SELECTION STUDIES IN CHICKEN FOR EGG NUMBER ON PART RECORDS

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "SELECTION STUDIES IN CHICKEN FOR EGG NUMBER ON PART RECORDS" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship, or other similar title, of any other University or Society.

Mannuthy,
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Maheswar Rath

CERTIFICATE

Certified that this thesis, entitled "SELECTION STUDIES IN CHICKEN FOR EGG NUMBER ON PART RECORDS" is a record of research work done independently by Maheswar Nath under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

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DEDICATED TO MY
AFFECTIONATE PARENTS

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Introduction

INTRODUCTION

All India Co-ordinated Research Project on Poultry Breeding was initiated by the Indian Council of Agricultural Research to evolve suitable strains of egg and meat type chickens that would nick well for production of elite commercial layers and broilers. A centre of this project is locate at Kerala Agricultural University, Mannuthy, Trichur, Kerala where two strains of White Leghorn have been subjected to selection for high egg production. The criterion of selection has been I.D.S. method of index selection since the heritability of egg production is low, various schemes of family selection would be advantageous over mass selection. The accuracy of selection for such low heritable traits may be increased by combining the information of sire family, dam family averages with the individual's performance (Lush, 1945; Lerner *et al.*, 1949; Osborne, 1957a,b and Kinney *et al.*, 1970)

Dickerson and Hazel (1944) hypothesised that the efficiency of selection should be measured per unit of time rather than per generation. In confirmity to this hypothesis, Dempster and Lerner (1947) concluded that in poultry populations greater genetic gain could be derived from selection on early but incomplete egg record, compared to selection on full record, as the generation interval is halved. Theoretica confirmation of such an increase in genetic progress from selection on part record was presented by Lerner and Cruden

(1948), Maddison (1954), Morris (1956), Oliver et al. (1957), Vanvleck and Doolittle (1964), Saadeh et al. (1968) and Bohren et al. (1970). On the other hand Morris (1963), Gowe (1969, 1974) and Gowe et al. (1973) questioned the validity of selection on part record since exclusive reliance on early part record may only decrease age at sexual maturity at the expense of persistency. Bohren (1970) who reviewed the literature on this problem, concluded that selection on early partial records, either number of eggs or per cent production, should be more efficient in increasing annual egg production than selection on annual record. It is however felt that more studies should be conducted on this aspect as the issue still remains controversial (Abplanalp, 1970). Variability among the individuals of the populations provides the basis for selection. Progress derived from breeding will also vary depending upon the available variability. As such it will be interesting to know the variability existing in different populations so that specific breeding programme could be formulated for each population.

Estimates of genetic and phenotypic parameters like heritability and correlations constitute an essential component for formulating a breeding programme. Since these parameters are likely to vary from population to population and even in the same population at different times, there is a need to estimate them afresh in the different populations under study.

Further it has been reported that parameter estimates undergo change due to selection. But the trend observed has not been uniform in the different populations for which it has been reported. As such there is a need to estimate the trends in genetic parameters from year to year and over the years. This experiment was therefore planned with the following objectives:

1. To evaluate the response to the I.D.S. method of intra-population index selection for part period egg number upto 280 days of age in IWN and IWP strains of White Leghorn maintained at the Trichur Centre of All India Coordinated Research Project (Poultry Breeding).

2. To estimate the genetic and phenotypic parameters (like heritability, genetic and phenotypic correlations) for selected and unselected traits in the above two populations.

3. To evaluate the correlated responses in unselected traits viz., age at first egg, 20 week body weight, 40 week body weight and egg weight in the above two populations.

4. To measure the time trend in genetic parameters such as heritability, genetic and phenotypic correlations and

5. To measure the inter-strain variation for some economic traits in the above two populations.

Review of Literature

REVIEW OF LITERATURE

Heritability

Heritability is one of the most important parameters of a metric trait. Heritability is important to breeder, as it provides the basis for predicting the breeding value from the phenotypic value and thus helps to choose suitable breeding method for further improvement of the traits under consideration.

Heritability is a property not only of a trait but also of the population and is influenced by the environment to which the breeding individuals are exposed. As such, estimates obtained from different methods and populations may vary in magnitude.

Several methods such as full- and half-sib correlations ~~method~~, intrasire regression of offspring on dam and realised heritability have been described in the literature to estimate the heritability (Lush, 1946; Lerner, 1950, 1958; Kempthorne, 1957 and Falconer, 1960). Due to unequal subclass numbers, the method as described by King and Henderson (1954a) based on sib correlations from variance component analysis is widely used in chicken for heritability estimation.

The various components of variance that could be derived from such analysis are:

a) Between sires (σ^2_S), (b) between dams (σ^2_D) and (c) between full sibs (σ^2_e). The genetic explanation to those variance components are indicated below (Lerner, 1958; Dickerson, 1960):

$$\sigma^2_S = 1/4\ \sigma^2_A + 1/16\ \sigma^2_{AA} + \sigma^2_L$$

$$\sigma^2_D = 1/4\ \sigma^2_A + 1/4\ \sigma^2_D + 1/16\ \sigma^2_{ID}$$

$$\sigma^2_W = 1/2\ \sigma^2_A + 3/4\ \sigma^2_D + 41/16\ \sigma^2_{IW}$$

where, σ^2_L - Variance due to sex linked genes in female progeny.

$$\sigma^2_{ID} = 3/16\ \sigma^2_{AA} + 2/16\ \sigma^2_{AD} + 1/16\ \sigma^2_{DD}$$

$$\sigma^2_{IW} = 12/16\ \sigma^2_{AA} + 14/16\ \sigma^2_{AD} + 15/16\ \sigma^2_{DD}$$

