Strain P 0.32±0.05		Strain N 0.39±0.05 Strain P 0.29±0.05	Churchil *et al.* (2019)

Table 2.7 Heritability estimates of egg production up to different ages in White Leghorn

	Egg production upto			Author(s)
	40 weeks age	52 weeks age	64 weeks age	
h^2_S h^2_D h^2_{S+D}	0.35±0.10 0.19±0.08 0.27±0.06			Nayak and Mishra (1985)
h^2_S h^2_D	0.19±0.10 0.25±0.06			Singh *et al.* (1986)
h^2_S	0.24±0.03			Thakur *et al.* (1989)
h^2_S	0.64±0.15			Thangaraju and Ulaganathan (1990a)
h^2_S h^2_D h^2_{S+D}	-ve 0.54±0.55 0.36±0.28			Chaubal *et al.* (1994)
h^2_S	0.33±0.10			Brah *et al.* (1996a)
h^2_S h^2_D h^2_{S+D}	0.07±0.03 0.17±0.06 0.11±0.02			Bais *et al.* (1997)
h^2_S	0.16±0.06			Singh *et al.* (2000)
h^2_S	0.26±0.00			Chatterjee and Mishra (2001)
 h^2_S h^2_S	Strain H 0.02±0.09 Strain I 0.01±0.05			Reddy *et al.* (2001)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}	Generation 1 0.17±0.08 0.23±0.18 0.19±0.06 Generation 2 0.16±0.10 0.22±0.07 0.20±0.09			Singh *et al.* (2001)
h^2_S	0.45±0.37			Devi (2002)
h^2_S	0.184±0.045			Singh *et al.* (2002)
h^2_S	0.60±0.17			Rahman *et al.* (2003)
 h^2_S h^2_D h^2_{S+D} 	Strain D 0.31±0.09 0.12±0.08 0.22±0.06 Strain F		 0.14±0.06 0.06±0.08 0.10±0.04 	Kumar *et al.* (2004)

	Egg production upto			**Author(s)**
	40 weeks age	52 weeks age	64 weeks age	
h^2_S	010±0.07		0.05±0.07	
h^2_D	0.11±0.14		0.09±0.15	
h^2_{S+D}	0.11±0.07		0.17±0.07	
			Strain I	Vasu *et al*. (2004)
h^2_S			0.04±0.10	
h^2_D			0.24±0.18	
h^2_{S+D}			0.14±0.08	
			Strain C	
h^2_S			0.12±0.19	
h^2_D			-ve	
h^2_{S+D}			0.00±0.08	
h^2_S	0.20±0.09			Singh and Singh (2005)
h^2_S	0.38±0.13			Ahmed ad Singh (2006)
	Strain H			Chatterjee *et al.* (2008)
h^2_S	0.04±0.08			
h^2_D	0.07±0.17			
h^2_{S+D}	0.05±0.10			
	Strain I			
h^2_S	0.08±0.09			
h^2_D	0.14±0.14			
h^2_{S+D}	0.11±0.08			
	Strain K			
h^2_S	0.14±0.12			
h^2_D	0.29±0.18			
h^2_{S+D}	0.22±0.11			
	Strain C			
h^2_S	0.43±0.18			
h^2_D	0.19±0.15			
h^2_{S+D}	0.31±0.12			
	Strain H		Strain H	Jaya Laxmi (2008)
h^2_S	0.17±0.12		0.41± 0.17	
h^2_D			0.41± 0.21	
h^2_{S+D}	0.09±0.07		0.21± 0.08	
	Strain I		Strain I	
h^2_S	0.10± 0.08		.05± 0.07	
h^2_D	0.23± 0.14		0.24± 0.14	
h^2_{S+D}	0.17± 0.07		0.15± 0.06	
	Strain K		Strain K	
h^2_S	0.12± 0.12		0.12± 0.12	
h^2_D			0.09± 0.18	
h^2_{S+D}	0.06± 0.07		0.11± 0.08	
	Control		Control	
h^2_S	0.15± 0.12		0.27± 0.14	
h^2_D				
h^2_{S+D}	0.07± 0.07		0.13± 0.08	
h^2_S	0.26±0.07		0.18±0.06	Veeramani *et*

	Egg production upto			**Author(s)**
	40 weeks age	52 weeks age	64 weeks age	
h^2_D h^2_{S+D}	0.12±0.06 0.19±0.04		0.11±0.06 0.14±0.04	*al.* (2008)
h^2 animal model	0.23±0.09	0.20±0.09	0.26±0.10	Chandan *et al.* (2019a)
h^2 animal model	0.15±0.10	0.21±0.11	0.24±0.12	Chandan *et al.* (2019b)
h^2	Strain N 0.28±0.05 Strain P 0.24±0.04		Strain N 0.18±0.04 Strain P 0.22±0.04	Churchil *et al.* (2019)

Table 2.8 Heritabilities of egg weight at different ages in White Leghorn

	Egg weight at				Author(s)
	28 weeks of age	40 weeks of age	52 weeks of age	64 weeks of age	
h^2_S		0.90±0.20			Thangaraju and Ulaganathan (1990a)
h^2_S		0.77±0.22			Ferdoci *et al.* (1992)
h^2_S h^2_D h^2_{S+D}		0.66±0.66 -ve 0.42±0.29			Chaubal *et al.* (1994)
h^2_S		0.22±0.04			Sharma *et al.* (1994)
h^2_S		0.71±0.11			Brah *et al.* (1996a)
h^2_S		0.70±0.09			Brah *et al.* (1996b)
h^2_S		0.20±0.03			Chaudary *et al.* (1996)
h^2_S		0.50±0.85			Singh *et al.* (1996)
h^2_S h^2_D h^2_{S+D}		0.22±0.06 0.55±0.07 0.41±0.04			Bais *et al.* (1997)
h^2_S h^2_D h^2_{S+D}		029±0.12 0.54±0.13 0.41±0.08			Brah *et al.* (1998)
h^2_S		0.41±0.01			Chatterjee *et al.* (2000)
				Strain D 0.24±0.19 Strain F 0.37±0.24 Strain K 0.16±0.20	Jaya Laxmi *et al.* (2001)
h^2_S		0.23±0.05			Singh *et al.* (2002)
h^2_S		0.65±0.18			Rahman *et al.* (2003)
h^2_S h^2_D h^2_{S+D} h^2_S h^2_D	Strain I 0.25±0.18 0.38±0.19 0.32±0.09 Strain C 0.44±0.20 0.11±0.20	Strain I 0.06±0.13 0.62±0.22 0.34±0.09 Strain C 0.52±0.19 -ve			Vasu *et al.* (2004)

	Egg weight at				Author(s)
	28 weeks of age	40 weeks of age	52 weeks of age	64 weeks of age	
h^2_{S+D}	0.28±0.11	0.17±0.10			
h^2_S	0.21±0.04				Singh and Singh (2005)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}	Strain H 0.31±0.15 0.19±0.18 0.25±0.15 Strain I 0.52±0.18 0.11±0.12 0.32±0.13 Strain K 0.51±0.18 0.05±0.14 0.23±0.13 Strain C 0.67±0.21 0.01±0.12 0.33±0.15	Strain H 0.54±0.19 0.15±0.16 0.34±0.16 Strain I 0.55±0.17 0.06±0.10 0.25±0.11 Strain K 0.73±0.23 0.09±0.14 0.41±0.15 Strain C 0.08±0.26 0.28±0.15 0.55±0.17			Chatterjee *et al.* (2008)
 h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D} h^2_S h^2_D h^2_{S+D}	Strain H 0.01±0.09 0.51±0.19 0.26±0.09 Strain I 0.70±0.19 0.29±0.14 0.50±0.09 Strain K 0.20±0.14 0.19±0.18 0.20±0.09 Control 0.12±0.11 0.06±0.07	Strain H 0.23±0.11 0.61±0.19 0.42± 0.10 Strain I 0.51±0.16 0.26±0.07 Strain K 0.47±0.18 0.27±0.19 0.37±0.10 Control 0.30±0.15 0.15±0.08	Strain H 0.35±0.16 0.45±0.19 0.40±0.10 Strain I 0.48±0.16 0.07±0.13 0.28±0.08 Strain K 0.37±0.17 0.26±0.19 0.32±0.10 Control 0.38±0.16 0.14±0.17 0.26±0.09	Strain H 0.67±0.21 0.43±0.19 0.55±0.10 Strain I 0.79±0.20 0.01±0.12 0.40±0.08 Strain K 0.99±0.25 0.05±0.17 0.52±0.11 Control 0.26±0.17 0.72±0.11	Jaya Laxmi (2008)
h^2_S h^2_D h^2_{S+D}	0.58±0.14 0.27±0.07 0.42±0.08	0.48±0.13 0.36±0.08 0.42±0.07			Veeramani *et al.* (2008)
h^2_S		0.43±0.12.			Manjeet *et*

	Egg weight at				Author(s)
	28 weeks of age	40 weeks of age	52 weeks of age	64 weeks of age	
					al. (2018)
h^2 animal model	0.28±0.09	0.32±0.09	0.18±0.08	0.65±0.12	Chandan *et al.* (2019a)
h^2 animal model	0.37±0.10	0.58±0.11	0.52±0.14	0.683±0.12	Chandan *et al.* (2019b)
h^2	Strain N 0.38±0.05 Strain P 0.46±0.06	Strain N 0.45±0.05 Strain P 0.49±0.06		Strain N 0.39±0.05 Strain P 0.51±0.06	Churchil *et al.* (2019)

Heritability estimates for egg production up to 52 weeks was 0.196±0.088 and 0.210±0.109 as reported by Chandan *et al.* (2019a) and Chandan *et al.* (2019b) respectively in different strains of White Leghorn. Whereas those for egg production up to 64 weeks of age ranged from -0.003±0.08 (Vasu *et al*., 2004a) to 0.414± 0.213 (Jaya Laxmi, 2008).

2.2.4 Egg Weight

Heritability estimates of egg weights at different ages in White Leghorns as reported in literature were presented in table 2.8.

Heritability estimates of egg weight at 28 weeks of age extended from 0.01±0.12 in C strain (Chatterjee *et al.,* 2008) to 0.698±0.188 in I strain (Jaya Laxmi, 2008). Those for egg weight at 40 weeks of age extended from 0.06±0.10 (Chatterjee *et al.,* 2008) to 0.90±0.20 (Thangaraju and Ulaganathan, 1990a) based on dam and sire component of variance respectively.

Similarly heritability for egg weight at 52 weeks of age as reported in literature stretched from 0.073±0.128 (Jaya Laxmi, 2008) to 0.522±0.138 (Chandan *et al.,* 2019b). Whereas that for egg weight at 64 weeks of age ranged widely from as low as 0.005±0.124 to as high as 0.986±0.250 (Jaya Laxmi, 2008) in different strains of White Leghorn.

2.3 GENETIC, PHENOTYPIC AND ENVIRONMENTAL CORRELATIONS

2.3.1 Age at Sexual Maturity with Other Traits

The genetic, phenotypic and environmental correlations of age at sexual maturity with body weights, egg production and egg weights at different ages in White Leghorn as reported in literature was summarized in table 2.9.

The genetic correlation of age at sexual maturity with body weight at 0 day is reported to be low and positive whereas phenotypic correlation was reported to be very low and was positive by Chandan *et al.* (2019a) in IWK and negative in IWH by Chandan *et al.* (2019b).

As per the literature age at sexual maturity and body weight at 16 weeks of age showed a negative genetic correlation except that Sharma *et al*. (2002) reported a positive genetic correlation. The phenotypic correlation between age at sexual maturity and body weight at 16 weeks was reported as negative, however environmental correlation is reported to be both positive and negative in different strains of White Leghorn.

A wide variation in both magnitude and direction was observed in genetic correlation among age at sexual maturity and body weight at 20 weeks of age with a lowest of 0.01±0.40 (Chatterjee *et al.*, 2008) to a highest of 0.83±0.48 (Sharma *et al*., 2002). The phenotypic correlation was reported to be negative in most of the reports except a positive correlation of 0.57±0.02 (Sethi *et al.*, 2003). All the reports suggested a negative environmental correlation between age at sexual maturity and body weight at 20 weeks.

The genetic correlation of age at sexual maturity with 40 weeks body weight depicted a wide variation with majority of reports indicating a positive while others a negative correlation. The phenotypic correlation with a weak magnitude varied in direction among the reports. A very weak environmental correlation was reported by Jaya Laxmi (2008) in different strains.

Table 2.9 Correlations of age at sexual maturity with body weights, egg production and egg weights at various ages in White Leghorn

Age at sexual maturity with	r_g	r_p	r_e	Author(s)
Body weight at 0day	0.17±0.16	0.02±0.05		Chandan *et al.* (2019a)
	0.07±0.18	–0.08±0.06		Chandan *et al.* (2019b)
Body weight at 16 weeks of age	Strain H -0.48±0.20 Strain I -0.02±0.01	Strain H -0.03 Strain I -0.09		Reddy *et al*. (2001)
	0.43±0.52	-0.15±0.05		Sharma *et al*. (2002)
	-0.20±0.18	-0.11±0.02		Veeramani *et al.* (2008)
	Strain H -0.64± 0.63 Strain I -0.09± 0.25 Strain K -0.07± 0.91 Control -0.42± 0.38	Strain H -0.01 Strain I -0.08 Strain K -0.04 Control -0.18	Strain H 0.06 Strain I -0.08 Strain K -0.04 Control -0.13	Jaya Laxmi (2008)
	-051±0.15	-0.43 ±0.04		Chandan *et al.* (2019a)
	-0.13±0.26	-0.42±0.04		Chandan *et al.* (2019b)
	Strain N -0.28±0.11 Strain P -0.23±0.18	Strain N -0.22±0.02 Strain P -0.19±0.02		Churchil *et al.* (2019)

Age at sexual maturity with	r_g	r_p	r_e	**Author(s)**
Body weight at 20 weeks of age	-0.41±0.23	-0.32± 0.03		Singh *et al*. (1986)
	0.08±0.07	-0.24± 0.12		Chaudary *et al*. (1988)
	0.11±0.27	-0.30± 0.04		Ferdoci *et al.* (1992)
	-0.22±0.05	-0.23± 0.01		Sharma *et al.* (1994)
	-0.13	-0.24		Kumararaj *et al.* (1995)
	-0.06±0.11	-0.13± 0.05		Sharma and Krishna (1998)
	0.83±0.48	-0.13± 0.05		Sharma *et al.* (1999)
	Generation 1 -0.25±0.23 (S) -0.60±0.31 (D) -0.29±0.30 (S+D) Generation 2 -0.79±0.24 (S) -0.40±0.26 (D) -0.58±0.18 (S+D)	-0.28 -0.38		Singh *et al*. (2001)
	0.83±0.48	-0.13± 0.05		Sharma *et al.* (2002)
	0.16±0.12	-0.01± 0.04		Rahman *et al.* (2003)
	0.10± 0.24 (S) -0.22±0.18 (D) -0.17±0.16(S+D)	0.57± 0.02	-0.75 -0.76 -0.76	Sethi *et al.* (2003)
	Strain H -0.47±0.41 Strain I -0.45±0.26 Strain K -0.83±0.11 Strain C	Strain H -0.22 Strain I -0.38 Strain K -0.37		Chatterjee *et al.* (2008)

Age at sexual maturity with	r_g	r_p	r_e	**Author(s)**
	0.01±0.40	Strain C -0.23		
	Strain H 0.24± 0.30 Strain I -0.22± 0.35 Strain K -0.26± 1.14 Control -0.33± 0.70	Strain H -0.10 Strain I -0.09 Strain K -0.07 Control -0.04	Strain H -0.21 Strain I -0.07 Strain K -0.06 Control -0.01	Jaya Laxmi (2008)
	–0.18±0.25	–0.21±0.06		Chandan *et al.* (2019b)

Age at sexual maturity with	**r_g**	**r_p**	**r_e**	**Author(s)**
Body weight at 40 weeks of age	0.17±0.26	0.13±0.03		Singh *et al*. (1986)
	0.44±0.05	0.09±0.01		Chaudary *et al*. (1988)
	0.71±0.12	0.04±0.05		Ferdoci *et al.* (1992)
	0.48±0.04	0.20±0.01		Sharma *et al.* (1994)
	-0.06	0.14		Kumararaj *et al.* (1995)
	0.05±0.11	0.02±0.02		Sharma and Krishna (1998)
	0.15±0.13	0.01±0.04		Rahman *et al.* (2003)
	Strain I 0.86±0.26 (S) -0.03±0.24 (D) 0.09±0.18 (S+D) Control 0.52±0.31 (S) 0.39±0.39 (D) 0.45±0.18(S+D)	-0.01±0.04 -0.04±0.05		Vasu *et al.* (2004a)
	Strain H -0.44± 0.39 Strain I 0.13± 0.46 Strain K 0.42± 0.34 Strain C -0.26± 0.36	Strain H -0.01 Strain I -0.03 Strain K 0.02 Strain C 0.04		Chatterjee *et al.* (2008)
	0.10±0.19	0.03±0.02		Veeramani *et al.* (2008)
	Strain H 0.22± 0.27 Strain I 0.41± 0.25 Strain K	Strain H 0.06 Strain I 0.05 Strain K	Strain H 0.01 Strain I -0.04 Strain K	Jaya Laxmi (2008)

Age at sexual maturity with	**r_g**	**r_p**	**r_e**	**Author(s)**
	-0.28± 0.85 Control 0.12± 0.46	0.04 Control -0.02	0.08 Control -0.04	
	0.20±0.23	–0.03±0.05		Chandan *et al.* (2019b)
	Strain N -0.01±0.01 Strain P 0.27±0.17	Strain N -0.11±0.02 Strain P 0.07±0.02		Churchil *et al.* (2019)
Egg production upto 40 weeks of age	-0.86±0.02	-0.59±0.01		Chaudary *et al*. (1988)
	-0.92±0.02	-0.66±0.01		Thakur *et al.* (1989)
	-0.80±0.09	0.41±0.04		Ferdoci *et al.* (1992)
	-1.04±0.08	-0.60±0.05		Mishra *et al.* (1992)
	-0.63±0.05	-0.49±0.01		Sharma *et al.* (1994)
	-1.08	-0.74		Kumararaj *et al.* (1995)
	-0.66±0.08	-0.39± 0.01		Sharma and Krishna (1998)
				Sharma *et al.*

Age at sexual maturity with	r_g	r_p	r_e	Author(s)
	-0.62± 0.48	-0.50±0.04		(1999)
	-0.39± 0.04	-0.08±0.03	0.10	Singh *et al.* (2000)
	Generation 1 >1 (S) -0.21±0.09 (D) -0.44±0.24 (S+D) Generation 1 -0.90±0.21 (S) -0.23±0.14 (D) -0.44±0.24 (S+D)	-0.30 -0.26		Singh *et al.* (2001)
	-0.47	-0.25		Chatterjee *et al.* (2002)
	-0.05±0.20	-0.26±0.02		Singh *et al.* (2002)
	-0.53±0.20	-0.40±0.03		Rahman *et al.* (2003)
	-0.08±0.26 (S) -0.14±0.24 (D) -0.11±0.19 (S+D)	-0.13±0.03	-0.15 -0.13 -0.14	Sethi *et al.* (2003)
	Strain D -0.59±0.11 Strain F -1.04±0.20	Strain D -0.50±0.02 Strain F -0.57±0.02		Kumar *et al.* (2004)
	Strain H -0.77±0.29 Strain I -0.69±0.29 Strain K -0.46±0.38 Strain C -0.65±0.21	Strain H -0.21 Strain I -0.22 Strain K -0.25 Strain C -0.18		Chatterjee *et al.* (2008)
	–0.81±0.07	-0.41±0.02		Veeramani *et al.* (2008)
	Strain H -0.18± 0.50 Strain I	Strain H -0.21 Strain I	Strain H -0.22 Strain I	

Age at sexual maturity with	**r_g**	**r_p**	**r_e**	**Author(s)**
	-0.91± 0.34 Strain K 0.736± 0.23 Control -0.83± 0.90 -0.69±0.17 -1.00±0.34 Strain N -0.83± 0.12 Strain P -0.84± 0.20	-0.36 Strain K -0.14 Control -0.31 -0.04±0.04 -0.45±0.04 Strain N -0.67± 0.02 Strain P -0.48± 0.02	-0.23 Strain K -0.18 Control -0.26	Jaya Laxmi (2008) Chandan *et al.* (2019a) Chandan *et al.* (2019b) Churchil *et al.* (2019)
Egg production upto 52 weeks of age	-0.63±0.19 –0.73±0.25	-0.29±0.04 -0.38±0.04		Chandan *et al.* (2019a) Chandan *et al.* (2019b)
Egg production upto 64 weeks of age	Strain D -0.21±0.02 Strain H -0.53±0.21 Strain I <-1 (S) -0.65±0.20 (D) -0.73±0.12 (S+D) Control -0.01±0.63 (S) -0.28±0.72 (D) <-1 (S+D) –0.34±0.19 Strain H	Strain D -0.1± 0.03 Strain H -0.34±0.03 Strain I -0.35±0.04 (D) Control -0.33±0.05 (D) -0.21±0.02 Strain H	Strain H	Kumar *et al.* (2004) Vasu *et al.* (2004a) Veeramani *et al.* (2008)

Age at sexual maturity with	**r_g**	**r_p**	**r_e**	**Author(s)**
	0.29± 0.34 Strain I -0.62± 0.32 Strain K -0.73± 0.74 Control 0.16± 0.49	-0.07 Strain I -0.20 Strain K -0.04 Control -0.11	-0.16 Strain I -0.10 Strain K -0.00 Control -0.15	Jaya Laxmi (2008)
	-0.47±0.19	0.19±0.05		Chandan *et al.* (2019a)
	–0.58±0.26	0.28±0.04		Chandan *et al.* (2019)
	Strain N -0.50±0.14 Strain P -0.52±0.20	Strain N -0.42±0.02 Strain P -0.31±0.02		Churchil *et al.* (2019)
Egg weight at 28 weeks of age	Strain I 0.99±0.04 (S) -0.61±0.18 (D) -0.13±0.18 (S+D) Control -0.57±0.29 (S) 0.43± 0.66 (D) -0.18±0.26 (S+D)	Strain I 0.04±0.04 Control 0.01±0.05		Vasu *et al.* (2004a)
	Strain H 0.92±0.06 Strain I 0.19±0.28 Strain K 0.30±0.27 Strain C -0.04±0.32	Strain H 0.03 Strain I 0.09 Strain K 0.08 Strain C 0.10		Chatterjee *et al.* (2008)
	0.27±0.17	0.05±0.02		Veeramani *et al.* (2008)
	Strain H	Strain H	Strain H	