The heritability estimate from sire component of variance (half-sib) has been claimed to be the most reliable as it is least affected by environmental variation (Falconer, 1960). However, some doubts have been raised by Lerner (1950) considering the smaller degrees of freedom involved with such estimations. The heritability estimates from dam component of variance are usually over estimates as it is likely to be augmented by maternal effects in addition to interaction effects between sire and dam (King and Henderson, 1954b). However according to Hale and Clayton (1965) such interaction effects are small and negligible. Estimates from sire plus dam component of variance which averages over the effects of sire and dam was considered to be more reliable by those authors. According to Becker (1964), it's reliability dependent on the magnitude of sire and dam components of variance which should be nearly equal. The heritability estimates from intra-sire regression of offspring on dam are affected by maternal effects (Lush, 1940; Kempthorne and Tandon, 1953 and Bohren et al., 1966).

Regression of response on cumulative selection differential has been defined as the realised heritability. According to Falconer (1960), reliable or not, it provides an image of additive genetic variance in the population, it provides a most critical measure of the effectiveness of selection and is helpful for comparison of different experiments irrespective of differential selection intensities.

Hill (1972a,b) emphasised that in practical situations factors like genetic drift and measurement error variances should be taken into account to obtain the reliable standard error estimate of the realised heritability. It is because in estimation of realised heritability, the responses in different generations are assumed to be uncorrelated and with equal variances. The heritability estimates from variance components analysis are mostly positive, but there are reports of heritabilities below the threshold limit of zero as well as above one (Allaire and Lin, 1980; Jungsøt et al., 1981).

Searle (1971) attempted to develop strategies when negative heritability values were obtained but could not ensure estimates within zero and one. Lamotte (1973) suggested non-negative quadratic unbiased estimates of linear functions of variances as a suitable method for heritability estimates within the theoretical limits.

The heritability estimates beyond the theoretical limits are not rare in selection experiments (King, 1961; Friars et al., 1962; Anjaneyulu, 1972; Balachandran, 1973; [illegible] and Grammas, 1973; Jain and Roberts, 1980; Kartha, 1981; Venkatramaiah, 1982; Barua, 1983 and Thayagarajan et al., 19[illegible]). The probable reason for such erratic values is sampling as suggested by Robertson (1959) and Thompson (1976).

Egg production

The estimates of heritability from sire, dam and sire plus dam components as reported in the literature for part period egg production have been summarized in Table 1. The average of all these estimates were 0.25, 0.31 and 0.27, from sire, dam and sire plus dam components of variance. The higher values from dam component of variance suggest the influence of maternal effects in the inheritance of part period egg production. The maternal effects are important in the inheritance of part period egg production as reported by King and Henderson (1954b), Waring et al. (1962), Orozco and Lazo (1964), Beadoh et al. (1963), Acharya et al. (1969), Tiwana and Dev (1972), Trehan (1973), Quadeer et al. (1977ab) and [illegible] et al. (1976). Oliver et al. (1957), Anjaneyulu (1972), Ramaswamy (1973), Renganathan (1976) and Ayyagari et al. (1983)

also reported the influence of sex-linked genes in the inheritance of egg production.

Table 1. Heritability estimates of part period egg production

Authors	Year	Criterion of measurement	h^2 from various components		
			h^2_S	h^2_D	h^2_{S+D}
1	2	3	4	5	6
Lerner and Cruden	1948	EN till Jan. end	0.351	0.233	0.29
		EN till March end	0.261	0.376	0.31
		EN annual	0.358	0.427	0.39
King and Henderson	1954b	EN to Jan 1st	0.212	0.526	-
		EN to March 1st	0.157	0.516	-
		EN to June 1st	0.122	0.439	-
Maddison	1954	EN to Nov.	-	0.24	-
Wyatt	1954	EN to March 1st	-	0.41	-
Yamada	1955	Winter EN	-	-	0.315
		Spring EN	-	-	0.169
Morris	1956	Part record EN	-	-	0.320
Jerome *et. al.*	1956	4 months EP	0.370	0.210	0.090
Abplanalp	1957	Winter EP	-	-	0.26
Oliver *et. al.*	1957	EN Jan. 1st	0.162	0.124	0.143
Yamada	1958	Percent EP Jan. 1st	0.137	0.239	0.180

1	2	3	4	5	6
Schaff and Wendt	1959	EN - Oct. to Dec.	-	-	0.38
		EN - Oct. to Jan.	-	-	0.43
		EN - Oct. to Feb.	-	-	0.41
King	1951	Percent production to Jan. 1st	0.06	0.43	0.36
Orozco	1962	EN to 9 months age	0.19	0.06	-
Warring *et al.*	1962	EN to 40 weeks	0.16	0.23	0.19
Hussaini and Singh	1964a	90 days egg production	0.25	-	-
Orozco and Lobo	1964	EN to 9 months of age	0.13	0.51	0.32
Krause *et al.*	1965	Percent production to 4 months from sexual maturity			
		Line A	0.21	-	-
		Line B	0.22	-	-
Shibata and Suzuki	1965		0.232 to 0.146	-	-
Clayton and Robertson	1966	EN from 28-44 weeks			
		Strain-2	0.27	0.26	0.27
		Strain-5	0.13	0.45	0.29
Saeki *et al.*	1966	Strain-1	-	-	0.12
		Strain-2	-	-	0.66