Age at sexual maturity with	r_g	r_p	r_e	**Author(s)**
	0.35± 0.30 Strain I 0.51± 0.18 Strain K 0.42± 0.16	0.06 Strain I 0.08 Strain K 0.02 Control -0.05	-0.02 Strain I -0.14 Strain K -0.01 Control 0.06	Jaya Laxmi (2008)
	-0.95±0.09	0.55 ±0.03		Chandan *et al.* (2019a)
	0.55±0.21	0.13±0.05		Chandan *et al.* (2019b)
	Strain N -0.37±0.10 Strain P 0.01±0.12	Strain N 0.10±0.02 Strain P 0.02±0.02		Churchil *et al.* (2019)
Egg weight at 40 weeks of age	0.51			Nayak and Mishra (1985)
	0.02±0.16	-0.01±0.02		Singh *et al.* (1986)
	0.36±0.05	0.13± 0.01		Chaudary *et al.* (1988)
	-0.03	-0.05		Thangaraju and Ulaganathan (1990b)
	0.72± 0.11	0.12±0.05		Ferdoci *et al.* (1992)
	0.43	0.00		Kumararaj *et al.* (1995)
	-0.07±0.12	0.03±0.04		Rahman *et al.* (2003)
	Strain I 0.24±0.49 (S) -0.51±0.19 (D) -0.29±0.16 (S+D) Control 0.07±0.38 (S) -0.60±0.37 (D) -0.27±0.31 (S+D)	Strain I 0.04±0.04 Control 0.05±0.05		Vasu *et al.* (2004a)

Age at sexual maturity with	r_g	r_p	r_e	Author(s)
	Strain H 0.72±0.20 Strain I 0.28± 0.26 Strain K -0.20±0.27 Strain C 0.21±0.31	Strain H 0.08 Strain I 0.04 Strain K -0.02 Strain C -0.01		Chatterjee *et al.* (2008)
	0.11±0.19	0.03c0.02		Veeramani *et al.* (2008)
	Strain H -0.12± 0.27 Strain I 0.27± 0.24 Strain K 0.42± 0.01 Control -0.49± 0.46	Strain H 0.05 Strain I 0.06 Strain K 0.03 Control 0.03	Strain H 0.12 Strain I -0.00 Strain K -0.01 Control 0.10	Jaya Laxmi (2008)
	0.38± 0.19	0.14± 0.05		Chandan *et al.* (2019a)
	0.28±0.21	0.10±0.05		Chandan *et al.* (2019b)
	Strain N -0.19±0.11 Strain P 0.21±0.15	Strain N 0.05±0.02 Strain P 0.05±0.02		Churchil *et al.* (2019)
Egg weight at 52 weeks of age	Strain H -0.23± 0.27 Strain I -0.09± 0.24 Strain K 0.64± 0.35 Control -0.21± 0.38	Strain H 0.01 Strain I -0.02 Strain K -0.04 Control -0.03	Strain H 0.09 Strain I 0.01 Strain K -0.11 Control 0.01	Jaya Laxmi (2008)
	0.18±0.25	0.13± 0.05		Chandan *et al.* (2019a)
	0.33±0.23	0.11±0.06		Chandan *et al.* (2019b)
Egg weight at	Strain I	Strain I		

Age at sexual maturity with	r_g	r_p	r_e	Author(s)
64 weeks of age	-0.21±0.36 (S) -0.10±0.30 (D) -0.13±0.17 (S+D) Control 0.36±0.36(S) 0.11±1.86 (D) 0.25±0.28 (S+D)	-0.04±0.04(S) Control 0.03±0.05 (S)		Vasu *et al.* (2004a)
	Strain H 0.48± 0.24 Strain I 0.17± 0.22 Strain K -0.33± 0.89 Control 0.05± 0.29	Strain H 0.02 Strain I -0.02 Strain K 0.02 Control 0.02	Strain H -0.22 Strain I -0.10 Strain K 0.02 Control 0.02	Jaya Laxmi (2008)
	0.19±0.18	0.12±0.05		Chandan *et al.* (2019a)
	0.18±0.20	0.04±0.06		Chandan *et al.* (2019b)

Alphabets within the parenthesis indicate the components used for estimation of correlation
S = sire component, D = dam component, S+D = sire + dam component

Majority of reports suggested a negative genetic, phenotypic and environmental correlation between age at sexual maturity and egg production up to 40, 52 and 64 weeks of age.

Reports in literature depicted a wide variation in the genetic correlation between age at sexual maturity and egg weight at 28 weeks from a lowest of 0.005±0.118 (Churchil *et al.,* 2019) to a highest of 0.99±0.04 (Vasu *et al.,* 2004a) and were both positive and negative in direction in the literature.

The genetic correlation between age at sexual maturity and egg weight at 40, 52 and 64 weeks of age indicated both positive and negative correlation of varying magnitude.

However the phenotypic and environmental correlation between age at sexual maturity and egg weight at 24, 40, 52 and 64 weeks of age were found to be weak with both positive and negative variation in direction as per the reported literature.

2.3.2 Body Weight at 0 day with Other Traits

The estimates of genetic, phenotypic correlations of body weight at 0 day with other traits was summarized in table 2.10.

Body weight at 0 day showed a positive genetic and phenotypic correlation of varying magnitude with body weight at 16, 20 and 40 weeks of age.

The genetic and phenotypic correlation of 0 day body weight with egg production up to 40, 52 and 64 weeks of age was negative in direction with genetic correlation being moderate in magnitude.

There was a positive genetic and phenotypic correlation between 0 day body weight with 28, 40, 52 and 64 week egg weight as per the available literature.

Table 2.10 Correlations of body weight at 0 day with body weights, egg production and egg weights at various ages in White Leghorn as reported in the literature

Body weight at 0 day with	r_g	r_p	Author(s)
Body weight at 16 weeks of age	0.18±0.16 0.51±0.14	0.08±0.05 0.20±0.04	Chandan *et al.* (2019a) Chandan *et al.* (2019b)
Body weight at 20 weeks of age	0.40±0.18	0.40±0.18	Chandan *et al.* (2019b)
Body weight at 40 weeks of age	0.36±0.15	0.36±0.15	Chandan *et al.* (2019b)
Egg production upto 40 weeks of age	-0.64±0.17 -0.50±0.25	-0.18±0.05 -0.20±0.05	Chandan *et al.* (2019a) Chandan *et al.* (2019b)
Egg production upto 52 weeks of age	-0.65±0.15 -0.56±0.21	-0.17±0.05 -0.22±0.05	Chandan *et al.* (2019a) Chandan *et al.* (2019b)
Egg production upto 64 weeks of age	-0.53±0.16 -0.49±0.20	-0.17±0.05 -0.21±0.05	Chandan *et al.* (2019a) Chandan *et al.* (2019b)
Egg weight at 28 weeks of age	0.66±0.12 0.68±0.13	0.25±0.05 0.11±0.05	Chandan *et al.* (2019a) Chandan *et al.* (2019b)
Egg weight at 40 weeks of age	0.69±0.12 0.61±0.12	0.25±0.05 0.22±0.05	Chandan *et al.* (2019a) Chandan *et al.* (2019b)
Egg weight at 52 weeks of age	0.77±0.13 0.31±0.16	0.24±0.05 0.19±0.06	Chandan *et al.* (2019a) Chandan *et al.* (2019b)
Egg weight at 64 weeks of age	0.60±.011 0.31±0.14	0.26±0.05 0.15±0.06	Chandan *et al.* (2019a) Chandan *et al.* (2019b)

Table 2.11 Correlations of body weight at 16 weeks of age with body weights, egg production and egg weights at various ages in White Leghorn

Body weight at 16 weeks of age with	r_g	r_p	r_e	Author(s)
Body weight at 20 weeks of age	Strain I 0.18±0.33 Control 0.11±0.44	Strain H -0.03 Strain I 0.10 Strain K 0.31 Control 0.07	Strain H 0.14 Strain I 0.09 Strain K 0.12 Control 0.07	Jaya Laxmi (2008)
	1.00±0.12	0.70±0.03		Chandan *et al.* (2019b)
Body weight at 40 weeks of age	0.33±0.17	0.40±0.02		Veeramani *et al.* (2008)
	Strain H -0.62±0.51 Strain I 0.20±0.26 Strain K 0.46±0.22 Control -0.22±0.30	Strain H 0.01 Strain I 0.04 Strain K 0.31 Control 0.08	Strain H 0.13 Strain I -0.01 Strain K 0.26 Control 0.17	Jaya Laxmi (2008)
	0.80±0.13	0.55±0.04		Chandan *et al.* (2019b)
	Strain N 0.74±0.06 Strain P 0.42±0.11	Strain N 0.08±0.02 Strain P 0.35±0.02		Churchil *et al.* (2019)
Egg production upto 40 weeks of age	–0.00±0.19	-0.04±0.02		Veeramani *et al.* (2008)
	Strain H 0.63±0.86 Strain I -0.15±0.28 Strain K	Strain H -0.07 Strain I 0.06 Strain K	Strain H -0.12 Strain I 0.11 Strain K	Jaya Laxmi (2008)

Body weight at 16 weeks of age with	r_g	r_p	r_e	Author(s)
	-0.47±0.57 Control 0.72±0.41	0.04 Control 0.15	0.11 Control 0.04	
	0.242±0.23	0.26±0.04		Chandan *et al.* (2019a)
	–0.50±0.33	0.06±0.06		Chandan *et al.* (2019b)
	Strain N 0.219±0.112 Strain P 0.090±0.135	Strain N 0.148±0.02 Strain P 0.093±0.02		Churchil *et al.* (2019)
Egg production upto 52 weeks of age	0.251 ±0.206	0.195 ±0.047		Chandan *et al.* (2019a)
	-0.555±0.270	0.032±0.058		Chandan *et al.* (2019b)
Egg production upto 64 weeks of age	-0.13±0.20	0.05±0.02		Veeramani *et al.* (2008)
	Strain H -0.024±0.522 Strain I -0.026±0.293 Strain K 0.294±0.405 Control -0.078±0.311	Strain H -0.069 Strain I -0.013 Strain K 0.092 Control 0.013	Strain H -0.077 Strain I -0.010 Strain K 0.055 Control 0.040	Jaya Laxmi (2008)
	0.285 ±0.225	0.164± 0.049		Chandan *et al.* (2019a)
	–0.488±0.266	0.002±0.058		Chandan *et al.* (2019b)
	Strain N -0.234±0.125 Strain P -0.030±0.138	Strain N 0.053±0.02 Strain P 0.027±0.02		Churchil *et al.* (2019)

Body weight at 16 weeks of age with	r_g	r_p	r_e	Author(s)
Egg weight at 28 weeks of age	0.18±0.17	0.15±0.02		Veeramani *et al.* (2008)
	Strain H -0.033±0.479 Strain I 0.101±0.207 Strain K 0.021±0.333 Control -0.141±0.434	Strain H 0.016 Strain I 0.100 Strain K 0.124 Control 0.148	Strain H 0.024 Strain I 0.106 Strain K 0.152 Control 0.216	Jaya Laxmi (2008)
	-0.177±0.216	0.039 ±0.047		Chandan *et al.* (2019a)
	0.534±0.0211	0.273±0.050		Chandan *et al.* (2019b)
	Strain N 0.159±0.107 Strain P 0.357±0.109	Strain N 0.172±0.02 Strain P 0.136±0.02		Churchil *et al.* (2019)
Egg weight at 40 weeks of age	0.30±0.17	0.18±0.02		Veeramani *et al.* (2008)
	Strain H -0.095±0.416 Strain I 0.168±0.241 Strain K 0.558±0.222 Control 0.038±0.299	Strain H 0.010 Strain I 0.037 Strain K 0.270 Control 0.134	Strain H 0.034 Strain I -0.005 Strain K 0.158 Control 0.169	Jaya Laxmi (2008)
	0.028 ±0.218	0.166 ±0.047		Chandan *et al.* (2019a)
	0.524±0.202	0.233±0.052		Chandan *et al.* (2019b)
	Strain N 0.222±0.103 Strain P 0.339±0.107	Strain N 0.236±0.02 Strain P 0.108±0.02		Churchil *et al.* (2019)

Body weight at 16 weeks of age with	r_g	r_p	r_e	Author(s)
Egg weight at 52 weeks of age	Strain H -0.009±0.420 Strain I 0.088±0.240 Strain K 0.541±0.247 Control -0.039±0.247	Strain H -0.008 Strain I -0.015 Strain K 0.169 Control 0.043	Strain H -0.099 Strain I -0.049 Strain K 0.033 Control 0.080	Jaya Laxmi (2008)
	-0.10 ±0.261	0.056 ±0.048		Chandan *et al.* (2019a)
	0.696±0.222	0.225±0.061		Chandan *et al.* (2019b)
Egg weight at 64 weeks of age	Strain H 0.508±0.446 Strain I -0.167±0.217 Strain K 0.133±0.247 Control -0.174±0.191	Strain H 0.006 Strain I -0.020 Strain K 0.082 Control -0.017	Strain H -0.135 Strain I 0.043 Strain K 0.061 Control 0.169	Jaya Laxmi (2009)
	0.167 ±0.107	0.154 ±0.052		Chandan *et al.* (2019a)
	0.606±0.190	0.349±0.048		Chandan *et al.* (2019b)
	Strain N 0.205±0.106 Strain P 0.327±0.109	Strain N 0.205±0.02 Strain P 0.086±0.02		Churchil *et al.* (2019)

Table 2.12 Correlations of body weight at 20 weeks of age with body weights, egg production and egg weights at various ages in White Leghorn

Body weight at 20 weeks of age with	r_g	r_p	r_e	Author(s)
Body weight at 40 weeks of age	0.92±0.03	0.46±0.03		Singh *et al.* (1986)
	0.86±0.02	0.64±0.01		Chaudary *et al.* (1988)
	0.96	0.58		Hazary (1988)
	0.54±0.17	0.46±0.04		Ferdoci *et al.* (1992)
	0.46±0.04	0.31±0.01		Sharma *et al.* (1994)
	0.67	0.44		Kumararaj *et al.* (1995)
	0.80±0.03	0.42±0.01		Sharma and Krishna (1998)
	0.74±0.10	0.54±0.02		Rahman *et al.* (2003)
	Strain H -0.33±0.55 Strain I 0.58±0.30 Strain K	 0.04 0.34		Chatterji *et al.* (2008)

Body weight at 20 weeks of age with	r_g	r_p	r_e	Author(s)
	-0.15±0.38 Strain C 0.85±0.01	0.26 0.26		
	Strain H 0.933±0.122 Strain I 0.421±0.291 Strain K 0.625±0.239 Control 0.921±0.546	Strain H 0.423 Strain I 0.434 Strain K 0.278 Control 0.275	Strain H 0.172 Strain I 0.441 Strain K 0.165 Control 0.211	Jaya Laxmi (2008)
	0.646±0.037	0.068±0.099		Chandan *et al.* (2019b)
Egg production upto 40 weeks of age	-0.05±0.07	0.23±0.01		Chaudhary *et al.* (1988)
	0.36±0.21	0.27±0.04		Ferdoci *et al.* (1992)
	1.78	0.04		Kumararaj *et al.* (1995)
	0.46±0.10	0.17±0.02		Sharma and Krishna (1998)

Body weight at 20 weeks of age with	**r_g**	**r_p**	**r_e**	**Author(s)**
	Generation 1 -0.10±0.09 (S) -0.11±0.10 (D) -0.10±0.09 (S+D) Generation 2 >1(S) -0.09±0.09 (D) -0.08±0.04 (S+D)	0.20(S) 0.24(S)		Singh *et al.* (2001)
	-0.08± 0.38	-0.23± 057		Devi (2002)
	0.173±0.136	0.046±0.025		Singh *et al.* (2002)
	0.22± 0.19	0.19±0.04		Rahman *et al.* (2003)
	0.122±0.25 (S) 0.311±0.20 (D) 0.256±0.170 (S+D)	0.032±0.025	0.046 -0.089	Sethi *et al.* (2003)

Body weight at 20 weeks of age with	**r_g**	**r_p**	**r_e**	**Author(s)**
	Strain H >1 Strain I 0.80±0.19 Strain K 0.32±0.40 Strain C 0.03±0.32	Strain H 0.04 Strain I 0.26 Strain K 0.18 Strain C 0.18	-0.050	Chatterjee *et al.* (2008)
	Strain H -0.568±0.416 Strain I -0.010±0.375 Strain K 0.101±0.602 Control -0.516±0.846	Strain H 0.026 Strain I 0.105 StrainK 0.175 Control -0.021	Strain H 0.148 Strain I 0.122 StrainK 0.185 Control 0.014	Jaya Laxmi (2008)
	-0.253± 0.245	0.153±0.071		Chandan *et al.* (2019b)
Egg production upto 52 weeks of age	–0.127±0.242	0.081±0.073		Chandan *et al.* (2019b)
Egg production upto 64 weeks of age	Strain H 0.150±0.274 Strain I	Strain H -0.002 Strain I	Strain H 0.170 Strain I	Jaya Laxmi (2008)

Body weight at 20 weeks of age with	r_g	r_p	r_e	Author(s)
	-0.433±0.390 Strain K0.035±0.472 Control 0.162±0.608 –0.004±0.243	0.030 Strain K0.021 Control 0.022 0.061±0.072	0.092 Strain K0.019 Control 0.008	Chandan *et al.* (2019b)
Egg weight at 28 weeks of age	Strain H -0.50±0.36 Strain I 0.09±0.28 Strain K 0.16±0.27 Strain C 0.70±0.14 Strain H 0.696±0.224 Strain I 0.515±0.272 Strain K -0.294±0.371 Control -0.215±0.847	Strain H 0.05 Strain I 0.11 Strain K 0.11 Strain C 0.15 Strain H 0.104 Strain I 0.066 Strain K 0.048 Control 0.096	 Strain H -0.128 Strain I -0.067 Strain K 0.121 Control 0.115	Chatterjee *et al.* (2008) Jaya Laxmi (2008)

Body weight at 20 weeks of age with	**r_g**	**r_p**	**r_e**	**Author(s)**
	0.667±0.180	0.257±0.063		Chandan *et al.* (2019b)
Egg weight at 40 weeks of age	0.43±0.19	0.06±0.03		Singh *et al.*(1986)
	0.57±0.04	0.26± 0.01		Chaudhary *et al.* (1988)
	-0.68±0.09	-0.05±0.03		Thangaraju and Ulanganathan (1990b)
	0.21±0.23	0.05±0.05		Ferdoci *et al.* (1992)
	-0.06±0.08	0.05±0.02		Sharma *et al.* (1994)
	0.04	0.14		Kumararaj *et al.* (1995)
	0.65±0.12	0.35±0.03		Rahman *et al.* (2003)
	Strain H -0.11± 0.41 Strain I 0.29± 0.24 Strain K	Strain H 0.02 Strain I 0.14 Strain K		Chatterjee *et al.* (2008)

Body weight at 20 weeks of age with	**r_g**	**r_p**	**r_e**	**Author(s)**
	-0.05± 0.27 Strain C 0.47± 0.22 Strain H 0.440±0.210 Strain I 0.515±0.321 Strain K 0.196±0.299 Control 0.999±0.758 0.670±0.154	0.15 Strain C 0.21 Strain H 0.049 Strain I 0.046 Strain K 0.164 Control -0.017 0.326±0.061	Strain H -0.170 Strain I -0.042 Strain K 0.159 Control -0.123	Jaya Laxmi (2008) Chandan *et al.* (2019b)
Egg weight at 52 weeks of age	Strain H 0.509±0.206 Strain I 0.190±0.316 Strain K 0.430±0.308 Control -0.547±0.512 0.747±0.162	Strain H 0.085 Strain I 0.088 Strain K 0.077 Control 0.063 0.429±0.069	Strain H -0.143 Strain I 0.071 Strain K -0.025 Control 0.157	Jaya Laxmi (2008) Chandan *et al.* (2019b)

Body weight at 20 weeks of age with	**r_g**	**r_p**	**r_e**	**Author(s)**
Egg weight at 64 weeks of age	Strain H 0.088±0.209 Strain I -0.010±0.293 Strain K 0.193±0.276 Control 0.135±0.374	Strain H 0.017 Strain I 0.068 Strain K 0.117 Control 0.017	Strain H -0.034 Strain I 0.094 Strain K 0.098 Control -0.021	Jaya Laxmi (2008)
	0.879±0.114	0.474±0055		Chandan *et al.* (2019b)

Alphabets within the parenthesis indicate the components used for estimation correlation
S = sire component, D = dam component, S+D = sire + dam component

Table 2.13 Correlations of body weight at 40 weeks of age with egg production and egg weights at various ages in White Leghorn

Body weight at 40 weeks of age with	r_g	r_p	r_e	Author(s)
Egg production upto 40 weeks of age	-0.48±0.21	-0.12±0.03		Singh *et al*.(1986)
	-0.46±0.05	0.02±0.01		Chaudhary *et al*.(1988)
	0.19	0.06		Hazary (1988)
	-0.35	0.06		Johari *et al*. (1988)
	-0.07±0.19	0.07±0.05		Ferdoci *et al*. (1992)
	0.15±0.06	-0.04±0.02		Sharma *et al*. (1994)
	-0.20±0.45	0.42±0.20		Devi (2002)
	Strain H 0.83±0.25 Strain I 0.24±0.72 Strain K -0.45±0.44 Strain C 0.42±0.25	Strain H 0.11 Strain I 0.08 Strain K -0.02 Strain C 0.10		Chatterjee *et al*. (2008)
	-0.08±0.20	-0.005±0.02		Veeramani *et al*. (2008)