1	2	3	4	5	6
Jaffe	1966	EN from 1st egg to November			
		Strain A_1	0.16	0.05	0.10
		A_2	0.23	0.29	0.26
		Strain B	0.29	0.35	0.33
Garewal *et al.*	1967	1st 100 days egg production	0.15	0.21	0.13
Malik and Singh	1967	EN part record	0.16	0.45	0.31
Nordskog *et al.*	1967	% production to 9 months age	-	-	0.08
Jain *et al.*	1968	EN part record	0.39	0.15	0.12
Kinney *et al.*	1968	% production from 1st egg to 40 weeks	0.18	-	-
Saadeh *et al.*	1968	Percent production to 260 days age	0.10	0.24	-
Craig *et al.*	1969	Percent production to 260 days age	0.10	-	-
Acharya *et al*	1969	70 days production from 1st egg	0.13	0.21	0.17
Johnson *et al.*	1970	EN to 40 weeks	0.23	-	-
		% production to 40 weeks	0.18	-	-
Chung *et al.*	1970	EN to 250 days	0.50	-	-
		EN to 300 days	0.60	-	-
Mohapatra and Srivastava	1971	100 days production from 1st egg	0.42	-	-

1	2	3	4	5	6
Tiwana	1971	1st 100 days production	0.14	0.26	0.2
Acharya *et al.*	1972	EN to 100 days from 1st egg	0.15	-	-
Mohapatra	1972	EN to 100 days	0.40	-	-
		EN to 40 weeks	0.27	-	-
Ahuja	1972	1st 100 days production	0.07	-	-
Anjeneyulu	1972	EN to 280 days age	0.38	0.16	0.27
Sandhu and Dev	1972	1st egg to 2 months lay	0.12	-	-
		1st egg to 3 months lay	0.25	-	-
		1st 100 days	0.13	-	-
Sing *et al.*	1972	90 days egg production	0.64	0.70	0.67
Tiwana and Dev	1972	100 days EN from 1st egg	0.14	0.26	0.21
Prakashbabu	1973	EN to 260 days age			
		Strain-T	0.16	0.09	0.03
		Strain-M	0.32	0.27	0.22
		Strain-V	0.10	0.24	0.17
Trehan	1973	EN to 40 weeks age	0.15	0.48	0.3
Trehan and Dev	1973	Egg production to 40 weeks	0.15	-	-
Nanda *et al.*	1973	100 days EN from 1st egg	0.03	-	-

1	2	3	4	5	6
Gowe *et al.*	1973	Hen-housed egg production to 273 days	0.10 0.26	0.25 0.50	- -
		Hen day EP to 273 days	0.37 0.37	0.37 0.57	- -
Bulbule	1974	EN to 280 days of age	0.11	-	-
Gohar and McGibbon	1974	Rate of lay first 3 months	0.17	-	-
Mehta	1974	Egg production upto 300 days age	0.29	-	-
Poggenpoel	1974	EN to 275 days age	-	-	0.19
Chaudhuri *et al.*	1975	EN to 260 days age	0.24	-	-
		EN to 280 days age	0.30	-	-
		EN to 300 days age	0.27	-	-
Chaudhuri	1975	280 days egg production	0.32	0.20	0.26
Iqbaluddin *et al.*	1975	90 days egg production	0.29 0.37	0.25 0.36	0.27 0.36
Manickavel *et al.*	1975	Egg production to 40 weeks age	0.11	-	-
Ozosco and Campo	1975	Rate of lay to 9 months age	0.09 0.14	- -	- -
Flock	1975	% production 44 weeks age	-	-	0.27
		EN to 36 weeks age	-	-	0.49

1	2	3	4	5	6
Barua	1976	Egg production to 260 days age	0.73	0.60	0.56
Choudhuri *et al.*	1976	EN to 40 weeks age	0.41	0.01	0.21
			0.33	-0.11	0.11
			0.10	0.68	0.39
			0.42	0.23	0.33
Renganathan	1976	Rate of lay to 260 days age	0.10	-0.10	0.00
		EN to 260 days	0.23	0.19	0.24
			0.28	0.22	0.25
Singh *et al.*	1976	100 days egg production	0.17	0.62	-
Banerjee *et al.*	1976	Part period EN	0.10	0.16	0.13
Sivasamy *et al.*	1976	40 week egg production	0.14	-	-
Sinha	1977	EN for 1st 90 days	0.31	0.21	0.26
Emsley *et al.*	1977	For cont production to 40 weeks age	0.12	-	-
Lianmawia	1977	EP to 260 days	0.40	0.28	0.34
Quadeer *et al.*	1977 (a,b)	Short term rate of lay			
		Hen day	0.09	0.19	0.14
		Hen housed	0.13	0.24	0.1
Gowe	1977	EP to 273 days age			
		Survivor rate of lay	0.15	0.34	-
			0.30	0.41	-
		HH egg production	0.13	0.29	-
			0.26	0.48	-

1	2	3	4	5	6
Murty	1977	EP to 260 days	0.23	0.36	0.30
Virmani and Singh	1977	EP from 151-271 days age	0.44	-	-
Ayyagari	1978	EP to 280 days age	0.63	0.43	0.53
			0.26	-0.00	0.12
			0.15	0.28	0.22
			0.57	-0.01	0.20
			0.43	0.22	0.32
Mishra *et al.*	1978	EN to 280 days age	0.20	0.32	0.26
Poggenpoel and Erasmus	1978	EN to 275 days age	0.35	0.29	0.32
Prakashbabu	1978	EN to 280 days age	0.32	0.36	0.28
Prakashbabu *et al.*	1978	EN to 260 days age	0.16	-0.09	0.03
			0.32	0.27	0.02
			0.10	0.24	0.17
Singh and Hussaini	1978	1st 90 days production	0.08	0.78	0.43
		EP to 300 days age	0.15	0.69	0.42
Mehta *et al.*	1978	EN 270 days age time I, I year	0.34	-	-
		II Year	0.32	-	-
		time II, I year	0.38	-	-
		II year	0.38	-	-
Gonzales *et al.*	1979	EN 3 months	0.48	0.41	-
Krishna and Chaudhary	1970	90 days egg production	0.11	-	-

1	2	3	4	5	6
Liljedahl *et al.*	1979	EN to 42 weeks age	0.46	0.62	0.54
Ayyagari *et al.*	1980	EN to 40 week age	0.13 to 0.33	0.18 to 0.40	0.18 to 0.27
Jayanna *et al.*	1980	EN upto 260 days	-	0.28	-
Kotaiah and Ramanathan	1980	EN to 40 weeks age	0.51	-	-
		% production to 40 weeks age	0.33	-	-
Trehan *et al.*	1980	280 days egg production	0.33	-	-
Foster	1981	EN to 40 weeks age	-	-	0.40
		% production to 40 weeks age	-	-	0.30
Das	1982	EN to 280 days age	0.35	0.16	0.29
Johari *et al.*	1982	EN to 40 weeks age	0.18	-	-
Singh and Chaudhary	1982	90 days % production	0.60	-	-
Venkatramaiah	1982	EN to 280 days age	0.09 to 0.39	0.11 to 0.40	0.19 to 0.34
Akpoly	1982	Egg production part HH	0.39	0.32	0.36
Ahlawat *et al.*	1982	EN 90 days I. Generation	0.21	-	-
		II. Generation	0.22	-	-

1	2	3	4	5	6
Ayyagari *et al.*	1983	EN to 40 weeks age	0.47	0.19	0.33
Barua	1983	EN to 260 days age	0.36	0.27	0.32
			0.53	0.39	0.46
Renganathan *et al.*	1983	EN to 40 weeks age	0.09	0.31	0.20
Ahlawat *et al.*	1983	90 days EN	0.19	0.14	0.17
Rodke *et al.*	1983	EN 200 days	0.24	0.64	0.44
Thiyagasundarum	1984	EN 280 days			
		S_0	0.10	0.27	0.18
		S_1	0.23	0.10	0.16
		S_2	0.03	0.38	0.20
		S_3	0.01	0.67	0.34
		Pooled	0.09	0.34	0.22
Average			0.25	0.31	0.27

Age at first egg

Hays (1924) observed the influence of both sex-linked and autosomal genes on age at first egg. Hazel and Lamoreux (1947) however could not observe such effects. King *et al.* (1963) found maternal effect on age at first egg. The reported values of heritability for age at first egg are presented in Table 2. The average of those estimates were found to be 0.32, 0.37 and 0.34 from sire, dam and sire plus dam component of variance respectively. The average of reported values indicate that age at first egg is moderately heritable and sex-linked as well as maternal effects are not differentiate

Table 2. Heritability estimates of age at sexual maturity

Authors	Year	h^2_S	h^2_D	h^2_{S+D}
1	2	3	4	5
King and Henderson	1954b	0.38	0.55	-
Jerome *et al.*	1956	0.35	0.23	0.30
King	1961	0.26	0.57	-
Hussain and Singh	1964a	0.17	-	-
Kinney and Shoffner	1965	0.30	0.53	0.34
Shibata	1965	0.31	0.32	-
Hale and Clayton	1965	0.40	0.31	-
Clayton and Robertson	1966	0.28	0.32	-
Kawahara and Inone	1966	0.41	0.48	-
Saeki *et al.*	1966	-	-	0.39
Malik and Singh	1967	0.43	0.46	0.46
Acharya *et al.*	1969	0.37	0.08	-
Craig *et al.*	1969	0.40	-	-
Osborne	1970	0.32	-	-
Sinha and Garewal	1970	0.40	-	-
Bowman and Powell	1971	0.35	0.33	-
Hussaini and Das	1971	0.47	0.43	-
Mohapatra and Ahuja	1971a	0.75	0.34	-

1	2	3	4	5
Anjaneyulu	1972	0.25	0.99	0.62
Sandhu and Dev	1972	0.40	-	-
Singh *et al.*	1972	0.37	0.57	0.47
Kolstad	1972	-	0.44	-
Vaccaro and Vanvleck	1972	0.15	0.21	-
		0.50	0.29	-
Nanda *et al.*	1973	0.20	-	-
Pirchner and Vankrosigk	1973	0.31	0.45	-
Prakashbabu	1973	0.17	0.45	0.31
		0.16	0.15	0.16
		0.17	0.16	0.17
Bulbule	1974	0.42	-	-
Choudhuri	1975	0.34	0.03	0.18
		0.29	0.33	0.31
		0.09	0.84	0.46
		0.38	0.07	0.22
Iqbaluddin *et al.*	1975	0.23	0.20	0.24
		0.45	0.42	0.44
Ranganathan	1976	0.28	0.29	0.28
		0.42	0.71	0.57
Singh *et al.*	1976	0.163	0.618	-
Sivasamy *et al.*	1976	0.25	-	-
Murty	1977	0.53	0.34	0.44
		0.41	0.57	0.49