Body weight at 40 weeks of age with	**r_g**	**r_p**	**r_e**	**Author(s)**
	Strain H -0.841±0.481 Strain I -0.241±0.284 Strain K -0.581±0.537 Control 0.076±0.533	Strain H -0.103 Strain I 0.044 Strain K -0.059 Control 0.057	Strain H 0.059 Strain I 0.107 Strain K 0.048 Control 0.055	Jaya Laxmi (2008)
	–0.165±0.21	-0.026±0.054		Chandan *et al.* (2019b)
	Strain N -0.054± 0.116 Strain P -0.048± 0.130	Strain N -0.104± 0.02 Strain P -0.051± 0.02		Churchil *et al.* (2019)
Egg production upto 52 weeks of age	–0.213±0.212	–0.045±0.055		Chandan *et al.* (2019b)
Egg production up to 64 weeks of age	Strain I -0.37± 1.38 0.25± 0.34 0.18± 0.26	Strain I 0.14± 0.04 Control 0.09± 0.05		Vasu *et al.* (2004a)

Body weight at 40 weeks of age with	r_g	r_p	r_e	Author(s)
	Control 0.02±0.44 -0.71± 0.34 <-1.00			
	0.28±0.19	0.11±0.02		Veeramani *et al.* (2008)
	Strain H -0.061±0.268 Strain I -0.109±0.302 Strain K -0.065±0.339- Control 0.066±0.417	Strain H -0.028 Strain I 0.018 Strain K -0.023 Control 0.002	Strain H -0.017 Strain I 0.044 Strain K -0.012 Control 0.013	Jaya Laxmi (2008)
	–0.160±0.212	–0.071±0.056		Chandan *et al.* (2019b)
	Strain N -0.070± 0.132 Strain P -0.061± 0.134	Strain N -0.237± 0.02 Strain P -0.174± 0.02		Churchil *et al.* (2019)
Egg weight at	Strain I	Strain I		

Body weight at 40 weeks of age with	r_g	r_p	r_e	**Author(s)**
28 weeks of age	0.82± 0.26 0.19± 0.27 0.25± 0.18 Control 0.77± 0.13 0.21± 0.69 0.58± 0.16	0.29± 0.04 Control 0.21± 0.05		Vasu *et al.* (2004a)
	Strain H -0.45±0.35 Strain I 0.40±0.39 Strain K 0.57±0.23 Strain C 0.46±0.22	StrainH 0.05 Strain I 0.23 Strain K 0.12 Strain C 0.15		Chatterjee *et al*. (2008)
	0.09±0.18	0.09±0.02		Veeramani *et al.* (2008)
	Strain H 0.547±0.214 Strain I 0.693±0.172 Strain K -0.100±0.270	Strain H 0.161 Strain I 0.143 Strain K 0.054	Strain H -0.007 Strain I -0.116 Strain K 0.125	Jaya Laxmi (2008)

Body weight at 40 weeks of age with	r_g	r_p	r_e	Author(s)
	Control -0.158±0.585	Control 0.087	Control 0.114	
	0.482±0.174	0.345±0.047		Chandan *et al.* (2019b)
	Strain N 0.282± 0.101 Strain P 0.219± 0.110	Strain N 0.268± 0.02 Strain P 0.140± 0.02		Churchil *et al.* (2019)
Egg weight at 40 weeks of age	-0.69±0.12	0.33±0.03		Singh *et al.*(1986)
	0.65±0.03	0.39±0.01		Chaudhary *et al.*(1988)
	>1.00	0.24		Hazary (1988)
	0.45±0.16	0.24±0.05		Fedoci *et al.* (1992)
	0.39±0.07	0.17±0.02		Sharma *et al.* (1994)
	-0.87	0.18		Kumararaj *et al.*(1995)
	0.57			Singh *et al.*(1995)
	Strain I	Strain I		

Body weight at 40 weeks of age with	**r_g**	**r_p**	**r_e**	**Author(s)**
	0.59± 0.54 0.25± 0.26 0.29± 0.18 Control 0.37± 0.25 >1.00 0.91± 0.05	0.31± 0.04 Control 027± 0.05		Vasu *et al*. (2004a)
	Strain H -0.26±0.35 Strain I 0.11±0.32 Strain K -0.59±0.21 Strain C 0.58±0.18	Strain H 0.10 Strain I 0.20 Strain K 0.20 Strain C 0.12		Chatterjee *et al*. (2008)
	-0.14±0.19	0.08±0.02		Veeramani *et al.* (2008)
	Strain H 0.472±0.191 Strain I 0.318±0.239 Strain K	Strain H 0.128 Strain I 0.121 Strain K	Strain H -0.089 Strain I 0.064 Strain K	Jaya Laxmi (2008)

Body weight at 40 weeks of age with	r_g	r_p	r_e	Author(s)
	0.452±0.193 Control 0.673±0.379	0.214 Control 0.092	0.054 Control -0.008	
	0.551±0.144	0.405±0.045		Chandan *et al.* (2019b)
	Strain N 0.370± 0.095 Strain P 0.425± 0.096	Strain N 0.307± 0.02 Strain P 0.135± 0.02		Churchil *et al.* (2019)
Egg weight at 52 weeks of age	Strain H 0.586±0.193 Strain I 0.125±0.244 Strain K 0.621±0.195 Control 0.443±0.302	Strain H 0.049 Strain I 0.167 Strain K 0.108 Control 0.157	Strain H -0.276 Strain I 0.181 Strain K -0.203 Control 0.088	Jaya Laxmi (2008)
	0.694±0.150	0.349±0.054		Chandan *et al.* (2019b)
Egg weight at 64 weeks of age	Strain I 0.47± 0.47	Strain I 0.21± 0.04		

Body weight at 40 weeks of age with	r_g	r_p	r_e	Author(s)
	0.68± 0.17 0.47± 0.15 Control 0.69± 0.17 0.16± 1.64 0.53± 0.18	 Control 0.16± 0.05		Vasu *et al.* (2004a)
	Strain H 0.221±0.195 Strain I 0.313±0.215 Strain K 0.347±0.191 Control 0.398±0.246	Strain H 0.073 Strain I 0.102 Strain K 0.088 Control 0.074	Strain H -0.047 Strain I 0.020 Strain K -0.151 Control -0.114	Jaya Laxmi (2008)
	0.687±0.121	0.444±0.044		Chandan *et al.* (2019b)
	Strain N 0.386± 0.097 Strain P 0.370± 0.103	Strain N 0.267± 0.02 Strain P 0.120± 0.02		Churchil *et al.* (2019)

2.3.3 Body Weight at 16 Weeks of Age with Other Traits

The genetic, phenotypic and environmental correlations of body weight at 16 weeks with body weights at 20, 40 weeks of age, egg production up to 40, 52 and 64 weeks and egg weights at 28, 40, 52 and 64 weeks of age in White Leghorn were presented in table 2.11.

In majority of reports the body weight at 16 weeks of age showed a moderate positive genetic, phenotypic and environmental correlation with body weight at 20 and 40 weeks. However a high genetic correlation of 1.00±0.115 was observed in H strains of White Leghorn was reported by Chandan *et al.* (2019b).

The genetic correlation between 16 week body weight with egg production up to 40, 52 ad 64 week of age varied widely in both magnitude and direction in several reports suggesting a low to moderate correlation.

Majority of reports showed a positive genetic and phenotypic correlation between 16 week body weight and egg weight at 28, 40, 52 and 64 weeks of age, however some studies reported a negative correlation of a very low magnitude.

2.3.4 Body Weight at 20 Weeks of Age with Other Traits

The estimates of genetic, phenotypic and environmental correlations of body weight at 20 weeks of age with 40 week body weight, egg production and egg weights at different ages as reported in literature on White Leghorn were presented in table 2.12.

Most of the reports depicted a positive and high genetic correlation between body weights at 20 and 40 weeks of age. However negative genetic correlation of moderate magnitude was observed by Chatterjee *et al*. (2008). All the reviewed reports suggested a positive phenotypic and environmental correlation between these two traits.

The genetic correlation between body weight at 20 weeks and egg production up to 40 weeks of age varied both in magnitude and direction with some reports suggesting a correlation as high as >1. A positive phenotypic and environmental correlation was found between the two traits in most of the reports.

Body weight at 20 weeks of age mostly showed a genetic as well as phenotypic correlation of low magnitude with egg production up to 52 and 64 weeks of age.

The genetic, phenotypic correlation between body weight at 20 weeks and egg weight at 28, 40, 52 and 64 weeks was positive in most of the reports, however few reports suggested a negative correlation.

2.3.5 Body Weight at 40 weeks of Age with Other Traits

The genetic, phenotypic and environmental correlations of body weight at 40 weeks of age with egg production and egg weights at various ages as reported in literature on White Leghorn was presented in table 2.13.

The genetic correlation of 40 week body weight with egg production up to 40 weeks varied both in direction and magnitude from -0.841±0.481 (Jaya Laxmi, 2008) to 0.83±0.25 (Chatterjee *et al.*, 2008). The phenotypic and environmental correlation were found to be low in magnitude.

Body weight at 40 weeks of age showed a negative genetic correlation with egg production up to 52 and 64 weeks of age in most of the literature reviewed however a few reports suggested a positive correlation. The phenotypic and environmental correlations were found to be of low magnitude.

The genetic, phenotypic and environmental correlations between 40 week body weight with egg weight at 28, 40, 52 and 64 weeks were found to be positive and moderate in most of reports.

2.3.6 Egg Production up to 40 Weeks of Age with other Traits

Correlations of egg production up to 40 weeks of age with egg production and egg weights at various ages in White Leghorn as reported in the literature was presented in table 2.14.

The genetic, phenotypic and environmental correlation between egg production up to 40 weeks of age with egg production upto 52 and 64 weeks of age is positive in direction in all the literature reviewed with a moderate to high magnitude.

However the phenotypic correlation was found to be negative in direction and low in magnitude in most of the reports. Majority of reports were depicting a negative genetic correlation between egg production up to 40 weeks with egg weights at 28, 40, 52 and 64 weeks of age with a few reports showing a positive correlation with varying magnitude.

2.3.7 Egg Production up to 52 weeks of Age with Other Traits

Genetic and phenotypic correlations of egg production up to 52 weeks of age with egg production up to 64 weeks of age and egg weights at various ages were presented in table 2.15.

A positive strong genetic and phenotypic correlation was reported between egg production up to 52 and 64 weeks of age by Chandan *et al.* (2019a) and Chandan *et al.* (2019b) in K and H strains of White Leghorn respectively.

The genetic correlation between egg production up to 52 weeks and egg weights at 28, 40, 52 and 64 weeks of age are found to be negative in direction and moderate in magnitude. Similarly a negative phenotypic correlation was observed and reported between 52 week egg production with egg weights at different ages.

Table 2.14 Correlations of egg production up to 40 weeks of age with egg production and egg weights at various ages in White Leghorn

Egg production upto 40 weeks with	r_g	r_P	r_e	Author(s)
Egg production upto 52 weeks of age	0.867±0.090	0.790±0.018		Chandan *et al.* (2019a)
	0.976±0.036	0.922±0.008		Chandan *et al.* (2019b)
Egg production upto 64 weeks of age	0.71±0.11	0.67±0.02		Veeramani *et al.* (2008)
	Strain H 0.382±0.395 Strain I 0.789±0.196 Strain K 0.524±0.568 Control 0.505±0.473	Strain H 0.313 Strain I 0.445 Strain K 0.385 Control 0.301	Strain H 0.307 Strain I 0.382 Strain K 0.374 Control 0.280	Jaya Laxmi (2008)
	0.837±0.090	0.79 ±0.018		Chandan *et al.* (2019a)
	0.833±0.129	0.779±0.020		Chandan *et al.* (2019b)
	Strain N 0.824±0.045 Strain P 0.944±0.027	Strain N 0.783±0.01 Strain P 0.796±0.01		Churchil *et al.* (2019)
Egg weight at 28 weeks of age	Strain H -0.95± 0.06 Strain I 0.33± 0.42 Strain K -0.90± 0.08 Strain C -0.03± 0.25	Strain H -0.01 Strain I -0.05 Strain K -0.09 Strain C -0.04		Chatterjee *et al.* (2008)
	-0.50±0.14	-0.14±0.02		Veeramani *et al.* (2008)
	Strain H	Strain H	Strain H	

Egg production upto 40 weeks with	r_g	r_P	r_e	**Author(s)**
	-0.117±0.424 Strain I -0.636±0.227 Control 0.199±0.826	-0.106 Strain I -0.145 Strain K -0.030 Control -0.106	-0.107 Strain I 0.058 Strain K 0.120 Control -0.127	Jaya Laxmi (2008)
	-0.678±0.20	-0.213±0.045		Chandan *et al.* (2019a)
	–0.657±0.275	–0.296±0.049		Chandan *et al.* (2019b)
	Strain N -0.388±0.107 Strain P -0.063±0.117	Strain N -0.084±0.02 Strain P 0.029±0.02		Churchil *et al.* (2019)
Egg weight at 40 weeks of age	0.10±0.29	0.08±0.02		Verma *et al.* (1983)
	-0.48			Nayak and Mishra (1985)
	-0.36± 0.06	-0.19±0.01		Chaudhary *et al.* (1988)
	-0.59±0.11	-0.26± 0.03		Thangaraju and Ulaganathan (1990b)
	<-1.00	-0.28		Hazary (1991)
	0.10±0.09	-0.09±0.02		Sharma *et al.* (1994)
	-0.24±0.10	-0.11±0.02		
	0.262± 0.28	-1		Singh *et al.* (1996)
	-0.385±0.170	-0.117±0.025		Sabri *et al.* (1999)
	-0.520±0.176 (S)	-0.164±0.025 (S)	-0.052(S) -0.038(D)	Singh *et al.* (2002)

Egg production upto 40 weeks with	r_g	r_P	r_e	**Author(s)**
	-0.611±0.177 (D) -0.562±0.135 (S+D)		-0.045 (S+D)	Sethi *et al.* (2003)
	Strain H 0.84±0.16 Strain I 0.30±0.41 Strain K <-1 Strain C -0.16±0.25	Strain H -0.01 Strain I 0.01 Strain K -0.10 Strain C -0.01		Chatterjee *et al.* (2008)
	-0.31±0.18	-0.005±0.02		Veeramani *et al.* (2008)
	Strain H -0.629±0.423 Strain I -0.354±0.272 Strain K 0.349±0.499 Control 0.615±0.608	Strain H -0.088 Strain I -0.093 Strain K -0.038 Control -0.073	Strain H 0.043 Strain I -0.025 Strain K -0.116 Control -0.154	Jaya Laxmi (2008)
	-0.553±0.207	-0.233±0.044		Chandan *et al.* (2019a)
	–0.377±0.298	–0.057±0.053		Chandan *et al.* (2019b)
	Strain N -0.448±0.109 Strain P -0.016±0.124	Strain N -0.180±0.02 Strain P -0.071±0.02		Churchil *et al.* (2019)
Egg weight at 52 weeks of age	Strain H -0.526±0.394 Strain I -0.068±0.262 Strain K -0.482±0.543 Control	Strain H -0.012 Strain I 0.070 Strain K -0.033 Control	Strain H 0.115 Strain I 0.108 Strain K 0.041 Control	Jaya Laxmi (2008)

Egg production upto 40 weeks with	r_g	r_P	r_e	Author(s)
	-0.369±0.457	-0.015	0.044	
	-0.249±0.292	-0.176±0.045		Chandan *et al.* (2019a)
	–0.375±0.321	–0.263±0.059		Chandan *et al.* (2019b)
Egg weight at 64 weeks of age	Strain H -0.137±0.334 Strain I -0.119±0.239 Strain K -0.197±0.429 Control -0.461±0.369	Strain H 0.028 Strain I -0.013 Strain K 0.017 Control 0.005	Strain H 0.091 Strain I 0.025 Strain K 0.076 Control 0.217	Jaya Laxmi (2008)
	-0.267±0.210	-0.167±0.050		Chandan *et al.* (2019a)
	–0.432±0.276	–0.190±0.051		Chandan *et al.* (2019b)
	Strain N -0.235±0.116 Strain P 0.075± 0.126	Strain N -0.091±0.02 Strain P 0.017±0.02		Churchil *et al.* (2019)

Alphabets within the parenthesis indicate the components used for estimation of correlation
S = sire component, D = dam component, S+D = sire + dam component

Table 2.15 Correlations of egg production upto 52 weeks of age with egg production up to 64 weeks of age and egg weights at various ages in White Leghorn

Egg production upto 52 weeks of age with	r_g	r_p	Author(s)
Egg production up to 64 weeks of age	0.968±0.023	0.933±0.006	Chandan *et al.* (2019a)
	0.926±0.050	0.918±0.008	Chandan *et al.* (2019b)
Egg weight at 28 weeks of age	-0.552±0.231	-0.170±0.046	Chandan *et al.* (2019a)
	–0.490±0.245	–0.288±0.050	Chandan *et al.* (2019b)
Egg weight at 40 weeks of age	-0.467±0.232	-0.222±0.044	Chandan *et al.* (2019a)
	–0.414±0.243	–0.105±0.053	Chandan *et al.* (2019b)
Egg weight at 52 weeks of age	-0.334±0.301	-0.187±0.045	Chandan *et al.* (2019a)
	–0.266±0.283	–0.303±0.057	Chandan *et al.* (2019b)
Egg weight at 64 weeks of age	-0.509±0.380	-0.157±0.048	Chandan *et al.* (2019a)
	–0.348±0.296	–0.235±0.050	Chandan *et al.* (2019b)

Table 2.16 Correlations of egg production up to 64 weeks of age with egg weights at various ages in White Leghorn

Egg production upto 64 weeks of age with	r_g	r_p	r_e	Author(s)
Egg weight at 28 weeks of age	Strain I <-1.00 -0.02±0.43 -0.32±0.25 Control -0.12±0.48 <-1.00 <-1.00	Strain I -0.03±0.04 Control -0.03±0.05		Vasu *et al.* (2004a)
	-0.28±0.19	-0.02±0.02		Veeramani *et al.* (2008)
	Strain H -0.478±0.289 Strain I -0.604±0.224 Strain K -0.562±0.463 Control -0.235±0.627	Strain H 0.013 Strain I 0.015 Strain K -0.042 Control -0.019	Strain H 0.161 Strain I 0.269 Strain K 0.046 Control 0.002	Jaya Laxmi (2008)
	-0.356±0.237	-0.162±1.00		Chandan *et al.* (2019a)
	–0.355±0.205	–0.186±0.056		Chandan *et al.* (2019b)
	Strain N -0.293± 0.122 Strain P 0.006± 0.126	Strain N -0.073± 0.02 Strain P 0.013± 0.02		Churchil *et al.* (2019)
Egg weight at 40 weeks of age	Strain I -0.90 0.17 0.29 0.36 0.004 0.27 Control -0.59 0.28 -0.16 0.85 <-1.00	Strain I -0.10 0.04 Control -0.01 0.05		Vasu *et al.* (2004a)

Egg production upto 64 weeks of age with	**r_g**	**r_p**	**r_e**	**Author(s)**
	-0.16±0.20	-0.03±0.02		Veeramani *et al.* (2008)
	Strain H -0.378±0.256 Strain I -0.523±0.271 Strain K -0.227±0.369 Control 0.188±0.421	Strain H -0.044 Strain I 0.005 Strain K -0.090 Control -0.058	Strain H 0.097 Strain I 0.133 Strain K -0.059 Control -0.098	Jaya Laxmi (2008)
	-0.450±0.223	-0.253±0.046		Chandan *et al.* (2019a)
	–0.402±0.171	–0.228±0.054		Chandan *et al.* (2019b)
	Strain N -0.455± 0.120 Strain P -0.073± 0.124	Strain N -0.150± 0.02 Strain P -0.053± 0.02		Churchil *et al.* (2019)
Egg weight at 52 weeks of age	Strain H -0.403±0.258 Strain I -0.238±0.272 Strain K -0.169±0.377 Control -0.503±0.344	Strain H -0.037 Strain I 0.016 Strain K -0.050 Control -0.014	Strain H 0.114 Strain I 0.080 Strain K -0.024 Control 0.101	Jaya Laxmi (2008)
	-0.402 ±0.282	-0.215±0.047		Chandan *et al.* (2019a)
	–0.119±0.226	–0.276±0.060		Chandan *et al.* (2019b)
Egg weight at 64 weeks of age	Strain I 0.16 0.60 0.08 0.60 0.10 0.26 Control	Strain I 0.03 0.04 Control		Vasu *et al.* (2004a)

Egg production upto 64 weeks of age with	$\mathbf{r_g}$	$\mathbf{r_p}$	$\mathbf{r_e}$	**Author(s)**
	-0.96 0.04 <-1.00 <-1.00	-0.10 0.05		
	Strain H 0.070±0.237 Strain I -0.361±0.249 Strain K -0.438±0.352 Control -0.199±0.269	Strain H 0.091 Strain I -0.041 Strain K -0.106 Control -0.085	Strain H 0.112 Strain I 0.064 Strain K -0.004 Control -0.047	Jaya Laxmi (2008)
	-0.430 ±0.188	-0.234 ±1.00		Chandan *et al.* (2019a)
	0.319±0.319	-0.308±0.049		Chandan *et al.* (2019b)
	Strain N -0.274± 0.126 Strain P 0.000± 0.123	Strain N -0.118± 0.02 Strain P 0.010± 0.02		Churchil *et al.* (2019)

Table 2.17 Correlations of egg weight at 28 weeks of age with egg weights at various ages in White Leghorn as reported in the literature

Egg weights at 28 weeks of age with	$\mathbf{r_g}$	$\mathbf{r_p}$	$\mathbf{r_e}$	**Author(s)**
Egg weight at 40 weeks of age	Strain I 0.81± 0.15 Control >1.00	Strain I 0.05± 0.04 Control 0.46± 0.05		Vasu *et al.* (2004a)
	0.94±0.02	0.56±0.02		Veeramani *et al.* (2008)
	Strain H 0.779±0.136 Strain I 0.840±0.104 Strain K 0.622±0.204 Control -0.669±0.483	Strain H 0.475 Strain I 0.435 Strain K 0.421 Control 0.350	Strain H 0.332 Strain I 0.221 Strain K 0.357 Control 0.460	Jaya Laxmi (2008)
	0.888 ±0.078 1.000±0.060	0.653 ±0.026 0.641±0.031		Chandan *et al.* (2019a)
	Strain N 0.833± 0.043 Strain P 0.892± 0.036	Strain N 0.581± 0.02 Strain P 0.548± 0.02		Chandan *et al.* (2019b)
				Churchil *et al.* (2019)
Egg weight at 52 weeks of age	Strain H 0.863±0.154 Strain I 0.318±0.182 Strain K 0.601±0.243 Control 0.422±0.485	Strain H 0.322 Strain I 0.164 Strain K 0.244 Control 0.113	Strain H 0.067 Strain I 0.076 Strain K 0.128 Control 0.074	Jaya Laxmi (2008)
	0.722 ±0.162	0.325 ±0.034		Chandan *et al.* (2019a)

Egg weights at 28 weeks of age with	r_g	r_p	r_e	Author(s)
	1.000±0.084	0.580±0.039		Chandan *et al.* (2019b)
Egg weight at 64 weeks of age	Strain I 0.64± 0.19 Control >1.00	Strain I 0.29± 0.04 Control 0.25± 0.05		Vasu *et al.* (2004a)
	Strain H 0.453±0.188 Strain I 0.632±0.133 Strain K -0.035±0.261 Control 0.081±0.373	Strain H 0.274 Strain I 0.206 Strain K 0.048 Control 0.060	Strain H 0.178 Strain I -0.137 Strain K 0.095 Control 0.085	Jaya Laxmi (2008)
	0.690 ±0.117	0.543 ±0.035		Chandan *et al.* (2019a)
	0.999±0.063	0.610±0.034		Chandan *et al.* (2019b)
	Strain N 0.669± 0.067 Strain P 0.875± 0.038	Strain N 0.502± 0.02 Strain P 0.545± 0.02		Churchil *et al.* (2019)

Table 2.18 Correlations among egg weights at 40, 52, 64 weeks of age in White Leghorn

	r_g	r_P	r_e	Author(s)
Egg weight at 40 weeks of age with egg weight at 52 weeks of age	Strain H 0.890±0.111 Strain I 0.477±0.203 Strain K 0.735±0.163 Control 0.788±0.282	Strain H 0.385 Strain I 0.139 Strain K 0.338 Control 0.158	Strain H 0.038 Strain I 0.017 Strain K 0.133 Control 0.003	Jaya Laxmi (2008)
	0.890 ±0.117	0.629 ±0.028		Chandan *et al.* (2019a)
	0.982±0.031	0.787±0.023		Chandan *et al.* (2019b)
Egg weight at 40 weeks of age with egg weight at 64 weeks of age	Strain I 0.21± 1.17 Control >1.00	Strain I -0.03± 0.04 Control 0.34± 0.05		Vasu *et al.* (2004a)
	Strain H 0.405±0.167 Strain I 0.766±0.137 Strain K 0.295±0.201 Control 0.231±0.250	Strain H 0.269 Strain I 0.291 Strain K 0.189 Control 0.073	Strain H 0.145 Strain I 0.069 Strain K 0.110 Control -0.005	Jaya Laxmi (2008)
	0.877 ±0.063	0.693 ±0.026		Chandan *et al.* (2019a)
	0.937±0.038	0.782±0.022		Chandan *et al.* (2019b)
	Strain N 0.862± 0.038 Strain P 0.940± 0.026	Strain N 0.601± 0.02 Strain P 0.598± 0.02		Churchil *et al.* (2019)
Egg weight at 52 weeks of age with egg	Strain H 0.482±0.161 Strain I	Strain H 0.277 Strain I	Strain H 0.099 Strain I	Jaya Laxmi

	r_g	r_P	r_e	Author(s)
weight at 64 weeks of age	0.553±0.173 Strain K 0.218±0.212 Control 0.457±0.183	0.137 Strain K 0.291 Control 0.190	-0.070 Strain K 0.353 Control -0.019	(2008)
	0.978 ±0.070	0.619 ±0.031		Chandan *et al.* (2019a)
	0.988±0.032	0.784±0.023		Chandan *et al.* (2019b)

2.3.8 Egg Production up to 64 Weeks of Age with Egg Weights at Different Ages

The genetic, phenotypic and environmental correlations of egg production up to 64 weeks of age with egg weights at different ages as reported in literature were presented in table 2.16.

In most of the studies the egg production up to 64 weeks correlated negatively (phenotypic and genetic) with egg weights at 28, 40, 52 and 64 weeks of age, whereas positive correlation was observed in few reports.

2.3.9 Egg Weight at 28 Weeks with Egg Weights at Different Ages

The genetic, phenotypic and environmental correlations of egg weight at 28 weeks of age with egg weights at various ages in White Leghorn as reported in the literature was summarized in table 2.17.

Egg weight at 28 weeks showed a positive genetic, phenotypic and environmental correlation with egg weights at 40, 52 and 64 weeks in all the reports except a negative genetic correlation between egg weight at 28 and 40 weeks in control population and a negative genetic and environmental correlation between egg weight at 28 and 64 weeks in K and I strains respectively by Jaya Laxmi (2008). The genetic correlations were found to be higher in magnitude than the phenotypic correlations.

2.3.10 Among Egg Weights at 40, 52 and 64 Weeks of Age

The genetic, phenotypic and environmental correlations between egg weights at 40, 52 and 64 weeks of age were shown in table 2.18.

Positive genetic correlation of high magnitude was observed between egg weight at 40 and 52 weeks from the literature reviewed. The phenotypic and environmental correlations between the above traits were found to be positive.

The genetic, phenotypic and environmental correlations between egg weights at 40 and 64 weeks of age were found to be positive in all the reports, except that a negative phenotypic correlation of -0.03± 0.04 in I strain and a negative environmental correlation of -0.005 in control population of White Leghorn were reported by Vasu *et al.* (2004a) and Jaya Laxmi (2008) respectively.

The reported genetic and phenotypic correlations between 52 and 64 weeks egg weights were positive.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The study was carried out at the experimental poultry farm of ICAR-Directorate of Poultry Research, Hyderabad, Telangana, India. Hyderabad is in Deccan plateau in southern part of India placed between 17°23’ N and 78° 28’ E at 500 m from mean sea level. The location experienced usually hot and humid tropical with maximum temperature ranged from 20 °C in winter to 45 °C in summer.

3.1 Experimental Population and Management

The present study was carried out on IWI layer line maintained at Directorate of Poultry Research, Hyderabad. IWI Line was brought to Andhra Pradesh Agricultural University (APAU), Hyderabad under AICRP – PB Project. Fertile eggs of IWI were obtained from AICRP on Poultry Breeding, Hyderabad and hatched at PDP, Hyderabad in the month of December 1995 (DPR, 1995-96). In initial generations (S-0), no selection for any of the traits was practiced and the germplasm was evaluated for production traits up to 72 weeks of age (ICAR-Directorate of Poultry Research, 1996-97). Egg production up to 72 weeks of age in IWI line was 261.2. In S-1 generation, birds were selected through Osborne index for higher egg production up to 56 weeks of age. However, from S-2 generation onwards the criterion of selection used was Osborne index for higher egg production up to 64weeks of age.

As per the recommendations of the Quinquennial Review Team (QRT), populations of IWI lines maintained at PDP, Hyderabad were replaced with those from Central Avian Research Institute, Izatnagar maintained under AICRP on Poultry Breeding for egg production. A total of 2000 fertile eggs of IWI line were procured and hatched during the year 2008-09 (ICAR-Directorate of Poultry Research, 2008-09). IWI lines were evaluated for egg production traits up to 72 weeks of age and have undergone selection for higher egg production up to 64 weeks of age using Osborn index.

About 1500-2200 chicks were hatched in every generation of IWI line. About 500-600 adult females were housed for performance recording. About 200-250 dams and 40-50 sires were selected in each generation. Each sire was mated to five dams and progeny produced were utilized in the present study for the estimation of genetic parameters.

The chicks were reared in a deep litter brooder house till 16 weeks. In the brooder, the temperature was scheduled from 33°C during first week to 23°C at the end of fifth week in an open-sided house under standard management practices. The debeaking of the chicks was done on 4^{th}–5^{th} day. The chicks were fed ad lib with layer starter (2,900 kcal/kg ME and 22% CP) diet based on maize-soybean meal up to 16 weeks. Sexing was done at 6 weeks and male and females were separated. At the end of the 16 weeks period, 500-600 females and 200 males were transferred to individual cages in cage house. The individual data recordings of body weight, Age at sexual maturity and egg production and egg weights were done regularly. After 16 weeks adult females and males were given layer and male breeder rations respectively. The eight hours of day light and 7 h of artificial light were provided in the layer house. In the summer, proper ambience temperature was maintained through sprinklers on roof top. The mortality in the flock was within the standard limit. The egg production was recorded daily. The birds were vaccinated against Marek's disease (1^{st} day), Newcastle disease (ND), Lasota (7^{th} and 30^{th} day), Infectious Bursal Disease (14^{th} and 26^{th} day), fowl pox (6^{th} week), New Castle Disease R2B (9^{th} week), Infectious Bronchitis (IB) and New Castle Disease inactivated (18^{th} week).

3.2 DATA AND TRAITS STUDIED

The data collected from last four generations G-4 (2015-2016) G-5 (2017-2018) G-6 (2018-2019) and G-7 (2020-2021) were used in the present study. Growth traits such as body weights on day of hatch (BW0), 16 (BW16), 20 (BW20) and 40 (BW40) weeks, were measured to 0.1g accuracy using digital balance. Production parameters like age at sexual maturity (ASM), the age in days at the time of laying its first egg was taken as age at sexual maturity. Egg weights at 28 (EW28), 40 (EW40), 52 (EW52) and 64 (EW64) weeks. The egg weights were recorded using a digital balance to an accuracy of 0.01g and egg productions up to 40 (EP40), 52(EP52) and 64 (EP64) weeks were recorded. The female birds were housed in individual cages at 16 weeks and the egg production data of individual birds were recorded every day. For egg weights at 52 (EW52) and 64 (EW64) weeks and egg productions up to

52(EP52) and 64 (EP64) weeks, data from G-7 was not taken because they were under recording. The detailed characteristics of data are presented in Table 3.1.

Table 3.1 Characteristics of data on growth and production traits of IWI line chicken

Items	No. of birds with records	No. of sires	No. of sires with progeny	No. of sires with records and progeny	No. of dams	No. of dams with progeny	No. of dams with records and progeny	Mean
BW0	5238	152	152	108	546	546	424	33.95
BW4	4168	152	152	99	537	536	365	184.42
BW8	4247	152	152	103	535	534	383	431.52
BW16	2499	150	150	59	477	475	362	970.16
BW20	1824	148	136	0	457	423	258	1100.15
BW40	1434	147	133	0	425	386	229	1396.50
ASM	1845	149	149	0	474	472	369	145.22
EP40	1328	138	121	0	417	373	211	113.16
EP52	1094	102	100	0	281	277	192	179.14
EP64	1053	102	100	0	278	274	189	243.53
EW28	1404	147	134	0	436	399	225	47.08
EW40	1323	146	132	0	420	378	214	54.01
EW52	1048	102	100	0	276	272	187	53.42
EW64	833	99	97	0	260	236	68	55.06

BW0: Day old body weight (g), BW4: 4^{th} week body weight(g), BW8: 8^{th} week body weight(g), BW16: 16^{th} week body weight(g), BW20: 20^{th} week body weight(g), BW40: 40^{th} week body weight(g), ASM: Age at sexual maturity(d), EP40: 40week egg production(no.), EP52: 52 week egg production(no.), EP64: 64 week egg production(no.). EW28: 28^{th} week egg weight(g), EW40: 40^{th} week egg weight(g), EW52: 52^{nd} week egg weight(g), EW64: 64^{th}week egg weight(g).

3.3 STATISTICAL ANALYSIS

Variance and covariance components were estimated by average information restricted maximum likelihood (AIREML) fitting an animal model. Data were first analyzed by least squares analysis of variance (SPSS 12) to identify the fixed effects to be included in the model. Duncan's Multiple Range Test (Duncan, 1995) was used for identifying the significant effects on the traits.

The statistical model for generation and hatch effect was

$Y_{ijk} = u + h_i + G_j + e_{ijk}$

Where

$Y_{ijk} =$ measurement of a trait on k^{th} bird belonging to j^{th} generation of i^{th} hatch

u = overall mean

h_i = effect of i^{th} hatch

G_j = effect j^{th} generation

e_{ijk} = uncontrolled environmental and genetic deviations attributable to the individuals

For BW0, BW16, BW20, BW40, ASM, EP40 and EW28, EW40 the statistical model included the fixed effect of generations (4 levels) and hatch number (5 levels) and for EP52, EP64, EW52, EW64 generations (3 levels) and hatch number (5 levels). Only significant effects ($P \leq 0.05$) were included in the models, which were subsequently used for the genetic analysis.

Univariate animal models were fitted to estimate (co)variance components for all the traits. The six single–trait models used to estimate variance components are defined as follows:

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z_a a} + \boldsymbol{\varepsilon} \quad (1)$$

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z_a a} + \mathbf{Z_m m} + \boldsymbol{\varepsilon} \text{ with Cov } (a_m, m_o) = 0 \quad (2)$$

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z_a a} + \mathbf{Z_m m} + \boldsymbol{\varepsilon} \text{ with Cov } (a_m, m_o) = \mathbf{A}\sigma_{am} \quad (3)$$

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z_a a} + \mathbf{Z_{pe} pe} + \boldsymbol{\varepsilon} \quad (4)$$

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z_a a} + \mathbf{Z_m m} + \mathbf{Z_{pe} pe} + \boldsymbol{\varepsilon} \text{ with Cov } (a_m, m_o) = 0 \quad (5)$$

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z_a a} + \mathbf{Z_m m} + \mathbf{Z_{pe} pe} + \boldsymbol{\varepsilon} \text{ with Cov } (a_m, m_o) = \mathbf{A}\sigma_{am} \quad (6)$$

Where **y** is the vector of records; $\boldsymbol{\beta}$, **a, m, p, e** and $\boldsymbol{\varepsilon}$ are vectors of fixed, direct additive genetic, maternal additive genetic, permanent environmental effects of the dam, and residual effects, respectively; with association matrices X, $\mathbf{Z_a}$, $\mathbf{Z_m}$ and $\mathbf{Zpe}$;

A is the numerator relationship matrix between animals; and σ_{am} is the covariance between additive direct and maternal genetic effects. Assumptions for variance (**V**) and covariance (**Cov**) matrices involving random effects were **V**(a) = **A**σ^2_a, **V**(m) = **A**$\sigma^2_{m,}$ **V**(c) = **I**σ^2_c, **V**(e) = **I**σ^2_e, and **Cov**(a,m) = **A**σ_{am} , where **I** is an identity matrix and $\sigma^2_{a,}$ $\sigma^2_{m,}$ σ^2_c and σ^2_e are additive direct (a), additive maternal (m), maternal permanent environmental (c) and residual variances (e), respectively. The heritability (h^2) was calculated as $h^2= \sigma^2_a/\sigma^2_{p,}$ where $\sigma^2_p=\sigma^2_a+ \sigma^2_m + \sigma_{am} + \sigma^2_c+ \sigma^2_e$. The m^2, r_{am} and c^2 were calculated as $m^2= \sigma^2_{m/}\sigma^2_p$, $r_{am}=\sigma_{am}/\sigma^2_p c^2= \sigma^2_{c/}\sigma^2_{p,}$ respectively. The total heritability (h^2_t), was calculated using the formula $h^2_t= h^2 + 0.5m^2 + 1.5mr_{am}h$ (Willham RL, 1972). Akaike's Information Criterion (AIC) was used for selecting the best model among the tested models (Meyer K, 1992). The model with lowest AIC value was chosen as the most appropriate model and used to study the genetic parameters.

The best models from the single trait analyses were combined with appropriate (co)variance between random effects in the model for the bivariate analysis. The best model identified for a specific trait using likelihood ratio test was only used for the bivariate analysis. The estimates of genetic parameters i.e., genetic, phenotypic and environmental correlations between different economic traits were obtained by AIREML fitting an animal model WOMBAT (Meyer K, 2007). To test the significance of the genetic covariance, the full model was compared with the model in which genetic covariance was zero (COV_A=0). Significance of maternal permanent environmental covariance was also tested accordingly (COV_C=0). Significance of phenotypic correlations was tested by the hypothesis test to decide whether the value of the correlation coefficient was significantly different from zero.

The EBV obtained from the best single trait model suited for each trait was used to plot the genetic trend. The genetic trend was estimated by regression of the EBV of the females that contributed in each generation for the trait under selection i.e., higher egg production up to 64 weeks of age (EP64) and the other production traits under study. The EBV of contributed individuals was utilized for estimating the genetic trends of growth traits.

RESULTS

CHAPTER IV

RESULTS

4.1 MEAN PERFORMANCE

4.1.1 Body Weights

The least squares means (LSMs) over the generations for growth traits i.e., body weights at 0 day 4, 8, 16, 20 and 40 weeks of age are presented in Table 4.1. The body weights varied significantly ($p \leq 0.01$) among the generations. Hatch effect is significant ($p \leq 0.01$) on the body weights at 0 day, 4, 8, 16 and 40 weeks of age. The generation×hatch interaction has a significant influence on body weight at 0 day, 4, 8 and 16 ($p \leq 0.01$) and 20 week body weight ($p \leq 0.05$). The least squares means are 33.74±0.06, 202.80±0.80, 457.38±1.64, 974.38±3.95, 1114.55±3.50 and 1372.76±5.19 grams for body weights at 0 day, 4, 8, 16, 20 and 40 weeks of age respectively.

4.1.2 Age at Sexual Maturity

The least squares means (LSMs) for 4 generations of hatches are analyzed and are presented in Table 4.2. Generation, hatch and their interactions has a significant effect ($p \leq 0.01$) on age at sexual maturity with an overall LSM of 143.69±0.263 days.

4.1.3 Egg Production

Egg production up to 40 weeks of 4 generations and 52, 64 weeks of only 3 generations was analyzed and the least square means are summarized in Table 4.2. Generation effect is significant ($p \leq 0.01$) while hatch effect is non-significant on egg production up to 40, 52 and 64 weeks of age. The generation×hatch interaction effect is significant ($p \leq 0.01$) only for egg production up to 40 weeks. The overall LSM of 115.02±0.61, 186±0.98 and 250.25±1.20 eggs are observed for egg production upto 40, 52 and 64 weeks respectively.

4.1.4 Egg Weight

The data on egg weight at 28, 40 weeks of age of 4 generations and 52, 64 weeks of age for 3 generations was analyzed and presented in Table 4.3. Both generation and hatch has significant influence ($p \le 0.01$) on egg weights. The generation×hatch interaction effect is significant ($p \le 0.01$) in case of egg weights at 40, 52 and 64 weeks of age. The overall LSM for egg weight at 28, 40, 52 and 64 weeks of age are 46.34±0.10, 50.98±0.12, 53.17±0.15 and 55.21± 0.18 grams respectively.