1	2	3	4	5
Quadeer *et al.*	1977	0.07	0.39	0.22
Johari *et al.*	1977	0.19	-	-
Virmani and Singh	1977	0.51	-	-
Sinha	1977	0.24	0.19	0.22
Tawfik *et al.*	1977	0.46	0.21	-
Prakashbabu *et al.*	1978	0.17	0.45	0.31
		0.16	0.15	0.16
		0.17	0.16	0.17
Mishra *et al*	1978	0.30	0.18	0.24
Boggenpoel and Erasmus	1978	0.32	0.59	0.45
Trehan	1978	0.64	-	-
		0.41	-	-
Balachandran *et al.*	1979	0.31	-	-
Ahlawat *et al.*	1980	0.20	-	-
Jayanna *et al.*	1980	-	0.18	-
Kotaiah and Renganathan	1980	0.40	-	-
Yi and Ye	1980	0.36	-	0.04
Jain *et al.*	1980	0.24	-	-
Das	1982	0.49	0.15	0.33
Venkatramaiah	1982	0.34	0.27	0.36
Singh and Choudhary	1982	0.78	-	-
Das *et al.*	1982	0.39	-	-
Barua	1983	0.35	0.35	0.36
		0.54	0.34	0.44

1	2	3	4	5
Ayyagari *et al.*	1983	0.32	-	-
Renganathan *et al.*	1983	0.36	0.22	0.24
Ahlawat *et al.*	1983	0.21	0.23	0.22
Bodke *et al.*	1983	-0.25	-	0.51
Singh	1984	0.30	-	-
Thiyagasundaram	1984			
	S_0	0.30	0.14	0.23
	S_1	0.12	0.46	0.30
	S_2	0.18	0.37	0.27
	S_3	0.16	0.71	0.45
	Pooled	0.14	0.43	0.31
Average		0.32	[illegible]	0.34

Body weight

Body weights both at housing and adult stage have significant physiological relationship with egg production or its because body weight and age are limiting factors which can delay the onset of sexual maturity until an optimum threshold is reached. This ultimately affects the production efficiencies. Hence the inheritance pattern of body weight is significantly important. Hazel and Lamoreux (1947) reported the heritability as 0.33 and most of the reports indicated that it is a highly heritable trait (Hogsett and Nordskog, 1958;

Kawahara, 1965; Jaffe, 1966; Trohan, 1973; Choudhuri, 1975 Barua, 1976; Ranganathan, 1976; Tawfilk *et al.*, 1977; Baru 1983; and Thiyagasundarum, 1984).

The various heritability estimates of body weights ar presented in Table 3. The averages of those values fro sire, dam and sire plus dam components of variance are 0.6 0.58 and 0.55, respectively.

Table 3. Heritability estimates of body weight

Authors	Year	Body weight (B.W.)	h^2_S	h^2_D	h^2_{S+D}
1	2	3	4	5	6
Lerner and Cruden	1951	Dec. BW	0.17	0.47	-
Wyatte	1954	March BW	-	-	0.31
		March BW	-	-	0.65
Yamada	1958	BW at 1st egg	-	-	0.43
		300 days BW	-	-	0.46
Hogsett and Nordskog	1958	March BW	0.81	0.39	0.60
King	1961	32-wk BW	0.48	-	-
King *et al.*	1963	32-wk BW	0.48	-	-
Hussaini and Singh	1964a	BW at maturity	0.52	-	-
Hale and Clayton	1965	18-week BW	0.55	0.82	-
Kawahara	1965	Adult BW	0.79	0.53	-
Kinney and Shoffner	1965	Early BW	0.39	0.71	0.56
		Mature BW	0.54	0.53	0.46

1	2	3	4	5	6
Shibata	1965	Adult BW	0.25	0.56	-
Shibata and Susuki	1965	BW at 1st Egg	0.33	-	-
			0.54	-	-
Clayton and Robertson	1966	20 week BW	0.40	0.57	-
			0.69	0.56	-
		36 week BW	0.39	0.64	-
			0.67	0.57	-
Jaffe	1966	32 week BW	0.47	0.79	0.63
			0.92	0.69	0.81
			0.72	0.47	0.60
Saeki *et al.*	1966	BW at 1st egg	-	-	0.71
Nordskog *et al.*	1967	BW at 9 months	-	-	0.64
Kinney *et al.*	1968	32 week BW	0.63	-	-
Craig *et al.*	1969	32 week BW	0.44	-	-
		55 week BW	0.47	-	-
Osborne	1970	18 week BW	0.44	-	-
Sinha and Carewal	1970	BW at sex. maty.	0.33	-	-
Bowman and Powell	1971	25 week BW	0.44	0.50	-
			0.01	0.14	-
			0.30	0.77	-
Hussaini and Das	1971	BW at sex. maty.	0.69	0.79	0.74
Mohapatra and Ahuja	1971a	BW at sex. maty.	0.15	-	-

1	2	3	4	5	6
Anjaneyulu	1972	BW at sex. maty.	0.62	0.12	0.37
Vaccaro and Van Vleck	1972	32 week BW	0.59	1.06	-
			0.32	1.15	-
Nanda	1973	BW at sex. maty.	0.34	1.03	-
Pirchner and Vonkrosigk	1973	18-week BW	0.51	0.74	-
			0.62	0.76	-
Prakashbabu	1973	32-week BW	0.40	0.45	0.46
			0.62	0.35	0.48
			0.39	0.34	0.31
Trehan	1973	40 week BW	0.84	0.50	0.67
Trehan and Dev	1973	40 week BW	0.84	-	-
Bulbule	1974	20 week BW	0.72	-	-
		32 week BW	0.60	-	-
Nordskog *et al.*	1974	20 week BW	0.40	-	-
Vanchev *et al.*	1974	154 days BW	0.40	-	-
		356 days BW	0.55	-	-
Choudhuri	1975	20 week BW	0.59	0.30	0.56
			0.54	0.61	0.57
			0.30	0.41	0.36
			0.37	0.56	0.47
		40 week BW	0.80	0.39	0.60
			0.39	0.85	0.62
			0.69	0.19	0.44
			0.34	0.80	0.57