Table 4.1 Least squares means of body weights at different ages in IWI line

Particulars	**Body weight (g) at different ages**					
	0 day	4wks	8wks	16wks	20wks	40wks
Overall LSM	33.74±0.06 (5238)	202.80±0.80 (4168)	457.38±1.64 (4247)	974.38±3.95 (2499)	1114.55±3.50 (1824)	1372.76± 5.19 (1434)
Generation	**	**	**	**	**	**
S-4	33.55 ± 0.1^{b} (1142)	261.00 ± 1.3^{d} (1073)	537.87 ± 2.93^{c} (1048)	1021.64 ± 6.72^{c} (701)	1146.04 ± 5.98^{d} (478)	1359.98 ± 7.92^{b} (435)
S-5	32.62 ± 0.0^{a} (1779)	122.85 ± 1.3^{a} (1361)	362.52 ± 2.7^{a} (1210)	923.20 ± 6.83^{b} (641)	1099.46 ± 5.16^{b} (599)	1326.35 ± 10.76^{a} (275)
S-6	34.84 ± 0.1^{c} (1340)	170.47 ± 1.5^{b} (820)	446.88 ± 2.8^{b} (1115)	912.84 ± 5.21^{a} (974)	1119.56 ± 5.93^{c} (451)	1468.43 ± 7.57^{d} (452)
S-7	35.88 ± 0.1^{d} (977)	184.08 ± 1.4^{c} (914)	360.49 ± 3.1^{a} (874)	963.55 ± 11.79^{b} (183)	997.32 ± 7.32^{a} (296)	1433.80 ± 9.76^{c} (272)
Hatch	**	**	**	**	NS	**
1	34.24 ± 0.7^{c} (2651)	194.88 ± 0.9^{b} (2488)	470.74 ± 2.1^{c} (2271)	1026.12 ± 4.65^{c} (1449)	1093.72±4.38 (1073)	1368.91 ± 5.90^{b} (1016)
2	32.87 ± 0.1^{a} (1547)	200.41 ± 1.6^{c} (815)	459.01 ± 2.9^{b} (1130)	941.82 ± 6.87^{b} (700)	1118.73±7.55 (306)	1314.20 ± 12.24^{a} (175)
3	32.99 ± 0.1^{a} (657)	249.49 ± 1.9^{e} (515)	430.42 ± 4.2^{a} (496)	913.76 ± 14.87^{b} (115)	1124.66±7.47 (300)	1344.66 ± 15.56^{ab} (107)
4	35.19 ± 0.2^{c} (225)	214.67 ± 3.0^{d} (208)	471.13 ± 6.4^{c} (207)	1013.34 ± 12.0^{c} (175)	1129.16±13.28 (90)	1470.90 ± 17.99^{c} (80)
5	34.45 ± 0.2^{b} (158)	134.12 ± 3.6^{a} (142)	439.25 ± 7.7^{a} (143)	886.80 ± 20.59^{a} (60)	1154.66±16.99 (55)	1435.21 ± 21.50^{c} (56)
Gen x Hatch	**	**	**	**	*	-

Values in the parentheses indicate number of observations; Means with same superscripts do not differ significantly, * (P<0.05), ** (P<0.01)

Table 4.2 Least squares means of age at sexual maturity and egg production in IWI line

Particulars	Age at sexual maturity, d	Egg production at different ages (No)		
		40wks	52wks	64wks
Overall LSM	143.69±0.263 (1846)	115.02± 0.61 (1412)	186±0.98 (1096)	250.25±1.20 (1055)
Generation	**	**	**	**
S-4	139.58±0.48[a] (462)	117.40±0.94[c] (452)	187.52±1.35[b] (434)	253.56±1.64[b] (421)
S-5	143.85±0.42[b] (575)	121.67±1.26[d] (286)	193.93±1.91[c] (257)	254.58±2.37[b] (240)
S-6	149.91±0.45[c] (517)	94.51±0.98[a] (396)	160.16±1.36[a] (405)	225.04±1.66[a] (394)
S-7	151.36±0.58[d] (292)	110.33±1.16[b] (278)	-	-
Hatch	**	NS	NS	NS
1	144.22±0.36[b] (941)	111.26±0.70 (979)	179.88±1.23 (689)	244.63±1.51 (661)
2	143.87±0.47[b] (477)	119.97±1.44 (184)	191.79±2.14 (168)	254.68±2.63 (160)
3	141.46±0.61[a] (285)	118.65±1.88 (107)	189.62±2.72 (102)	257.38±3.29 (100)
4	145.50±1.7[b] (86)	114.93±2.13 (83)	185.43±3.05 (81)	252.37±3.70 (79)
5	143.72±1.31[ab] (57)	116.63±2.53 (59)	187.34±3.66 (56)	248.98±4.43 (55)
Gen x Hatch	**	**	NS	NS

Values in the parentheses indicate number of observations; Means with same superscripts do not differ significantly, * (P<0.05), ** (P<0.01)

Table 4.3 Least squares means of egg weights at different ages

Particulars	Egg weight (g)			
	28wks	40wks	52wks	64wks
Overall LSM	46.34±0.10 (1404)	50.98±0.12 (1325)	53.17±0.15 (1050)	55.21± 0.18 (845)
Generation	**	**	**	**
S-4	45.05± 0.16^{a} (432)	50.79±0.18^{b} (427)	53.89±0.20^{b} (411)	55.49± 0.23^{b} (374)
S-5	47.09±0.17^{b} (393)	51.20±0.24^{c} (268)	50.76±0.28^{a} (241)	53.70± 0.41^{a} (107)
S-6	48.33± 0.19^{c} (302)	49.89±0.19^{a} (363)	54.34±0.20^{c} (398)	55.33± 0.23^{b} (364)
S-7	49.28± 0.20^{d} (277)	52.59±0.22^{d} (267)	-	-
Hatch	**	**	**	**
1	47.16±0.12^{c} (882)	50.91±0.13^{ab} (919)	53.13±0.18^{b} (666)	54.45±0.22^{a} (556)
2	45.73±0.21^{b} (278)	50.31±0.27^{a} (170)	51.17±0.32^{a} (158)	55.25±0.47^{ab} (85)
3	43.56±0.33^{a} (104)	50.48±0.35^{a} (102)	53.64±0.40^{b} (96)	54.28±0.46^{a} (88)
4	45.65±0.37^{b} (80)	52.39±0.40^{c} (79)	54.89±0.44^{c} (78)	56.37±0.50^{bc} (73)
5	47.72±0.43^{c} (60)	51.70±0.48^{bc} (55)	55.08±0.54^{c} (52)	57.25±0.65^{c} (43)
Gen x Hatch	NS	**	**	**

Values in the parentheses indicate number of observations; Means with same superscripts do not differ significantly, * (P<0.05), ** (P<0.01)

4.2 HERITABILITIES

Variance and covariance components were estimated by average information restricted maximum likelihood (AIREML) fitting an animal model to estimate the heritabilities. The best model suitable for the trait was selected based on the likelihood ratio test on loglikelihood (logL) values obtained from the WOMBAT from the six models employed for analysis. The estimates of heritability as well as correlations ranged from 0 to 0.2 were considered as low, 0.2 to 0.4 as moderate and 0.4 to 1 were high in the present study.

4.2.1 Body Weight

The estimates of (co) variance components and genetic parameters for body weights i.e., body weight at 0 day (BW0), 4 weeks (BW4), 8 weeks (BW8),16 weeks (BW16), 20 weeks (BW20) and 40 weeks (BW40) are presented in Table 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9 respectively. For 0 day body weight model 5 with fixed, direct additive genetic, maternal additive genetic and maternal permanent environmental effects is the best model. Based on this model the additive heritability and maternal heritability are found to be 0.037±0.04 and 0.15±0.053, suggesting that the 0 day body weight of chick was highly influenced by the maternal component.

Model 4 with additive, maternal permanent environmental and residual effects is the best for BW4 and BW8. .Model 6 is best for BW16 which considered the covariance between direct additive and maternal genetic effects in addition to model 5. The best models for BW20 and BW40 are model 1 and model 3. Model 3 took maternal additive genetic effect into consideration in addition to fixed, direct additive genetic and residual effects of model 1.

The heritability estimates obtained based on the suitable best models for BW4, BW8, BW16, BW20 and BW40 are 0.15±0.04, 0.18±0.04, 0.30±0.07, 0.28±0.05 and 0.20±0.08 respectively. BW0 showed a very low heritability while the remaining body weight traits are found to be moderately heritable. The maternal heritability is found to be very low in comparison to additive heritability in case of BW16, BW20 and BW40 indicating a very low maternal effect on these traits.

The trend of additive, maternal genetic, maternal permanent environmental and total heritabilities for BW0, BW4, BW8 and BW16 are represented in Figure 4.1. It was found that the maternal heritability dropped from 0.15 to 0 from BW0 to BW4 and didn't show any change thereafter. Maternal permanent environmental heritability decreased with age whereas an upsurge is seen in additive heritability. A linear increase is noticed in total heritability with age from BW0 to BW16.

4.2.2 Age at sexual maturity

For age at sexual maturity the values of heritability are summarized in Table 4.10. The heritability of age at sexual maturity is found to be moderate with a value of 0.25±0.07 and maternal heritability is of low magnitude with 0.02±0.03 with model 3 being the best. This showed maternal component had less effect on age at sexual maturity.

Table 4.4 Estimates of covariance components and genetic parameters of BW0 in IWI line

	Model-1	Model-2	Model-3	Model-4	**Model-5**	Model-6
Trait: BW0						
σ^2_a	6.42± 0.41	0.74± 0.54	0.75± 0.59	1.17± 0.53	**0.43± 0.51**	0.21±0.58
σ^2_m	-	6.89± 0.58	6.90± 0.66		**1.74± 0.64**	1.27± 0.74
σ_{am}	-		-0.019± 0.52			0.51± 0.46
σ^2_c	-			4.37± 0.38	**3.13±0.52**	3.22± 0.53
σ^2_e	5.29± 0.23	6.09± 0.30	6.08±0.32	5.86±0.29	**6.23±0.29**	6.34±0.32
σ^2_p	11.71±0.29	13.72± 0.55	13.72± 0.55	11.40± 0.38	**11.53±0.41**	11.54± 0.42
h^2	0.55± 0.025	0.054±0.04	0.055± 0.04	0.10± 0.045	**0.037±0.04**	0.018±0.05
m^2		0.50± 0.03	0.50± 0.04		**0.15± 0.05**	0.11± 0.06
r_{am}			-0.008±0.23			0.998€
c^2				0.38±0.03	**0.27±0.05**	0.28±0.05
h^2_T	0.55	0.31	0.33	0.10	**0.11**	0.14
AIC	16898.52	16121.41	16123.40	16091.88	**16083.6**	16084.09

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_a$, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Table 4.5 Estimates of covariance components and genetic parameters of BW4 in IWI line

	Model-1	Model-2	Model-3	**Model-4**	Model-5	Model-6
Trait: BW4						
σ^2_a	670.34±94.66	404.69±102.56	413.37±115.64	**380.35± 96.63**	374.61±99.98	389.25±116.64
σ^2_m			169.31± 59.79		73.41±58.69	81.56± 69.29
σ_{am}			-14.53± 68.62			-19.95± 65.05
σ^2_c		161.58± 46.59		**137.49± 36.72**	79.94± 50.20	81.58± 50.39
σ^2_e	1852.19±70.25	1935.82±70.76	1931.72±75.61	**1942.71±68.44**	1944.94±69.67	1937.84±75.70
σ^2_p	2522.54±66.10	2502.10±65.04	2499.87±65.19	**2460.55±62.17**	2472.90±63.81	2470.28±63.62
h^2	0.266± 0.03	0.162±0.04	0.17±0.05	**0.16±0.04**	0.15±0.04	0.16±0.05
m^2			0.07±0.02		0.03±0.02	0.03±0.03
r_{am}			-0.06±0.25			-0.11±0.33
c^2		0.07±0.02		**0.06±0.02**	0.03±0.02	0.03±0.02
h^2_T	0.27	0.16	0.19	**0.15**	0.17	0.16
AIC	36455.00	36437.37	36439.33	**36437.07**	36437.33	36439.23

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_a$, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Table 4.6 Estimates of covariance components and genetic parameters of BW8 in IWI line

	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Trait: BW8						
σ^2_a	2621.66±398.28	1707.28±428.73	1762.05±487.62	**1679.33±403.27**	1621.56±420.21	1651.24±488.71
σ^2_m		418.34± 170.29	494.96± 234.12		86.65±194.52	115.80±245.29
σ_{am}			-114.40±269.80			-44.26±247.50
σ^2_c				**361.97± 132.34**	308.27±174.86	306.14±176.38
σ^2_e	7206.96±286.66	7569.01±286.58	7538.66±310.74	**7556.36±277.02**	7583.36±282.77	7567.75±309.73
σ^2_p	9828.62±263.26	9694.62±251.04	9681.27±250.37	**9597.66±245.96**	9599.84±246.14	9596.67±245.82
h^2	0.27±0.04	0.18±0.04	0.18±0.05	**0.18±0.04**	0.17±0.04	0.17±0.05
m^2		0.04±0.02	0.05±0.02		0.01±0.02	0.01±0.03

	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
				Trait: BW8		
r_{am}			-0.12±0.26			-0.10±0.50
c^2				**0.04±0.01**	0.03±0.02	0.03±0.02
h^2_T	0.27	0.20	0.19	**0.17**	0.17	0.17
AIC	42906.03	42902.28	42904.13	**42899.99**	42901.85	42903.82

Column in bold represents estimates from best model as per AIC. $^{+}\sigma^2_{a}$, σ^2_{c}, σ^2_{m}, σ^2_{e} and σ^2_{p} are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; $r_{am,}$ direct-maternal genetic correlation; $c^2 = \sigma^2_{c}/\sigma^2_{p}$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Table 4.7 Estimates of covariance components and genetic parameters of BW16 in IWI line

	Model-1	Model-2	Model-3	Model-4	Model-5	**Model-6**
			Trait: BW16			
σ^2_a	7532.10± 1398.38	6955.44± 1589.54	8811.14± 2153.07	5857.23± 1483.91	5857.98±1529.81	**8331.82± 2171.77**
σ^2_m		340.41± 544.22	1802.07± 929.008		0.944266E-01± 688.99	**957.49±959.87**
σ_{am}			-2729.39± 1204.13			**-2697.99±1192.31**
σ^2_c				868.47± 541.48	868.98± 696.24	**1173.15±653.80**
σ^2_e	20993.90± 1067.59	21176.60± 1086.28	20265.10± 1307.36	21475.00± 1042.09	21474.50±1056.20	**20244.90±1304.42**
σ^2_p	28526.00± 948.08	28472.40± 943.45	28148.90± 914.48	28200.70± 918.29	28201.60± 919.85	**28009.40±899.45**
h^2	0.26±0.04	0.24±0.05	0.31±0.07	0.21±0.05	0.21±0.05	**0.30±0.07**

	Model-1	Model-2	Model-3	Model-4	Model-5	**Model-6**
Trait: BW16						
m^2		0.01±0.02	0.06±0.03		0.00±0.02	**0.03±0.03**
r_{am}			-0.69±0.14			**-0.96±0.27**
c^2				0.03±0.02	0.03±0.03	**0.04±0.02**
h^2_T	0.26	0.25	0.20	0.21	0.21	**0.17**
AIC	27913.01	27914.64	27910.61	27912.55	27914.55	**27909.63**

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_{a,}$ $\sigma^2_{c,}$ $\sigma^2_{m,}$ σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; $r_{am,}$ direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed

Table 4.8 Estimates of (co)variance components and genetic parameters of BW20 in IWI line

	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
				Trait: BW20		
σ^2_a	**4638.36± 926.42**	4568.86± 1103.44	4755.64± 1363.69	4157.59± 1034.57	4159.97±1087.40	4514.04± 1381.24
σ^2_m		36.62± 369.35	113.82± 470.34		0.924846E-01± 483.63	16.86± 565.07
σ_{am}			-175.05±642.44			-275.41± 660.62
σ^2_c				233.64± 348.81	233.75±448.32	304.15± 446.43
σ^2_e	**11679.70± 721.01**	11704.60± 744.59	11608.80± 851.91	11831.00± 717.56	11829.60±733.43	11649.90± 851.65
σ^2_p	**16318.10± 621.17**	16310.10± 622.10	16303.2± 621.97	16222.30± 615.02	16223.40± 615.49	16209.50± 614.14
h^2	**0.28± 0.05**	0.28±0.06	0.29±0.08	0.26±0.06	0.26±0.06	0.28±0.08

	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
				Trait: BW20		
m^2		0.00±0.02	0.007±0.03		0.00±0.03	0.00±0.04
r_{am}			-0.24±0.67			-0.998± failed
c^2				0.01±0.02	0.01±0.03	0.02±0.03
h^2_T	**0.28**	0.28	0.28	0.26	0.26	0.25
AIC	**19372.97**	19374.96	19376.89	19374.54	19376.54	19378.31

Column in bold represents estimates from best model as per AIC. $^{+}\sigma^2_{a,}$ $\sigma^2_{c,}$ $\sigma^2_{m,}$ σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; $r_{am,}$ direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

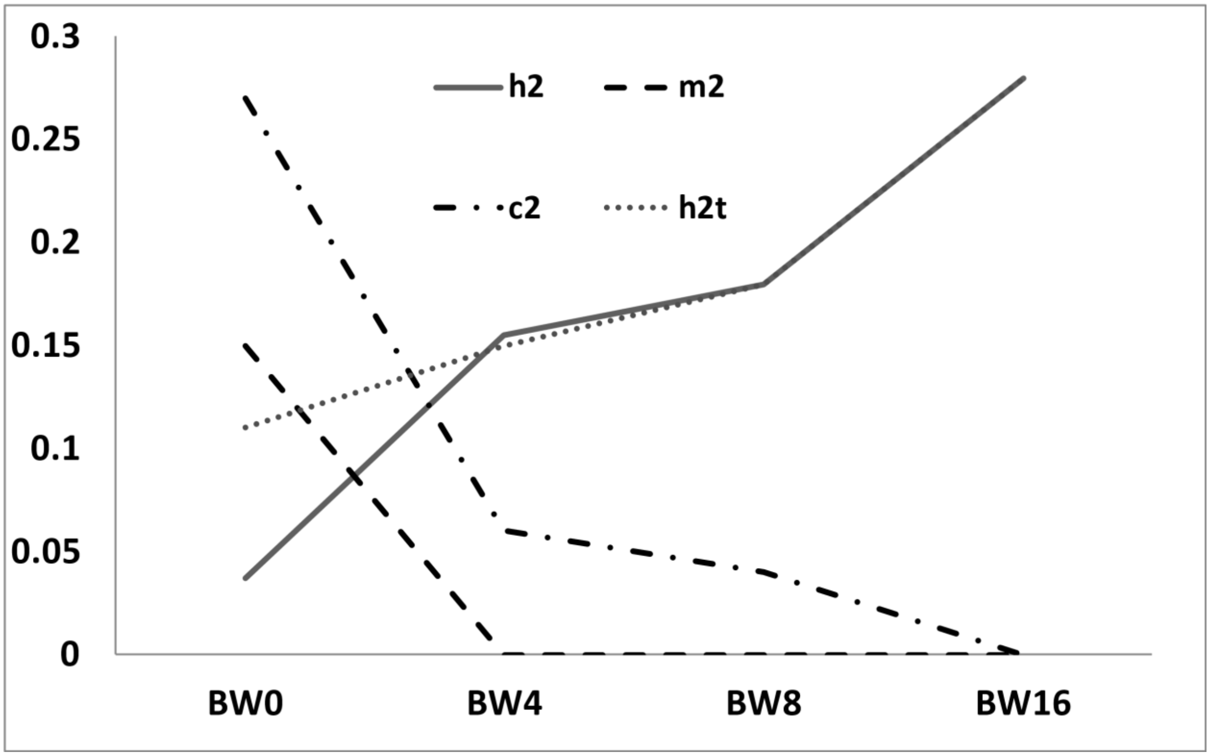
Table 4.9 Estimates of (co)variance components and genetic parameters of BW 40 in IWI line

	Model-1	Model-2	**Model-3**	Model-4	Model-5	Model-6
Trait: BW40						
σ^2_a	3808.59±1169.19	2788.66±1299.70	**5061.83±1997.53**	2053.30±1183.00	2056.94±1213.16	4451.06± 2027.75
σ^2_m		982.19± 684.89	**2416.66±1154.08**		0.33±743.67	1335.97±1291.83
σ_{am}			**-2611.85± 1345.79**			-2150.24± 1329.05
σ^2_c				1469.06±706.578	1466.97± 910.68	1065.72± 901.62
σ^2_e	22254.0±1211.50	22310.2±1190.90	**21096.7±1426.24**	22360.5±1149.47	22359.0± 1157.49	21178.8± 1409.88
σ^2_p	26062.6±1015.74	26081.0±1019.48	**25963.4±1012.34**	25882.9±998.599	25883.2± 999.37	25881.3±1004.60
h^2	0.15±0.04	0.11±0.05	**0.20±0.08**	0.08±0.05	0.08±0.05	0.17±0.08

	Model-1	Model-2	**Model-3**	Model-4	Model-5	Model-6
Trait: BW40						
m^2		0.04±0.03	**0.09±0.05**		0.000± 0.03	0.05±0.05
r_{am}			**-0.75± 0.17**			-0.88± 0.23
c^2				0.06±0.03	0.06±0.04	0.04±0.04
h^2_T	0.15	0.13	**0.09**	0.08	0.08	0.07
AIC	15936.07	15934.87	**15931.43**	15932.11	15934.11	15932.04

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_{a,}$ $\sigma^2_{c,}$ $\sigma^2_{m,}$ σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; $r_{am,}$ direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Figure 4.1 Trend of heritabilities in juvenile body weights



h^2, heritability; m^2, maternal genetic heritability; c^2, maternal permanent environmental heritability; h^2_t is total heritability; BW0, body weight at 0 day; BW4, body weight at 4 weeks age; BW8, body weight at 8 weeks age; BW16, body weight at 16 weeks of age.

Table 4.10 Estimates of (co)variance components and genetic parameters of ASM in IWI line

	Model-1	Model-2	**Model-3**	Model-4	Model-5	Model-6
Trait: ASM						
σ^2_a	18.18±4.42	18.18±4.98	**25.52±7.52**	15.99±4.70	15.99±4.95	23.99±7.77
σ^2_m		0.100000E-02 ±1.98	**2.07±2.90**		0.100000E-02±2.67	1.39±3.48
σ_{am}			**-5.95±4.05**			-5.77±4.31
σ^2_c					2.61±2.74	2.89±2.66
σ^2_e	83.22±4.17	83.22±4.19	**79.64±5.11**	82.70±4.11	82.70±4.18	78.76±5.14
σ^2_p	101.40 ±3.57	101.40± 3.57	**101.28± 3.57**	101.29± 3.56	101.29± 3.57	101.25± 3.57
h^2	0.18±0.04	0.18±0.05	**0.25±0.07**	0.16±0.04	0.16±0.05	0.24±0.07
m^2		0.000±0.02	**0.02±0.03**		0.000±0.03	0.01±0.03
r_{am}			**-0.82±0.34**	2.61±2.25		-1.00±0.84
c^2				0.03±0.02	0.03±0.03	0.03±0.03
h^2_T	0.18	0.18	**0.17**	0.16	0.16	0.16
AIC	10304.13	10306.13	**10303.46**	10304.62	10306.62	10305.55

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_a$, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

4.2.3 Egg Production

The estimates of (co) variance components and genetic parameters for egg production upto 40 (EP40), 52 (EP52) and 60 (EP60) weeks are presented in Table 4.11, 4.12 and 4.13 respectively. Model 1 is found to be the best one for egg production traits. The heritability estimates for EP40, EP52 and EP60 are found to be 0.15±0.03, 0.16±0.07 and 0.15±0.04 respectively. The egg production traits showed a heritability of low magnitude. It is found that egg production traits are not influenced by maternal genetic component.

4.2.4 Egg Weight

The covariance component and genetic parameter estimates for egg weights at 28 (EW28), 40 (EW40), 52 (EW52) and 64 (EW64) weeks are summarized in Table 4.14, 4.15, 4.16 and 4.17 respectively. The best model for all the egg weight traits is model 4 except for EW64, for which model 1 is found to be the best one. EW28 and EW40 showed a low heritability whereas EW52 and EW64 are found to be moderately heritable. The heritabilities of egg weights at 28, 40, 52 and 64 weeks of age are 0.05±0.05, 0.09±0.05, 0.23±0.09 and 0.17±0.06 respectively and the egg weights at different ages are found to be independent of maternal factors.