1	2	3	4	5	6
Iqbaluddin *et al.*	1975	BW at sex. maty.	0.34	0.27	0.30
			0.27	0.71	0.72
Barua	1976	32 week BW	0.80	0.30	0.55
			0.48	0.94	0.71
Renganathan	1976	20 week BW	0.53	0.89	0.71
			0.36	0.78	0.57
		32 week BW	0.99	0.64	0.82
			0.35	0.68	0.51
Banerjee *et al.*	1976	24 week BW	0.44	0.52	0.48
Brah	1977	20 week BW	0.59	0.71	0.67
		40 week BW	0.55	0.32	0.47
Mamnawis	1977	18 week BW	0.08	0.26	0.17
Murty	1977	20 week BW	1.33	0.37	0.80
			0.47	0.70	0.53
		32 week BW	1.27	0.57	0.92
			0.74	0.46	0.60
Sinha	1977	BW at sexual maturity	0.55	0.39	0.47
Tawfiik *et al.*	1977	18 week BW	0.81	0.65	-
Natarajan	1977	20 week BW	0.20	-	-
		40 week BW	0.18	-	-
Johari *et al.*	1977	20 week BW	0.18	-	-
Virmani and Singh	1977	BW 155 days	0.45	-	-

1	2	3	4	5	6
Prakashbabu	1978	20 week BW	0.44	0.56	0.53
		40 week BW	0.43	0.61	0.54
Natarajan and Rathnasabapathy	1978b	20 week BW	0.20	-	-
		40 week BW	0.18	-	-
Trehan	1978	20 week BW	0.48	-	-
		40 week BW	0.37	-	-
Nikolov and Bolorechkov	1978	20 week BW	0.15	-	-
			0.11	-	-
Reddy et al.	1978	BW 20 week	0.53	-	-
			0.34	-	-
			0.39	-	-
			0.26	-	-
Gonzalos et al.	1979	BW 133 days	0.58	0.83	-
		BW 308 days	0.36	0.64	-
Balachandran et al.	1979	BW at sex. maty.	0.46	-	-
Patel and Rathnasabapathy	1979	BW at 20 week	0.24	-	-
Ahlawat et al.	1980	BW at sex. maty.	0.34	-	-
			0.38	-	-
Jayanna et al.	1980	BW at Housing	-	-	0.69
Kotaiah and Renganathan	1980	BW at 40 week	0.50	-	-
Yi and Yo	1980	BW at 1st egg	0.11	-	0.11
Samir	1990	BW at 7 month	0.21	-	-

1	2	3	4	5	6
Mean	1980	BW 20 week age	0.50	-	-
Jain *et al.*	1980	BW at sex. maty.	0.27	-	-
Das	1982	20 week BW	0.39	0.48	0.50
		40 week BW	0.65	0.69	0.67
Johari *et al.*	1982	20 week BW	0.37	-	-
Venkatramaiah	1982	20 week BW	0.51	0.51	0.52
		40 week BW	0.56	0.56	0.62
Singh & Chaudhary	1982	BW at sex. maty.	0.64	-	-
Ayyagari *et al.*	1983	20 week BW	0.44	-	-
		40 week BW	0.49	-	-
Barua	1983	BW at 260 days	0.70	0.38	0.54
			0.70	0.58	0.64
Ahlawat *et al.*	1983	BW at sex. maty.	0.36	0.34	0.35
Zhang Lao	1984	BW at 1st egg	0.30	-	-
		BW at 36 week	0.56	-	-
Thiyagasundarum	1984	BW 20 week age	0.07	0.83	0.45
			0.44	0.44	0.44
			0.41	0.48	0.44
			0.38	0.30	0.34
		BW 40 week age	0.53	0.89	0.71
			0.51	0.69	0.60
			0.67	0.29	0.48
			0.89	0.40	0.68
Average			0.60	0.58	0.55

Egg weight

The heritability estimates for egg weight as published in the literature have been summarized in Table 4. The average of all those estimates are found to be 0.51, 0.47 and 0.51 from sire, dam and sire plus dam components of variance. Higher estimates from sire component than the dam component suggest the influence of sex-linked genes in the inheritance of this trait as reported by Jerome et al. (1956), Prakashbabu (1973), Barua (1976), Ranganathan (1976), Mishra et al. (1978). However, the importance of maternal effects in the inheritance of egg weight was reported by Lerner and Cruden (1951), King and Henderson (1954b), Hogsett and Nordskog (1958), King (1961), Waring et al. (1962), Clayton and Robertson (1966) and Sinha (1977).

Table 4. Heritability estimates of egg weight

Authors	Year	h^2_S	h^2_D	h^2_{S+D}
1	2	3	4	5
Lerner and Cruden	1951	0.73	0.47	-
King and Henderson	1954b	0.39	0.49	-
Wyatt	1954	-	-	0.52
Ghostley and Nordskog	1956	-	-	0.72
Jerome et al.	1956	0.62	0.56	0.59
Abplanalp	1957	0.49	-	-
Hicks	1958	0.71	0.58	0.61

1	2	3	4	5
Hogsette and Nordskog	1958	0.36	0.45	0.41
King	1961	0.60	0.73	0.24
Orosco	1962	0.15	0.23	-
Basing *et al.*	1962	0.70	0.80	0.75
King *et al.*	1963	0.51	-	-
Gulum	1963	-	-	0.67
		-	-	0.35
Hussain and Singh	1964a	0.81	-	-
Hale and Clayton	1965	0.36	0.19	-
Shibata	1965	0.20	0.63	-
Clayton and Robertson	1966	0.44	0.68	0.55
Jaffe	1966	0.56	0.54	0.55
Kawahara and Inoue	1966	0.39	0.47	-
Saeki *et al.*	1966	-	-	0.21
Amer	1967	0.31	0.26	-
Nordskog *et al.*	1967	-	-	0.59
Malik and Singh	1967	0.46	0.63	0.54
Merritt	1968	0.83	0.52	-
Craig *et al.*	1969	0.22	-	-
Osborne	1970	0.42	-	-
Mohapatra & Ahuja	1971a	0.65	0.31	-
Kovalanko and Mosenko	1971	0.04 to 0.53	0.28 to 0.77	-

1	2	3	4	5
Anjaneyulu	1972	-	0.89	-
Kotaiah	1972	0.90	0.04	0.43
Vacoro and Van Vleck	1972	0.45	0.69	-
Mohapatra	1972	0.95	-	-
		1.19	-	-
Malhotra and Narain	1973	0.50	-	-
Nanda	1973	0.78	0.36	-
Prakashbabu	1973	0.88	0.29	0.58
		0.69	0.37	0.53
		0.25	0.71	0.48
Kirchner and Vonkrosigk	1973	0.46	0.49	-
Trehan and Dev	1973	0.44	-	-
Bulkule	1974	0.63	-	-
Nordskog *et al.*	1974	0.40	-	-
Solonina and Shushu	1974	0.13	0.31	-
		0.11	0.35	-
Chaudhuri	1975	0.47	0.67	0.57
Trehan and Dev	1975	-	0.76	-
Barua	1976	0.66	0.20	0.43
Kotaiah *et al.*	1976	0.36	0.07	0.21
Renganathan	1976	0.75	0.33	0.54
		0.66	0.55	0.61
Singh *et al.*	1976	0.40	0.74	-

1	2	3	4	5
Sivasamy *et al.*	1976	0.51	-	-
Banerjee *et al.*	1976	0.44	0.70	0.57
Muller	1977	0.38 to 0.62	-	-
Jain	1977	0.30	0.16	0.23
Murty	1977	0.85	0.42	0.64
Quadeer *et al.*	1977	0.32	0.30	0.44
Sinha	1977	0.36	0.41	0.38
Thak *et al.*	1977	0.40	-	-
Virmani and Singh	1977	0.61	-	-
Mishra *et al.*	1978	0.57	0.36	0.47
Natarajan and Rathnasabapathy	1978b	0.32	-	-
Poggenpoel and Erasmus	1978	0.39	0.42	0.65
Prakashbabu	1978	0.66	0.40	0.57
Tzehan	1978	0.67	-	-
		0.35	-	-
Nikolov and Belorechkov	1978	0.18	-	-
		0.24	-	-
Gonzalez *et al.*	1979	0.40	0.27	-
Krishna and Choudhary	1979	0.43	-	-
Balachandran *et al.*	1979	0.24	-	-
Ranganathan *et al.*	1979	0.76	0.33	-
Jayanna *et al.*	1980	-	0.45	-

1	2	3	4	5
Kotaiah and Ranganathan	1980	0.79	-	-
Yi and Ye	1980	0.08	0.78	-
Aksoy	1982	0.42	0.63	0.52
Das	1982	0.51	0.59	0.55
Venkatramaiah	1982	0.60	0.47	0.62
Barua	1983	0.39	0.41	0.40
Ranganathan *et al.*	1983	0.53	0.62	0.58
Rodke *et al.*	1983	0.48	0.04	0.28
Zhang	1984	0.32	-	-
Thiyagasundarum	1984	0.34	0.64	0.49
		0.36	0.56	0.46
		0.61	0.50	0.56
		0.51	0.35	0.43
Average		0.51	0.47	0.51

Correlations

The association between two characters that can be directly observed is the correlation of phenotypic values or phenotypic correlation. The genetic correlation is defined as the correlation of breeding values, and the correlation of environmental deviations together with non-additive genetic deviations is known as environmental correlation (Falconer, 1960).

The theory of genetic correlations has been critically reviewed by Hazel (1943), Lerner (1950), Robertson (1957) and Falconer (1955). The various factors influencing the wide magnitude and direction of such estimates are genotype environmental interactions, dominance and epistatic interactions, maternal effects, sampling, etc. (Falconer, 1960).

Egg production and egg weight

The negative genetic correlation between egg number and egg weight in layers has been extensively reported (Blyth, 1952; Wyatt, 1954; Abplanalp, 1957; Hicks, 1958; Clayton and Robertson, 1966; Kinney et al., 1968; Quadeer et al., 1977; Das, 1982; Venkatramaiah, 1982; Barua, 1983 and Thiyagasundaram, 1984). The genetic correlation estimates between these two traits as reported in the literature are presented in Table 5. The averages of these various reports were -0.34, -0.05 and -0.11 respectively from sire, dam and sire plus dam components of variance and covariance. The mean phenotypic correlation was negative and low i.e., -0.09.