Table 4.11 Estimates of (co)variance components and genetic parameters of EP40 in IWI line

	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Trait: EP40						
σ^2_a	**39.08±9.62**	29.47±11.89	29.79±15.64	28.53±10.78	24.78±11.90	23.72±16.47
σ^2_m	**-**	12.47±5.88	3.97±10.14	-	3.86±6.97	5.05±12.75
σ_{am}	**-**	-	8.40±11.78	-	-	4.37±12.41
σ^2_c	**-**	-	-	11.74±6.61	8.16±8.02	2.84±8.58
σ^2_e	**224.58±12.42**	221.59±12.46	220.41±13.85	223.21±12.31	226.65±12.62	227.41±13.84
σ^2_p	**263.67±10.37**	263.53±10.36	263.59±10.41	263.49±10.35	263.47±10.35	263.61±10.44
h^2	**0.15±0.03**	0.11±0.04	0.11±0.06	0.10±0.04	0.09±0.05	0.09±0.06
m^2	**-**	0.05±0.02	0.02±0.04	-	0.01±0.03	0.02±0.04
r_{am}	**-**	-	1.000[€]	-	-	1.000[€]
c^2	**-**	-	-	0.04±0.02	0.03±0.03	0.01±0.03
h^2_T	**0.15**	0.14	0.17	0.11	0.10	0.12
AIC	**8721.74**	8723.53	8724.19	8723.37	8725.36	8726.19

Column in bold represents estimates from best model as per AIC. [+]σ^2_a, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Table 4.12 Estimates of (co)variance components and genetic parameters of EP52 in IWI line

	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Trait: EP52						
σ^2_a	**117.38±23.37**	94.99±29.97	96.41±38.92	95.45±27.25	91.37±30.06	94.95±44.85
σ^2_m	**-**	19.83±18.09	14.91±31.45	-	6.68±21.96	4.56±42.82
σ_{am}	**-**	-	5.61±34.11	-	-	4.74±38.28
σ^2_c	**-**	-	-	10.52±19.74	5.83±24.43	2.61±27.81
σ^2_e	**633.04±37.99**	635.53±37.91	633.88±41.40	644.09±37.58	646.52±38.07	643.87±38.54
σ^2_p	**750.42±32.18**	750.35±32.19	750.82±32.26	750.66±32.15	750.16±32.17	750.47±32.24
h^2	**0.16±0.07**	0.13±0.04	0.13±0.05	0.13±0.04	0.12±0.04	0.13±0.06
m^2	**-**	0.03±0.02	0.02±0.04	-	0.01±0.03	0.00±0.05
r_{am}	**-**	-	0.999€	-	-	1.000€
c^2	**-**	-	-	0.01±0.03	0.01±0.03	0.00±0.04
h^2_T	**0.16**	0.14	0.15	0.13	0.13	0.14
AIC	**8334.37**	8336.04	8337.82	8336.09	8337.98	8339.80

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_a$, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Table 4.13 Estimates of (co)variance components and genetic parameters of EP64 in IWI line

	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Trait: EP64						
σ^2_a	**157.13±29.00**	113.54±39.29	121.49±57.17	112.65±36.39	118.85±39.95	122.97±64.14
σ^2_m	**-**	43.64±27.19	24.08±46.13	-	21.69±34.37	24.27±64.94
σ_{am}	**-**	-	-9.33±49.29	-	-	-9.90±56.83
σ^2_c	**-**	-	-	44.87±27.90	26.56±35.26	14.65±41.76
σ^2_e	**922.51±54.99**	921.36±54.97	942.12±60.28	921.13±55.19	910.65±55.80	927.71±60.51
σ^2_p	**1079.52±47.15**	1078.01±47.19	1078.33±47.23	1078.01±47.05	1078.01±47.27	1079.01±47.34
h^2	**0.15±0.04**	0.11±0.04	0.11±0.05	0.11±0.03	0.11±0.04	0.11±0.06

	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Trait: EP64						
m^2	**-**	0.04±0.03	0.02±0.04	-	0.02±0.03	0.03±0.06
r_{am}	**-**	-	-1.00€	-	-	-1.00€
c^2	**-**	-	-	0.04±0.03	0.03±0.03	0.01±0.04
h^2_T	**0.15**	0.13	0.11	0.10	0.12	0.11
AIC	**8403.51**	8405.51	8407.34	8405.51	8407.51	8408.34

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_a$, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Table 4.14 Estimates of (co)variance components and genetic parameters of EW28 in IWI line

	Model-1	Model-2	Model-3	**Model-4**	Model-5	Model-6
Trait: EW28						
σ^2_a	1.51±0.54	0.94±0.62	1.25±0.76	**0.52±0.50**	0.52±0.56	0.83±0.77
σ^2_m		0.34±0.31	0.80±0.50		0.100000E-02±0.33	0.26±0.57
σ_{am}			-0.64±0.54			-0.35±0.54
σ^2_c				**0.66±0.33**	0.66±0.40	0.59±0.42
σ^2_e	9.71±0.56	9.90±0.55	9.73±0.60	**9.93±0.51**	9.93±0.52	9.78±0.58
σ^2_p	11.22±0.44	11.18±0.44	11.14±0.43	**11.11±0.43**	11.11±0.43	11.11±0.43
h^2	0.14±0.05	0.08±0.06	0.11±0.07	**0.05±0.05**	0.05±0.05	0.08±0.07
m^2		0.03±0.03	0.07±0.05		0.00±0.03	0.02±0.05
r_{am}			-0.64±0.29			-0.75±0.49
c^2				**0.06±0.03**	0.06±0.04	0.05±0.04
h^2_T	0.13	0.10	0.06	**0.05**	0.05	0.13
AIC	4786.82	4787.62	4788.28	**4784.68**	4786.68	4788.25

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_a$, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Table 4.15 Estimates of (co)variance components and genetic parameters of EW40 in IWI line

	Model-1	Model-2	Model-3	**Model-4**	Model-5	Model-6
Trait: EW40						
σ^2_a	2.27±0.68	1.19±0.76	1.26±0.91	**1.06±0.67**	0.96±0.72	0.80±0.90
σ^2_m		0.77±0.43	0.83±0.60		0.16±0.48	0.410693E-01±0.65
σ_{am}			-0.961632E-01±0.63			0.18±0.59
σ^2_c				**0.90±0.40**	0.78±0.51	0.82±0.53
σ^2_e	10.42±0.65	10.70±0.63	10.66±0.69	**10.61±0.60**	10.66±0.62	10.74±0.67
σ^2_p	12.69±0.52	12.66±0.52	12.66±0.52	**12.57±0.51**	12.57±0.51	12.57±0.51
h^2	0.18±0.05	0.09±0.06	0.10±0.07	**0.09±0.05**	0.08±0.06	0.06±0.07
m^2		0.06±0.03	0.07±0.05		0.01±0.04	0.00±0.05
r_{am}			-0.09±0.58			0.98±failed
c^2				**0.07±0.03**	0.06±0.04	0.07±0.04
h^2_T	0.18	0.12	0.02	**0.08**	0.08	0.10
AIC	4659.39	4657.66	4659.64	**4655.5**	4657.38	4659.29

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_a$, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Table 4.16 Estimates of (co)variance components and genetic parameters of EW52 in IWI line

	Model-1	Model-2	Model-3	**Model-4**	Model-5	Model-6
Trait: EW52						
σ^2_a	5.82±1.40	3.84±1.59	3.29±1.77	**3.68±1.46**	3.33±1.56	2.70±1.77
σ^2_m		0.99±0.69	0.74±0.79		0.37±0.86	0.14±1.04
σ_{am}			0.61±0.95			0.61±0.94
σ^2_c				**0.98±0.59**	0.77±0.78	0.78±0.82
σ^2_e	10.53±1.02	11.29±1.04	11.55±1.11	**11.28±0.98**	11.46±1.02	11.75±1.09
σ^2_p	16.35±0.86	16.12±0.82	16.19±0.83	**15.95±0.80**	15.93±0.80	15.97±0.81
h^2	0.36±0.07	0.24±0.09	0.20±0.11	**0.23±0.09**	0.21±0.09	0.17±0.11
m^2		0.06±0.04	0.05±0.05		0.02±0.05	0.01±0.07
r_{am}			0.39±0.78			1.00±failed
c^2				**0.06±0.04**	0.05±0.05	0.05±0.05
h^2_T	0.36	0.27	0.28	**0.23**	0.22	0.23
AIC	3894.50	3894.18	3895.86	**3893.52**	3895.32	3896.83

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_a$, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. **€** Indicates that the approximation used to define standard errors of parameter estimates failed.

Table 4.17 Estimates of (co)variance components and genetic parameters of EW64 in IWI line

	Model-1	Model-2	Model-3	Model-4	Model-5	Model-6
Trait: EW64						
σ^2_a	**3.02±1.14**	3.03±1.55	5.72±2.44	2.54±1.36	2.54±1.54	5.35±2.50
σ^2_m		0.100000E-02±0.76	1.21±1.37		0.100000E-02±1.06	0.73±1.69
σ_{am}			-2.35±1.64			-1.98±1.75
σ^2_c				0.48±0.74	0.48±0.97	0.39±0.96
σ^2_e	**15.30±1.16**	15.30±1.20	13.86±1.57	15.30±1.15	15.30±1.21	13.92±1.56
σ^2_p	**18.32±0.94**	18.33±0.94	18.43±0.96	18.32±0.93	18.32±0.94	18.42±0.96
h^2	**0.17±0.06**	0.17±0.08	0.31±0.13	0.14±0.07	0.14±0.08	0.29±0.13
m^2		0.00±0.04	0.07±0.07		0.00±0.06	0.04±0.09
r_{am}			-0.90±0.20			-1.00±0.59
c^2				0.03±0.04	0.03±0.05	0.02±0.05
h^2_T	**0.16**	0.17	0.15	0.14	0.14	0.15
AIC	**3244.42**	3246.42	3246.08	3245.99	3247.99	3247.9

Column in bold represents estimates from best model as per AIC. $^+\sigma^2_a$, σ^2_c, σ^2_m, σ^2_e and σ^2_p are additive direct, maternal permanent environmental, maternal genetic, residual variance and phenotypic variance, respectively; h^2, heritability; m^2, maternal heritability; r_{am}, direct-maternal genetic correlation; $c^2 = \sigma^2_c/\sigma^2_p$; h^2_t is total heritability; AIC is Akaike's Information Criterion for the model obtained from WOMBAT. log L is log likelihood for the model obtained from WOMBAT. € Indicates that the approximation used to define standard errors of parameter estimates failed.

4.3 CORRELATIONS

4.3.1 Body Weights at Different Ages

The correlations among body weights at different ages are presented in Table 4.18, the direct additive genetic correlation among body weights at 0 day, 4, 8, 16, 20 and 40 weeks is found to be positive and is of high magnitude. A positive phenotypic correlation with varying magnitude is reported between the body weight traits. A negative maternal genetic correlation is found between BW0 and BW16. Moderate to high positive maternal permanent environmental correlation is seen between BW0, BW4, BW8 and BW16.

4.3.2 Body Weight at 20 and 40 Weeks with other Production Traits

The correlations between body weight at 20 and 40 weeks with other production traits were summarized in table 4.18.

BW20 has a negative moderate genetic and phenotypic correlation with ASM. A moderate to high positive genetic correlation is observed between BW20 and other egg production and egg weight traits whereas the phenotypic correlation is of low magnitude and positive. The genetic and phenotypic association between BW40 and ASM is positive and is of a very low magnitude. However a high positive maternal genetic correlation is found between them. A moderate to high positive genetic correlation is found between BW40 with other production traits and a phenotypic correlation being low and positive.

Table 4.18 Correlations among different body weight traits in IWI layer line

Trait combinations	Direct additive genetic correlation (r_a)	Maternal genetic correlation (r_m)	Maternal permanent environmental correlation (r_c)	Phenotypic correlation (r_p)	Number of observations
BW0 and BW4	0.99±0.28	-	0.31±0.11	0.19±0.02	4163
BW0 and BW8	0.81±0.28	-	0.27±0.14	0.11±0.02	4203
BW0 and BW16	0.89±0.43	-0.71±0.25	0.56±0.25	0.16±0.02	2469
BW0 and BW20	0.99±0.28	-	-	0.13±0.02	1822
BW4 and BW8	0.93±0.05	-	0.70±0.16	0.45±0.01	3741
BW4 and BW16	0.68±0.12	-	0.75±0.26	0.36±0.02	2064
BW4 and BW20	0.60±0.13	-	-	0.27±0.02	1777
BW8 and BW16	0.82±0.07	-	0.34±0.38	0.50±0.02	2263
BW8 and BW20	0.65±0.10	-	-	0.41±0.02	1686
BW16 and BW20	0.75±0.08	-	-	0.66±0.02	1320
BW20 and BW40	0.84±0.12			0.47±0.02	1381
BW20 and ASM	-0.37±0.14	-	-	-0.33±0.03	1486
BW20 and EP40	0.63±0.20			0.26±0.03	1307
BW20 and EP52	0.43±0.18			0.15±0.03	1044
BW20 and EP64	0.32±0.14			0.11±0.03	1005
BW20 and EW28	0.60±0.22			0.23±0.03	1373
BW20 and EW40	0.69±0.17			0.20±0.03	1285
BW20 and EW52	0.59±0.14			0.27±0.03	1001

Trait combinations	Direct additive genetic correlation (r_a)	Maternal genetic correlation (r_m)	Maternal permanent environmental correlation (r_c)	Phenotypic correlation (r_p)	Number of observations
BW20 and EW64	0.25±0.19			0.11±0.04	615
BW40 and ASM	0.03±0.15	0.99±0.10		0.02±0.03	1148
BW40 and EP40	0.38±0.21			0.07±0.02	1303
BW40 and EP52	0.73±0.57			0.08±0.03	1066
BW40 and EP64	0.38±0.29			0.06±0.03	1030
BW40 and EW28	0.34±0.18			0.19±0.03	1232
BW40 and EW40	0.63±0.22			0.20±0.03	1285
BW40 and EW52	0.51±0.21			0.26±0.03	1021
BW40 and EW64	0.46±0.23			0.17±0.04	610

* P≤0.05; ** P≤0.01; NS, Non significant

4.3.3 Age at Sexual Maturity with other Traits

The correlations of ASM with other traits is summarized in Table 4.19. Age at sexual maturity showed a negative genetic correlation with egg production and egg weight traits except with EW64 where a positive association of low magnitude is found. ASM showed a negative phenotypic association with egg production traits and the phenotypic correlation between ASM and egg weight traits under study is found to be low in magnitude and positive in direction.

4.3.4 Egg Production and Egg Weight Traits

The correlations between egg production and egg weight traits are summarized in Table 4.19. A strong positive genetic and phenotypic correlation is found among the egg productions of different ages. However the egg production and egg weights at different ages correlated in opposite direction with varying magnitude.

The genetic, phenotypic and maternal permanent environmental correlations between egg weights at different ages are found to be high and positive in direction.

Table 4.19 Correlations among ASM, egg production and egg weight traits in IWI layer line

Trait combinations	Direct additive genetic correlation (r_a)	Maternal genetic correlation (r_m)	Maternal permanent environmental correlation (r_c)	Phenotypic correlation (r_p)	Number of observations
ASM and EP40	-0.73±0.17			-0.39±0.03	1130
ASM and EP52	-0.68±0.28			-0.22±0.04	843
ASM and EP64	-0.35±0.15			-0.16±0.04	807
ASM and EW28	-0.11±0.22			0.03±0.03	1202
ASM and EW40	-0.15±0.23			0.06±0.03	1103
ASM and EW52	-0.21±0.20			0.04±0.03	809
ASM and EW64	0.08±0.18			0.01±0.03	409
EP40 and EP52	0.97±0.14			0.89±0.01	1030
EP40 and EP64	0.66±0.20			0.75±0.02	1001
EP40 and EW28	-0.91±0.33			0.03±0.03	1250
EP40 and EW40	-0.53±0.17			-0.06±0.02	1228
EP40 and EW52	-0.26±0.18			-0.03±0.03	976
EP40 and EW64	-0.37±0.28			-0.02±0.02	566
EP52 and EP64	0.92±0.24			0.90±0.02	1052
EP52 and EW28	-0.64±0.43			0.06±0.03	949
EP52 and EW40	-0.39±0.29			-0.06±0.03	985
EP52 and EW52	-0.04±0.02			-0.02±0.02	1026
EP52 and EW64	-0.50±0.45			-0.06±0.03	605
EP64 and EW28	-0.51±0.40			0.07±0.04	920
EP64 and EW40	-0.34±0.30			-0.06±0.03	952
EP64 and EW52	-0.41±0.34			-0.05±0.03	1006
EP64 and EW64	-0.50±0.38			-0.08±0.04	596
EW28 and EW40	0.98±0.17		0.57±0.33	0.34±0.03	1175
EW28 and EW52	0.91±0.17		0.97±0.22	0.50±0.03	908
EW28 and EW64	0.65±0.22			0.30±0.04	505
EW40 and EW52	0.92±0.16		0.29±0.18	0.39±0.03	942

Trait combinations	**Direct additive genetic correlation (r_a)**	**Maternal genetic correlation (r_m)**	**Maternal permanent environmental correlation (r_c)**	**Phenotypic correlation (r_p)**	**Number of observations**
EW40 and EW64	0.91±0.19			0.11±0.04	534
EW52 and EW64	0.94±0.09			0.42±0.04	578

* P≤0.05; ** P≤0.01; NS, Non significant

4.4 BREEDING VALUES AND GENETIC TREND

The average breeding values for body weights at 0 day, 4, 8, 16, 20 and 40 weeks of age and age at sexual maturity are summarized in Table 4.20. The genetic gain per generation is not significant for all the body weight traits except BW16 with a value of 3.386±0.621 ($P<0.05$).

For age at sexual maturity and egg production the generation wise average breeding values, overall mean and genetic gain per generation are presented in Table 4.21. Among the egg production traits EP52 showed a significant genetic gain per generation of 0.254±0.02 ($P<0.05$). Average breeding values of egg weight traits are presented in Table 4.22. Egg weights at different ages did not show any significant genetic gain per generation.

The genetic trend of body weights at 8 and 16 weeks of age and egg production up to 40, 52 and 64 weeks of age are presented in Figure 4.2 and egg weights at 28 and 40 weeks of age are presented in Figure 4.3. The genetic trend, estimated by regression of the estimated BV on generation is significant ($P<0.05$) for egg production upto 52 weeks of age. The breeding value of EP52 in the population increased linearly from 0.02 to 0.19 due to selection during the last three generations. The average genetic gain is 0.25 per generation for EP52. EP 40 improved from -0.1 to 0.5 in fourth to sixth generation then declined to 0.3 in seventh generation. EP64 also increased linearly with 0.095 average genetic gain from fourth to sixth generation.

Egg weight at 28 weeks of age showed an increase from fourth to sixth generation and then declined in seventh generation. 40 weeks egg weight recoded a diminution from 0.04 to -0.13 in last four generations.

Table 4.20 Average breeding values of body weight traits in IWI line

Gen. /Trait	Average Breeding Value					
	BW0	BW4	BW8	BW16	BW20 (g)	BW40 (g)
4	-0.003	2.12	3.40	0.24	4.04	2.90
5	0.01	2.29	2.65	1.93	6.62	10.98
6	0.04	4.46	8.49	4.94	12.68	16.82
7	0.02	3.22	9.08	10.52	9.06	14.05
Overall Mean	0.017	2.90	5.70	4.41	7.96	11.08
Genetic gain/ Gen.	0.01 ± 0.007^{NS}	0.55 ± 0.44^{NS}	2.29 ± 0.86^{NS}	3.39±0.62*	2.11 ± 1.35^{NS}	3.93 ± 1.78^{NS}

* P≤0.05; ** P≤0.01; NS, Non significant

Table 4.21 Average breeding values of age at sexual maturity and egg production traits in IWI line

Gen. /Trait	Average Breeding Value (egg number)			
	ASM (d)	EP40	EP52	EP64
4	-0.28	-0.11	-0.04	-0.01
5	-0.04	0.17	0.22	0.11
6	-0.20	0.52	0.47	0.18
7	0.02	0.30	-	-
Overall Mean	-0.14	0.22	0.20	0.08
Genetic gain/ Gen.	0.08 ± 0.06^{NS}	0.16 ± 0.09^{NS}	0.25±0.02*	0.10 ± 0.02^{NS}

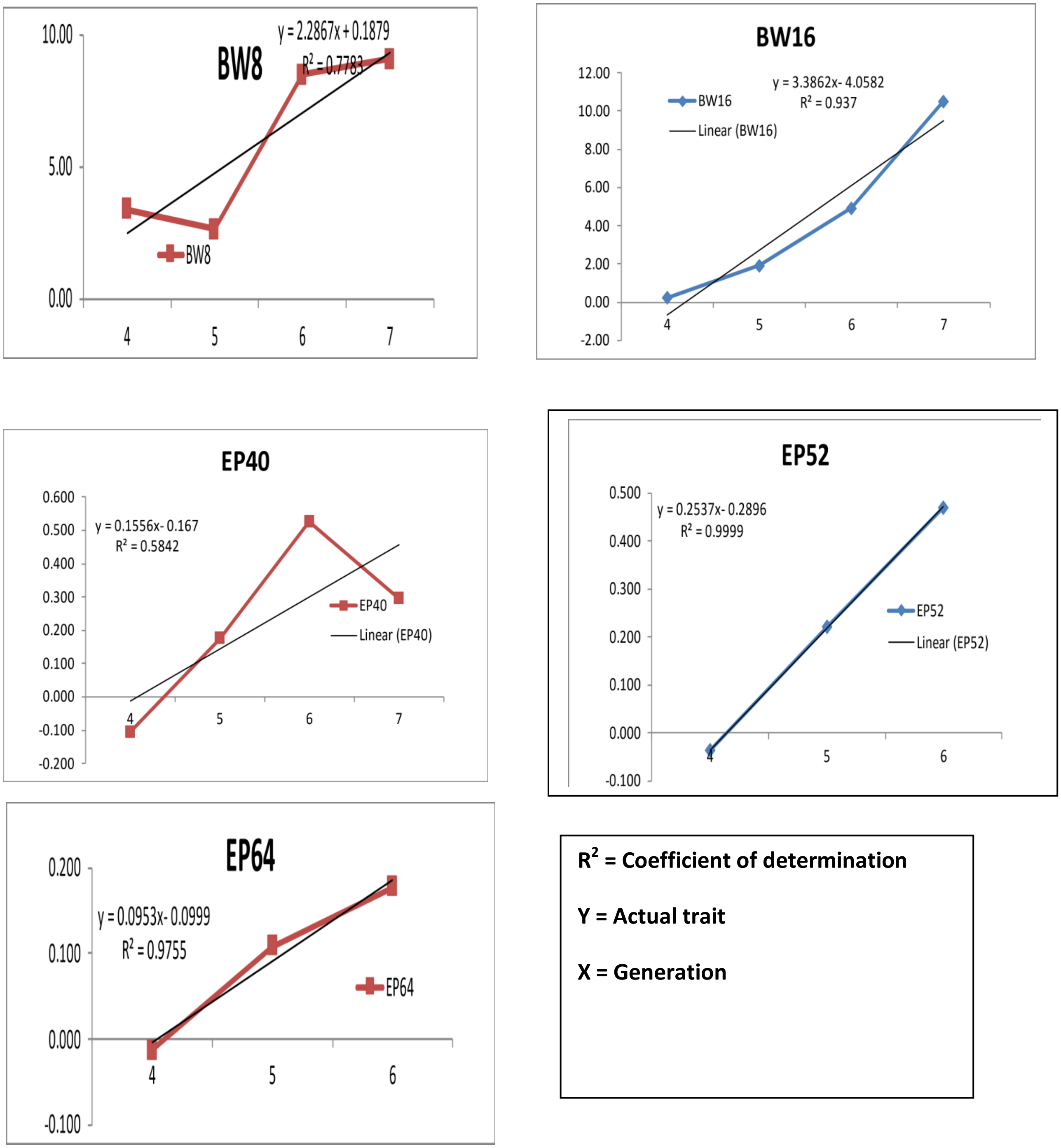
* P≤0.05; ** P≤0.01; NS, Non significant

Table 4.22 Average breeding values of egg weight traits in IWI line

Gen. /Trait	Average Breeding Value (g)			
	EW28	EW40	EW52	EW64
4	0.01	0.04	0.02	0.08
5	0.02	0.04	0.08	0.14
6	0.03	0.03	0.20	0.25
7	-0.00	-0.14	-	
Overall Mean	0.02	-0.003	0.10	0.15
Genetic gain/ Gen.	0.003 ± 0.01^{NS}	0.06 ± 0.03^{NS}	0.09 ± 0.02^{NS}	0.084 ± 0.017^{NS}

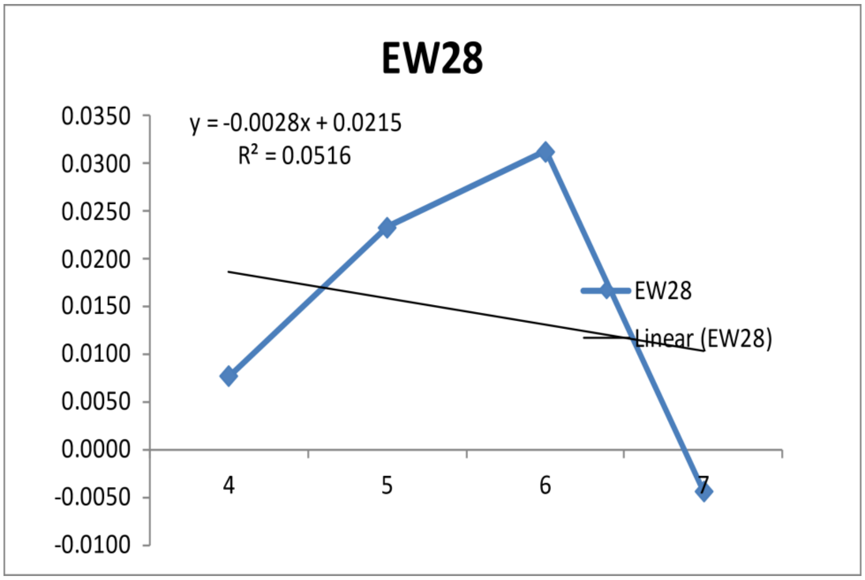
* P≤0.05; ** P≤0.01; NS, Non significant

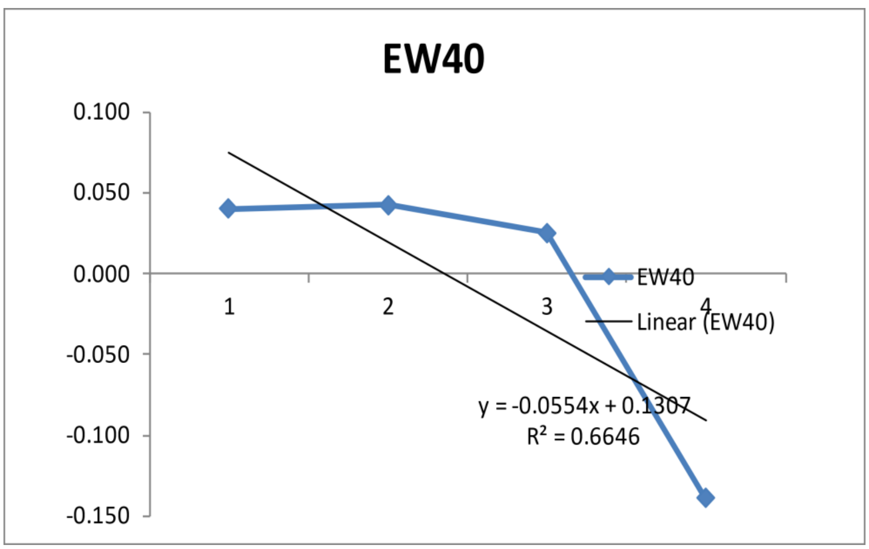
Figure 4.2 Genetic trend of BW8, BW16 and egg production traits



BW8, body weight at 8 weeks of age; BW16, body weight at 16 weeks of age; EP40, egg production upto 40 weeks of age; EP52, egg production upto 52 weeks of age; EP64, egg production upto 64 weeks of age.

Figure 4.3 Genetic trend of EW28 and EW40





EW28, egg weight at 28 weeks of age; EW40, egg weight at 40 weeks of age

DISCUSSION

CHAPTER V

DISCUSSION

Selection programmes bring about changes in the genetic properties of the population. Changes in the genetic constitution of population under selection are manifested by changes in the phenotypic performance and heritability estimates over generations (Chatterjee *et al.*, 2000). Hence it is essential to evaluate the population with respect to the phenotypic performance and existing genetic variability periodically to implement selection and breeding programmes effectively.

5.1 MEAN VALUES OF TRAITS

The main effect of selection is the change in population mean, which is of primary interest to the breeder. The result of selection i.e., changes in the genotype cannot be seen directly, they can be felt in terms of changes in the phenotypic values of the economic traits. Hence, the mean values of the various economic traits in IWI line of White Leghorn were estimated.

5.1.1 Body Weights

Juvenile body development is of great importance for laying hens. It is known that around fifth week of hen’s life, there is a short period of intensive growth. This period is critical and must not be stunted (Theopeters, 1997). Hence, there is a need to monitor the growth up to 10 weeks of age.

In the present study, the overall LSM of body weight at 0 day was 33.74±0.06 grams and was comparable with the reports of Chandan *et al.* (2019a) and Chandan *et al.* (2019b). Body weight at 4 and 8 weeks of age were found to be 202.80±0.80 and 457.38±1.64 grams respectively.

Body weight at 16 weeks of age of the present study was in accordance with the findings of Reddy *et al*. (2001), Jaya Laxmi (2008) and Chandan *et al.* (2019b) and was found to be lower than that reported by Paleja *et al.* (2008).

The 20 weeks body weight in the present study was 1114.55±3.50 grams which was well within the range as reported in literature by Brah *et al.* (1996a), Chaudary *et al*. (1996), Jaya Laxmi (2008) and Chandan *et al.* (2019b).

The body weight at 40 weeks was in agreement with the earlier reports of Brah *et al.* (1996b), Vasu *et al*. (2004a), Devi and Mahipal Reddy (2005), Jaya Laxmi *et al.* (2009) and Chandan *et al.* (2019a) but lower than the findings of Devi (2002), Sharma and Krishna (1998) and Rahman *et al.* (2003). This variation could be due to the differences in the genetic history, selection criteria or environmental conditions such as feeding of the stock etc.

The LSMs for body weights varied significantly in different generations and hatches in the population under study. The probable reason might be the variation of environmental factors (maternal effect, hatching conditions androlling reactions) over the generations and the significant effect of hatch may be due to non-genetic factors like variation in temperature of environment, the density of chicks at brooding and grower.

5.1.2 Age at Sexual Maturity

The age at sexual maturity is defined as the number of days after hatching when the first egg is laid (Dunnington and Siegel, 1984). The average age at sexual maturity was 143.69±0.263 days which was in accordance with the reports of Paleja *et al.* (2008) and Jaya Laxmi (2008), but in the literature the ASM ranged from 136.85 days (Chandan *et al.,* 2019a) to 203.029±0.330 days (Rahman *et al.,* 2003). The wide variation in the reported means could be due to the variation in the genetic history, selection criteria and varied environments in which they were reared.

5.1.3 Egg Production

The mean values of egg production are of utmost important to assess the progress of selection programme with the egg production being the primary trait of selection in layer birds.

The egg production up to 40 weeks in the present study was found to be 115.02± 0.61 and was well in agreement with the reports of Devi *et al*. (1998) and Devi and Mahipal Reddy (2005) and review of literature further indicated that egg production up to 40 weeks of age in the literature extended from as low as 70.397±0.715 (Rahman *et al.,* 2003) to as high as 121.21±0.02 (Veeramani *et al.,* 2008) in different strains of White Leghorns.

Egg production up to 52 weeks was 186±0.98 and was found to be in accordance with the findings of Chandan *et al.* (2019b). Egg production upto 64 weeks was 250.25±1.20 and was in agreement with the reports of Paleja *et al.* (2008), Veeramani *et al.* (2008) and Chandan *et al.* (2019b) and was found to be higher than that of Vasu *et al*. (2004a), Jaya Laxmi (2008) and Laxmi *et al.* (2009).

5.1.4 Egg Weight

Egg weights were measured at the ages of 28, 40, 52 and 64 weeks by taking five consecutive eggs laid by the bird at that age. The mean value of the five eggs is taken as the average egg weight of that age.

In the present study, the overall least squares mean egg weight at 28 weeks of age was 46.34±0.10 grams and was similar to the findings of Vasu *et al*. (2004a), Chatterjee *et al.* (2008), Jaya Laxmi (2008), Laxmi *et al.* (2009) and Chandan *et al.* (2019a).

The overall mean of egg weight at 40 weeks of age was 50.98±0.12 which agreed well with the reported literature of Brah *et al.* (1996a), Vasu *et al*. (2004a), Chatterjee *et al.* (2008), Paleja *et al.* (2008), Laxmi *et al.* (2009), Tomar *et al.* (2015) and Chandan *et al.* (2019b).

Egg weights at 52 weeks was 53.17±0.15 and was similar to the reports of Laxmi *et al.* (2009), Chandan *et al.* (2019a) and Chandan *et al.* (2019b). 64 weeks age egg weight had an overall mean of 55.21± 0.18 and was comparable with the findings of Jaya Laxmi (2008), Laxmi *et al.* (2009) and Chandan *et al.* (2019b) in different strains of White Leghorn.

Egg weights at different ages showed a significant increasing trend over the generations, which might be due to the decreasing trend in egg production.

5.2 HERITABILITIES

Heritability is one of the most important considerations in determining appropriate animal evaluation methods, selection methods and mating systems. Heritability measures the relative importance of additive genetic variance which is transmitted to the next generation. More specifically, it measures that part of the total variability of the trait caused by genetic differences among the animals on which the measurements were taken. Additive genetic variances and covariance of phenotypic traits determine the response to selection and so are key determinants of the processes of adaptation in response to natural selection and of genetic improvement in response to selection (Lynch and Walsh, 1998).

5.2.1 Body Weights

In the present study it was found that out of the total heritability, maternal heritability holds a major share compared to the direct heritability, in case of body weight on the day of hatch (BW0). Egg quality traits like egg weight, size and shell quality, which were determined by the maternal inheritance influence the chick weight at hatch which was also true in the present study as the BW0 had significant maternal genetic effects. The present findings were in accordance to the works of Mohammadi *et al.* (2018) and Ghorbani *et al.* (2012) stating that, though maternal genetic effects were essential for early body weight (hatch weight), the contribution of maternal permanent environmental effects was more than the direct and maternal genetic effects.

For the other body weight traits i.e., body weight at 4, 8, 16, 20 and 40 weeks of age the maternal genetic and maternal permanent environmental heritabilities were far less than the additive heritability indicating that the contribution of maternal effects to the phenotypic variation of body weight decreases with age and was well in agreement with the report of Kranis *et al.* (2006).

The possible reason for difference in heritabilities of body weights of the present study could be due to the method used in estimating the heritability of the traits. The traditional models ignore the maternal and permanent environmental effects in chicken leading to overestimation of additive genetic variance resulting in high heritability estimates. The maternal effect is defined as the situation where the phenotype of the offspring is determined not only by the environment and its genotype, but also by the genotype and environment of their mother. Maternal effects are important in the development and expression of the economic traits due to genetic or environmental differences between dams or by the combination of genetic or environmental differences (Grosso *et al.,* 2010 and Mohammadi *et al.,* 2018).

5.2.2 Age at Sexual Maturity

The heritability of ASM was 0.25±0.07, being moderate in magnitude. It was similar to the series of reports of Singh *et al.* (2001), Sethi *et al.* (2003), Kumar *et al*. (2004), Manjeet *et al.* (2018) and Chandan *et al.* (2019b). However, the heritability for ASM in reviewed literature stretched from as low as 0.01±0.09 in H strain (Reddy *et al.,* 2001) to as high as 0.94±0.21 (Thangaraju and Ulaganathan, 1990a). This difference in the results may be due to very little maternal effect.

5.2.3 Egg Production

The egg production traits i.e., EP40, EP52 and EP64 showed a heritability of lesser magnitude. In the current population intensive selection for the egg production up to 64 weeks was applied therefore, resulting into lower heritability of egg production traits at different age intervals. The heritability of egg production reported in literatures often varied in a wide range depending on the population, time and model of analysis. In a population not selected for egg production the heritability of the egg production may reach a higher value and if intensive selection is applied it may be even less than 0.2 (Preisinger and Savas, 1997).

Model 1 with direct additive effects was the best model for egg production traits, which showed the maternal effect (permanent environmental) of lesser magnitude. As the age advanced, the maternal effects gradually reduced and only the direct additive genetic effects prevailed. This may be the reason that egg production traits have only direct additive genetic effects in the present study.

5.2.4 Egg Weight

The heritability estimates of egg weights at 28, 40, 52 and 64 weeks of age were 0.05±0.05, 0.09±0.05, 0.23±0.09 and 0.17±0.06 respectively. The egg weights showed a low to moderate heritability. As the chicks grew older, the maternal effect which is non additive factor reduced, thereby resulting into reduced heritability.

The heritability estimated using REML animal model was more precise as it reduced the overestimation of the genetic parameters by partitioning the variance and covariance in to maximum possible components. Similar findings of less magnitude for heritability were reported by many authors using REML (Kruuk *et al.,* 2007; Mohammadi *et al.,* 2018 and Ghorbani *et al.,* 2012). Maternal effects account for small part of the variability of the economic traits (2-8%), but ignoring them will lead to significant overestimation of the h^2 (Norris and Ngambi, 2006 and Rahaman *et al.,* 2015). The non-inclusion of maternal effects in the model, despite their existence will result in overestimation of the direct heritability and the consequent wrong conclusion, and defective breeding programs (Grosso *et al.,* 2010).

5.3 CORRELATIONS

Correlations are of interest to the breeder since they permit prediction of direction and magnitude of change in the dependent trait as a correlated response to direct selection for the principal trait (Jaya Laxmi, 2008). The extent and direction of correlated selection response are determined by the genetic correlation or covariance between the concerned traits (Verma *et al.,* 1983).

Therefore, for improving the total economic value of an animal, it is important to know both the effect of the trait actually being selected and its effect on the other traits. This information becomes more relevant especially in flocks that undergo selection, in view of the fact that continued selection tends to bring about change in the genetic correlations among traits (Sharma and Krishna, 1998).

5.3.1 Among the Body Weight Traits

A high genetic and a low phenotypic correlation in a positive direction was found between 0 day body weight with body weight at 4, 8, 16 and 20 weeks of age. The correlation coefficients of maternal permanent environmental effects were moderate to high between BW0 and other juvenile body weights and among juvenile body weight traits with each other, which clearly revealed that there was a significant maternal effect on early body weights. It indicated that the non-genetic factors like mothering ability and uterus size have great influence on early body weight, which reduces or becomes negligible later on. Therefore, selection based on early body weight may not be a wise criterion for selecting individuals for higher body weight.

The genetic and phenotypic correlation between BW4, BW8, BW16 and BW20 with subsequent traits was higher in magnitude and positive in direction. Similar findings were reported by Chandan *et al.* (2019b) between body weights at 16 and 20 weeks of age.

The genetic and phenotypic association between BW20 and BW 40 were positive in direction and high in magnitude and this was well in accordance with the reports of Singh *et al.* (1986), Rahman *et al.* (2003) and Jaya Laxmi (2008).

5.3.2 Body Weight at 20 and 40 Weeks of Age with Other Traits

A negative and moderate genetic and phenotypic association was found between BW20 and ASM. These results agreed well with the reported literature on correlations (Singh *et al.,* 1986, Singh *et al*., 2001 and Chatterjee *et al.*, 2008). This indicates that heavier birds mature and start laying earlier than birds with lower body weights up to 20 weeks of age hence selection for earlier age at first egg could increase body weight at this age.

Body weight at 20 weeks of age showed a moderate to high positive genetic correlation and a low to moderate positive phenotypic correlation with egg production traits. This was in agreement with results of Sharma and Krishna (1998), Rahman *et al*. (2003) and Chatterjee *et al.* (2008). A moderate to high positive genetic and phenotypic correlation was found between BW20 with egg weight traits which indicates that the pullets attaining higher body weight at early ages up to 20 weeks due to genetic causes will also attain higher body weights at later ages and yield large sized eggs.

The genetic and phenotypic association between BW40 and ASM is positive and is of very low magnitude in the present study. BW 40 has a high positive maternal genetic correlation of 0.99±0.10 with ASM.

Egg production up to different ages and body weight at 40 weeks of age showed a moderate to high genetic and a low phenotypic correlation in a positive direction. These results agreed well with the earlier reports of Hazary, 1988 and Chatterjee *et al.*, 2008 in some strains of White Leghorn. However series of reports in literature indicated a negative association between BW40 and egg production traits (Singh *et al*., 1986; JayaLaxmi, 2008; Chandan *et al.*, 2019a; Chandan *et al.*, 2019b and Churchil *et al.*, 2019).

The association between BW40 and egg weights at 20, 40, 52 and 64 weeks of age was moderate to high in magnitude and positive in direction both genetically and phenotypically indicating that heavier birds produce larger eggs at all ages.

The association of body weights with egg production and egg weight traits of varying magnitude and direction specifies that body weight during growing and laying period bears a direct influence on feed consumption, production and viability. Laying stocks of different genetic back grounds differ in body weights at different ages and a part of these may be reflected as differences in production performances (Anonymous, 1998).

5.3.3 Age at Sexual Maturity with Other Traits

Age at sexual maturity has a moderate to high negative genetic and phenotypic correlation with egg production traits which was in close agreement with the findings of with most of the reviewed literature. This indicated that birds maturing earlier will produce more number of eggs which may be because of a longer productive life and production period. The inverse relationship between age at first egg and egg production indicated that any attempt to increase the egg production would favour early maturity and age at first egg of birds and ASM can be used as earlier indicator for higher egg production.

ASM showed a negative genetic association with egg weights at 28, 40 and 52 weeks of age. However, the genetic association with EW64 and phenotypic correlation with the egg weights at different ages was positive and of very low magnitude. Similar findings were observed by several authors with respect to correlations of ASM and egg weights (Chaudary *et al*., 1988; Kumararaj *et al.*, 1995; Chatterjee et al., 2008, Veeramani *et al.*, 2008; Jaya Laxmi, 2008 and Chandan *et al.*, 2019b) negative (Thangaraju and Ulaganathan, 1990b; Rahman *et al*, 2003 and Vasu et al., 2004a) in different strains of White Leghorn.

As the pleiotropic effects of genes are the main reason for genetic correlation, segregation of pleiotropic genes affecting both the traits may be responsible for the change in direction and /or magnitude of genetic correlation (Learner, 1958).

5.3.4 Egg Production Traits

A positive and high genetic and phenotypic correlation was found between egg production traits.

The perfect correlation was observed between EP52 and EP64. Therefore, the selection of higher egg numbers could be done earlier at 52 weeks rather than waiting for EP64. Similar results were reported by Chandan *et al.* (2019a) and Chandan *et al.* (2019b).

All the egg production traits showed a negative moderate to high magnitude genetic correlation with egg weights at 28, 40, 52 and 64 weeks of age. This was in harmony with the findings of Singh *et al.* (2002), Jaya Laxmi (2008), Chandan *et al.* (2019a), Chandan *et al.* (2019b), Churchil *et al.* (2019) in different strains of White Leghorn. A low magnitude phenotypic association was found between egg production traits with egg weight traits, it was negative in direction with egg weights at 40, 52 and 64 weeks of age and was positive with egg weight at 28 weeks.

This negative association between egg production traits with egg weight traits indicates that body tries to compensate the production stress by reducing egg size in case of high producing birds (Chandan *et al.*, 2019a).

5.3.5 Egg Weight Traits

The study realized that the genetic and phenotypic correlation of egg weight at 28 weeks of age with egg weight at 40, 52 and 64 weeks of age was positive with moderate to high magnitudes. Similarly egg weight at 40 weeks was positively correlated with 52 and 64 weeks egg weight and egg weight at 52 weeks was positively correlated with 64 weeks egg weight. This was analogous to the findings of Jaya Laxmi (2008), Chandan *et al.* (2019a), Chandan *et al.* (2019b) and Churchil *et al.* (2019). This indicates that birds laying heavier eggs at beginning continue to lay heavier eggs also at the later stages of production.

5.4 BREEDING VALUES AND GENETIC TREND

Determining the breeding value (BV) with the objective to select the parents for next generation is very important for the success of any breeding program. The precise estimation of BV depends on the effects considered in the statistical model in most of the cases.

The average EBV of BW 8 and BW 16 showed an increase over generations linearly. The average EBV of EP64, the primary trait of selection recorded a significant linear trend over the generations indicating the positive selection response in the population with significant improvement**.** The positive linear genetic trend was observed in EP52 as correlated responses to selection. An increasing trend was observed in EP40 with fluctuations over generations with an average genetic gain of 0.15 eggs per generation in the last four generations. The EBV of EW28 and EW40 reduced over the generations as an indirect response to selection for egg production since egg production and egg weight traits are negatively correlated.

SUMMARY

CHAPTERVI

SUMMARY

Data related to body weights, egg production and egg weight traits of 5238 birds belonging to 4 generations of IWI line of White Leghorns, maintained at the ICAR- Directorate of Poultry Research (DPR), Hyderabad were utilized for the study.

Mean performance

Significant generation differences were detected in all the traits under study *viz.*, body weights at 0 day, 4, 8, 16, 20 and 40 weeks of age, age at sexual maturity, egg production up to 40, 52 and 64 weeks of age and egg weights at 28, 40, 52 and 64 weeks of age. Hatch differences were significant for all the traits except body weight at 20 weeks of age and egg production traits.

The least square means of body weights at 0 day, 4, 8, 16, 20 and 40 weeks of age were 33.74±0.06, 202.80±0.80, 457.38±1.64, 974.38±3.95, 1114.55±3.50 and 1372.76±5.19 grams respectively. The interaction effect of generation × hatch was significant for all body weight traits except body weight at 40 weeks of age.

Age at sexual maturity had an overall mean of 143.69±0.263 days with significant generation × hatch interaction effect.

Generation × hatch interaction effect was non-significant for egg production traits except egg production up to 40 weeks of age. The overall least square means of egg production up to 40, 52 and 64 weeks of age were 115.02± 0.61, 186±0.98 and 250.25±1.20 eggs respectively.

All the egg weight traits were significantly affected by generation × hatch interaction except egg weight at 28 weeks age. Egg weight at 28, 40, 52 and 64 weeks of age showed an overall mean of 46.34±0.10, 50.98±0.12, 53.17±0.15 and 55.21± 0.18 grams respectively.

Heritability

The best model for body weight at 0 day was model five, for 4 and 8 weeks body weights it was model four, for body weights at 16, 20 and 40 weeks model six, one and three respectively were the best models. Heritability estimates of body

weights at the various ages studied indicated that it is low to moderately heritable with maternal influence on the 0 day body weight.

Heritability increased linearly in the juvenile body weight traits, maternal genetic heritability was effective only in case of 0 day body weight. A decrease in maternal permanent environmental heritability and increase in additive heritability among body weights at 0 day, 4, 8 and 16 weeks of age was noticed.

Age at sexual maturity revealed a moderate heritability of 0.25±0.07 with model three being the best model.

For all the egg production traits model one used in the study was the best model. The heritability for egg production up to 40, 52 and 64 weeks of age estimated by animal model was 0.15±0.03, 0.16±0.07 and 0.15±0.04 respectively.

Egg weights at 28 and 40 weeks were found to be very low heritable and egg weights at 52 and 64 weeks showed a moderate heritability in present study. Model four was found the best model for egg weight at 28, 40 and 52 weeks and model one was the best model for egg weight at 64 of age.

Correlation

Positive genetic and phenotypic correlations of moderate to high magnitude were observed among the body weights at 0 day, 4, 8, 16, 20 and 40 weeks of age. A moderate to high positive maternal permanent environmental correlation between 0 day, 4, 8 and 16 weeks body weights was noticed. A negative moderate maternal genetic correlation was found between body weight at 0 day and 16 weeks of age.

Body weight at 20 and 40 weeks showed a positive moderate to high genetic and low to moderate phenotypic correlation with egg production and egg weight traits under study. A negative genetic and phenotypic association was found between age at sexual maturity and body weight at 20 weeks of age. 40 weeks body weight manifested a maternal genetic correlation of 0.99±0.10 with age at sexual maturity.

Age at sexual maturity showed a negative genetic correlation of varying magnitude with egg production and egg weight traits except a very low magnitude positive association with egg weight at 64 weeks of age. Moderate negative and a very low magnitude positive phenotypic association was showed by age at sexual maturity with egg production and egg weight traits respectively under study.

From the study, it was observed that a high magnitude positive genetic and phenotypic correlation existed among the egg production up to 40, 52 and 64 weeks of age. Similar association was found among egg weights at 28, 40, 52 and 64 weeks of age. A positive maternal permanent environmental correlation of moderate to high magnitude was present between egg weights at 28, 40 and 52 weeks of age with each other.

Egg weight at 28 weeks showed a low positive phenotypic association with egg production traits except this the genetic and phenotypic association between egg production traits with egg weights at different ages was in opposite direction.

Genetic trend

The genetic trends plotted with average breeding values over generations showed a linear increase in body weight at 16 weeks of age, egg production up to 52 and 64 weeks of age. Body weight at 8 weeks of age showed an increase with fluctuations whereas egg production up to 40 weeks depicted an increasing trend from (-0.11 eggs) fourth to (0.30 eggs) sixth generation and decreased in seventh generation to 0.22 eggs. Egg weight at 28 and 40 weeks of age decreased with fluctuations over generations.

LITERATURE CITED

LITERATURE CITED

Ahmad and Singh S K. 2006. Estimation of direct and correlated responses for some production traits in White Leghorn. *Indian Journal of Poultry Science* **41**(1): 85-86.

Bais R K S, Johari D C, Hazary R C, Kataria M C, Deepak Sharma and Sharma R D. 1997. Inheritance of important economic traits in IWH strain of White Leghorn under reciprocal recurrent selection. *Indian Journal of Poultry Science* **32**: 189-191.

Bhushan B and Verma S K. 1986. Genetic studies of growth in control and full sib population of White Leghorn. *Indian Journal of Animal Science* **56**: 556-557.

Brah G S, Chaudhary, M L and Sandhu J S. 1996a. Evaluation of random bred control population of layer chickens. *Indian Journal of Poultry Science* **32**(1): 23-27.

Brah G S, Sandhu J S and Chaudhary M L. 1996b. Genetic analysis of hatching time and its relationship with other economic traits in egg type chicken. *Indian Journal of Animal Science* **66**: 89-91.

Brah G S, Chaudhary M L and Sandhu J S. 1998. Inheritance of shell quality related egg traits at two stages in the early part of laying in chickens. *Indian Journal of Poultry Science* **33**: 309-316.

Chandan P, Bhattacharya T K, Rajkumar U, Prince L L L and Chatterjee R N. 2019a. Estimation of genetic parameters of growth and egg production traits by animal model in IWK layer strain. *Indian Journal of Animal Research* **53**(9): 1252-1257.

Chandan P, Prince L L L, Bhattacharya T K, Rajkumar U and Chatterjee R N. 2019b. Estimation of heritability and genetic correlation of egg production traits using animal model in commercial layer. *Indian Journal of Animal Sciences* **89**(11): 1269–1273.

Chatterjee R N and Mishra B S. 2001. Time trends of genetic parameters and realized phenotypic response in a White Leghorn Population under long term selection. *Indian Veterinary journal* **78**: 1112-1115.

Chatterjee R N, Mishra B S and Singh H N. 2002. Time trends of genetic parameters in a White Leghorn population subjected to long term single trait selection. *Indian Journal of Animal Sciences* **72**: 465- 468.

Chatterjee R N, Misra B S and Singh H N. 2000. Time trends in estimates of genetic parameters in a White Leghorn population subjected to long-term selection. *Indian Journal of Animal Science* **70**(2): 184- 187.

Chatterjee R N, Niranjan M, Panda A K, Reddy B L N, Bhanja S K and Singh D. 2008. Inheritance of important economic traits in three pure lines and a control population of White Leghorn. *Indian Journal of Animal Science* **78**(1): 75-79.

Chaubal D V, Solanki J V, Shukla R K, Rank D N, Mishra R K and Khanna K. 1994. Performance of White Leghorn pullets under reciprocal recurrent selection for two generations. *Indian Journal of Poultry Science* **29**: 211-217.

Chaudhary M L, Bajwa N P S, Brah G S and Sandhu J S. 1996. Variance component analysis of cross and purebred egg type chickens. *Indian Journal of Poultry Science* **31**: 18-22.

Chaudhary M L, Brah G S and Sandhu J S .1988. Genetic, phenotypic and environmental relationships among some economic traits of egg type chickens. *Indian Journal of Poultry Science* **23**: 332-335.

Churchil R R, John L, Chacko B, Praveena E P and Anitha P. 2019. Genetic analysis of egg production and allied characters in two long term selected strains of White Leghorn. *International Journal of Current Microbiology and Applied Sciences* **8**(3): 1669-1678.

Devi K and Mahipal Reddy P. 2005. Genetic studies on certain economic traits in White Leghorn and crossbred chicken. *Indian Journal of Poultry Science* **40**(1): 56-58.

Devi K, Sreerama Murthy A, Prasad V L K, Eswara Reddy C, Mahipal Reddy P, Ramesh Gupta B and Satyanarayana A. 1998. Genetic studies on certain parameters of egg quality in White Leghorn. *Indian Journal of Poultry Science* **33**: 81-85.

Devi K. 2002. Prediction of annual egg production on the basis of part record egg production and other economic traits in White Leghorn hen. *Indian Veterinary Journal* **79**: 364-367.

Duncan D B. 1995. Multiple range and multiple F test. *Biometrics* **11**: 1-42.

Dunnington E A and Siegel P B. 1984. Thermoregulation in newly hatched chicks. *Poultry Science* **63**: 1303-1313.

Falconer D S and Mackay T F C. 1996. Introduction to quantitative genetics. Fourth edition Addison Wesley Longman Limited Edinburgh Gate, Harlow Essex CM20 2JE, England.

Ferdoci A M, Goswami R N, Das D, Laskar S and Shadap O. 1992. Genetic and phenotypic parameters for alkaline phosphates and other economic traits in White Leghorn. *Indian Journal of Poultry Science* **27**: 224-227.

Ghorbani S, Kamali M A, Abbasiand M A and Ghafouri-Kesbi F. 2012. Estimation of maternal effects on some economic traits of north Iranian native fowls using different models. *Journal for Agriculture, Science and Technology* **14**: 95–103.

Grosso J L, Balieiro J C, Eler J J P, Ferraz B, Mattosand E C and Filho T M. 2010. Comparison of different models to estimate genetic parameters for carcass traits in a commercial broiler line. *Genetics and Molecular Research* **9**: 908–918.

Harpal Singh and Mohanty D K. 1985. Efficiency of using residual egg production records on part of the flock for the genetic improvement of annual egg production. *Indian Journal of Animal Sciences* **55**: 362- 366.

Hazary R C. 1988. Evaluation of response to selection for egg mass in a R I R flock. M.V.Sc. Thesis, Deemed Univerity, IVRI, Izatnagr (UP).

Hazary R C. 1991. A comparative evaluation of different models of diallel analysis in White Leghorn. Ph.D. Thesis, Deemed University, IVRI, Izatnagar (UP). https://doi.org/10.2527/jas1972.3561288x

ICAR-Directorate of Poultry Research. Annual report 1995-96, Hyderabad, India.

ICAR-Directorate of Poultry Research. Annual report 1996-1997, Hyderabad, India.

ICAR-Directorate of Poultry Research. Annual report 2008-2009, Hyderabad, India.

Jaya Laxmi P, Prasad V L K, Sree Rama Murthy A and Eswara Reddy C. 2001. Inheritance of various egg quality traits in three strains of White Leghorns. *Indian Veterinary Journal* **78**: 820-823.

Jaya Laxmi P. 2008. Genetic analysis of various productive and immunocompetence traits in white leghorns under long term selection. Ph.D. Thesis. SVVU. Hyderabad, India.

Johari D C, Dey B R, Kataria M C, Ayyagari V, Mohapatra S C and Gopal R. 1988. Genetic variation and covariation of production traits in White Leghorn selected for part record egg production. *Indian Journal of Poultry Science* **23**(1): 40-46.

Kranis A, Hocking P M, Hill W G and Wooliams J A. 2006. Genetic parameters for heavy female turkey line: Impact of simultaneous selection for body weight and total egg number. *British Poultry Science* **47**: 685-693.

Kruuk L E B and Hadfield J D. 2007. How to separate genetic and environmental causes of similarity between relatives. *Journal of Evolutionary Biology* **20**: 1890-1903.

Kumar G, Mahipal Reddy P, Ramesh Gupta B and Praharaj N K. 2004. Relative efficiency of selection based on segments of the part record to improve annual egg production in White Leghorns. *Indian Journal of Poultry Science* **39**(3): 224-228.

Kumararaj R, Kothandaraman P and Ulaganathan V. 1995. Phenotypic and genetic correlations between production traits in two White Leghorn strains and their reciprocal crosses. *Indian Journal of Animal Science* **65**: 770-774.

Laxmi J P, Gupta B R, Chartterjee R N, Sharma R P and Reddy R V. 2009. Combining ability analysis for certain economic traits in White Leghorn. *Indian Journal of Poultry Science* **44**(3): 291–95.

Learner I M. 1958. The genetic basis of selection. John Willey and Sons, Inc., New York.

Ledur M C, Fairful R W, Mc Millan I and Asseltine L. 2000. Genetic effects of aging on egg production traits in the first laying cycle of White Leghorn strains and strain crosses. *Poultry Science* **79**: 296-304.

Lynch M and Walsh B. 1998. Genetics and analysis of quantitative traits Sunderland, MA: Sinauer Associates.

Manjeet, Dalal D S, Dhaiya S P and Patil C S. 2018. Genetic parameters of various performance traits in different generations of synthetic White Leghorn strain. *International Journal of Advanced Biological Research* **8**(4): 438-440.

Meyer K. 1992. Variance components due to direct and maternal effects for growth traits of Australian beef cattle. *Livestock Production Science* **31**: 179-204.

Meyer K. 2007. WOMBAT: A tool for mixed model analyses in quantitativegenetics by restricted maximum likelihood (REML). *Journal of Zheijiang University Science* **8**: 815-821.

Mishra P K, Solanki J V Rank D N, Khanna K and Shukla R K. 1992. Prediction of annual egg production on the basis of part record egg production and other economic traits in White Leghorn. *Indian Journal of Poultry Science* **27**: 125-130.

Mohammadi A, Naderi Y, Nabavi Y, Jafari F. 2018. Determination of the best model for estimation of genetic parameters on the Fars native chicken traits using Baysian and REML methods. *Genetica* **50**: 431-447.

Nayak S K and Mishra S C. 1985. Heritability estimates for some production traits in a White Leghorn flock. *Indian Journal of Poultry Science* **20**: 140-141.

Neelam Singh and Singh R P. 2005. Heritability estimates of performance traits in purebred and crossbred egg type chicken. *Indian Journal of Poultry Science* **40**: 52-55.

Norris D and Ngambi J. 2006. Genetic parameter estimates for body weights in local Venda chicken. *Tropical Animal Health and Producion* **44**: 1437-1443.

Paleja, H I, Savalia, F P, Patel A B, Khanna K, Vataliya P H and Solanki J V. 2008. Genetic parameters in white leghorn (IWN line) chicken. *Indian Journal of Poultry Science* **43**(2): 151-154.

Prabhakaran K B, Jalaludeen A, Unni A K K and Leo Joseph. 2000. Genetic evaluation of White Leghorn strains for egg weight. *Indian Journal of Animal Science* **70**: 656-658.

Preisinger R and Savas T. 1997. VergleichzweierMethodenzurSchätzung der VarianzkomponentenfürLeistungsmerkmalebeiLegehenne. Züchtungkunde **69**: 142–52.

Provine W B. 2001. *The Origins of Theoretical Populationgenetics*. University of Chicago Press, Chicago.

Rahaman A, Hafezian H, Rahimi G H, Farhadi A and Baneh H. 2015. Inbreeding depression for economically important traits of Mazandaran native fowls. *British Animal Science* **56**:22-29.

Rahman M, Roy T C and Bulla Das. 2003. Genetic studies on some economic traits of White Leghorn Chickens of Meghalaya. *Indian Veterinary Journal*: 999-1001.

Reddy B L N, Panda A K, Reddy M R, Rao S V R and Praharaj N K. 2001. Studies on the influence of juvenile growth traits on laying performance in egg type chickens. *Indian Journal of Poultry Science* **36**(3): 290-293.

Sabri H M, Henry R Wilson, Robert H Harms and Chaarles J Wilcox. 1999. Genetic parameters for egg and related characteristics of White Leghorn Hens in a subtropical environment. *Genetics and Molecular Biology* **22**(2): 183-186.

Santosh H, Padhi M K, Chatterjee R N, Bhattacharya T K and Rajaravindra K S. 2016. Genetic characterization of layer germplasm evolved by AICRP on poultry breeding. *Indian Journal of Animal Sciences* **86**(12): 1431–1435.

Sethi S, Mishra P K, Mishra S C and Dehuri P K. 2003. Genetic characterization of a White Leghorn population for some production traits. *Journal of Poultry Science* **38**(3): 277-280.

Sharma A K and Krishna S T. 1998. Genotypic and phenotypic parameters of economic traits in 'V' strain of White Leghorns under selection. *Indian Journal of Poultry Science* **33**: 198-201.

Sharma K K, Singh H N and Singh P K. 1994. Inheritance of egg production and its correlation with certain other economic traits in White Leghorn. *Indian Journal of Poultry Science* **29**: 79-81.

Sharma P K, Varma S K, Brijesh Singh and Rachana Varma. 1999. Genetic and phenotypic effects of full sib mating on growth and production traits in White Leghorn populations. *Indian Journal of Poultry Science* **34**(1): 80-82.

Sharma P K, Varma S K, Sharma R K and Brijesh Singh. 2002. Inheritance of body weights and egg production in White Leghorn. *Indian Journal of Poultry Science* **37**(2):172-174.

Sharma P K, Varma S K, Sharma R K and Brijesh Singh. 2003. Genetic studies of inbred and control population of White Leghorn. *Indian Journal of Poultry Science* **38**(3): 274-276.

Sillanpaa M J. 2011. On statistical methods for estimating heritability in wild populations. *Molecular Ecology* **20**(7): 1324–1332.

Singh B P, Sharma K K and Singh H N. 1995. Estimates of genetic and phenotypic parameters for some growth and production traits in White Leghorn. Souvenir and Abstracts, 17th Annual Conference and Symposium of the Indian Poultry Science Association, Bangalore, 2-4 th March, 1995. Abstr: 205.

Singh B S, Chhikara D S, Dalal D S and Malik C P. 2001. Estimation of genetic and phenotypic parameters of economic traits of White Leghorn. *Indian Journal of Poultry Science* **36**(2): 163-168.

Singh H S, Singh C V and Brijesh Singh. 2000. Genetic parameters of growth, egg production and egg quality traits in White Leghorn. *Indian Journal of Poultry Science* **35**(1): 13-16.

Singh N P, Chaudhary M C, Brah G S and Sandhu J S. 1996. Heritabilities of and correlations among part and annual traits in pure and cross-line White Leghorns. *Indian Journal of Animal Science* **66**: 806-810.

Singh N P, Chaudhary M L, Brah G S and Sandhu J S. 1992. Evaluation of two White Leghorn strains and their reciprocal crosses for part year productivity. *Indian Journal of Poultry Science* **27**: 139-143.

Singh R P, Kumar J and Balaine D S. 1986. Genotypic and phenotypic parameters of production traits in a population of White Leghorn under selection. *Indian Journal of Poultry Science* **21**: 1-4.

Singh U B, Chhikara B S and Raheja K L. 2002. Estimation of genetic parameters of various economic traits over different generations of selection in a closed population of White Leghorn. *Indian Journal of Poultry Science* **37**(2): 135-138.

Thakur Y P, Singh B P and Singh H N. 1989. Estimates of various genetic and phenotypic parameters in a flock of White Leghorn. *Indian Journal of Poultry Science* **24**: 148-152.

Thangaraju P and Ulaganathan V. 1990a. Heritability associated with characters affecting production in two White Leghorn strains. *Indian Journal of Animal Sciences* **60**: 231-232.

Thangaraju P and Ulaganathan V. 1990b. Genetic, phenotypic and environmental correlations among egg production and other related economic traits. *Indian Journal of Animal Science* **60**: 444-449.

Theopeters. 1997. Weight at five weeks determines future laying performance. *World Poultry Misset* **13**: 43- 44.

Tomar A K, Poonia J S, Chaudhari M and Kumar P. 2015. Evaluation of production performance of some economic traits in white leghorn birds. *Haryana Vet* **54** (1): 19-21.

Vasu Y, Narasimha Rao G, Sharma R P,Hazary R C, Ramesh Gupta B and Satyanarayana A. 2004. Inheritance of important economic traits in IWI and control strains of White Leghorn. *Indian Journal of Poultry Science* **39**(1): 1-8.

Veeramani P, Narayanankutty K and Richard Churchil R. 2008. Estimation of heritability and correlation of economic traits in IWP strain of White Leghorn chicken Indian Journal Animal Research **42**(4): 257-260.

Verma S K, Pani P K and Mohapatra S. 1983. Genetic, phenotypic and environmental correlations among some of the economic traits in White Leghorn. *Indian Journal of Animal Science* **53**: 1113-1117.

Willham R L. 1972. The role of maternal effects in animal breeding, III. Biometrical aspects of maternal effects in animals. *Journal of Animal Sciences* **35**:1288-1293.

Yadav A K, Varma S K, Prasad R V and Gupta U D. 1992. Genetic relationship of production and feed efficiency traits in a strain of White Leghorn. *Indian Journal of Animal Science* **62**: 777-778.