Table 5. Genetic and phenotypic correlation estimates between egg production and egg weight

Authors	Year	Criterion	rG_S	rG_D	rG_{S+D}	rG pooled	r_P
1	2	3	4	5	6	7	8
Blyth	1952	EP-EW BLH	-	-	-	-0.20	-
Wyatt	1954	Dec-Mar. EP-Mar. EW	-	-	-	-0.43	-
Van Alboda	1955	Annual EP-EW	-	-	-	-0.03	-
Farnsworth	1956	EP-EW in Leghorn	-	-	-	-0.55	-
Hogsett and Nordskog	1956	Winter EP-March EW	-	-	-	0.10	-0.75
Jerome *et al.*	1956	4 months EP-Egg wt. in RH	-	-	-	-0.24	-0.12
Abplanalp	1957	Winter EP-EW	-	-	-	-0.38	-
Hogsett and Nordskog	1958	Winter EP-March EW	-	-	-	-0.42	-0.06
Hicks	1958	EM-EW	-	-	-	-0.45	-
Goodman and Jaap	1961	46 wk EP-40 wk EW	-	-	-	0.05	-0.09
King	1961	% prodn to Jan 1st-32 wk EW	-0.50	0.06	-0.35	-	-0.02
		72 wk EP-32 wk EW	-0.24	0.26	0.21	-	0.11

1	2	3	4	5	6	7	8
Friars *et al.*	1962	EP-EW	0.22	0.19	-0.14	-	0.07
Waring *et al.*	1962	40 wk EP-EW	-0.32	0.02	-0.13	-	-0.05
Hussaini and Singh	1964	100 d EP-initial EW	0.16	-	-	-	-0.13
Rico	1964	250 d EP-EW	-	-	-	-0.10	0.04
						-0.46	0.11
Baczkowska and Kaminska	1964	EP-EW Sussex Flock	-	-	-	0.06	-
Hale and Clayton	1965	250 d EP to Spring	0.13	0.23	-	-	-
		E; B.W	-0.53	-0.27	-	-	-
Clayton and Robertson	1966	36-44 wk EP-36 wk EW	-	-	-	-0.[illegible]3	-
			-	-	-	-0.06	-
Jaffe	1966	EP to Nov. 32 wk EW	-	-	-	0.03	-
Kawahara and Inoue	1966	EP-EW	-	-	-	-0.14	-
Nordskog *et al.*	1967	Part record % prod. to 9 month age EW	-	-	-	-0.15	-
		Full record % prod. to 15 month age EW	-	-	-	0.08	-
Orlov and Elocevakaja	1967	EP-EW	-	-	-	-0.15	-0.16
			-	-	-	-0.22	-0.18

1	2	3	4	5	6	7	8
Kinney and Lowe	1968	40 wk EP-32 wk EW	-	-	-	-0.58	-
Kinney *et al.*	1968	% prodn. to 40 wk-32 wk EW	-	-	-	-0.55	-
Saadeh *et al.*	1968	Rate of lay upto 260 days of age-32 wk EW	-	-	-	-0.51	-
		Rate of lay upto 260 days-55 wk EW	-	-	-	-1.16	-
Ragab and Hossari	1969	EN to 1st Jan.-EW 1st egg	-	-	-	-0.59	-
		-do- EW 12 M	-	-	-	0.29	-
Craig *et al.*	1969	260 days rate of lay-32 wk EW	-	-	-	-0.40	-
		260 d rate of lay-55 wk EW	-	-	-	-0.67	-
Aggarwal	1970	280 d EP-EW	-	-	-	-	-0.18
Mohapatra and Ahuja	1971b	280 d EP-EW	-0.89	-	-	-	-0.23
Anjaneyulu	1972	100 d EP-EW	-0.44	-	-	-	-0.28
		260 d EP-250 d EW	-0.85	-	-	-	-0.38
Kolstad	1972	EP-EW	-	-	-	0.18	-
Reddy *et al.*	1972	Part record EP-Av. EW	-	-	-	-	-0.17
Nanda	1973	Part record EP-Av. EW	-0.22	-	-	-	-0.23

1	2	3	4	5	6	7	8
Mehta	1974	300 d EP-EW	-0.71	-	-	-	-
Nordskog *et al.*	1974	EP-EW	-	-	-	-0.31	-
Choudhuri	1976	280 d EN-EW	-0.73	-	-	-	-0.21
			-0.66	-	-	-	-0.06
			-0.26	-	-	-	-0.03
			0.04	-	-	-	0.12
Trohan and Dev	1975	EN-EW	-0.14	-	-	-	-
Barua	1976	260 d EP-32 wk EW	-0.30	-	-	-	-0.12
Renganathan	1976	-do-	-0.16	-	-	-	-0.10
			0.31	-	-	-	-0.08
Singh *et al.*	1976	100 d EP-EW	-0.15	-	-	-	-0.45
Sivasamy *et al.*	1976	100 d EP-EW	-0.32	-	-	-	0.19
Chung	1977	EP-EW	-	-	-	0.27	
Lianmawia	1977	260 d EP-37 wk EW	0.05	-0.52	0.17	-	-0.02
Murty	1977	260 d EP-32 wk EW	-0.12	-	-	-	-
Quadeer *et al.*	1977	Hd rate of lay-EW	-0.13	-0.06	-0.08	-	-
Sinha	1977	EP-EW	0.02	-	-	-	0.09
			-0.12	-	-	-	-0.02
			0.33	-	-	-	0.13
Mishra *et al.*	1978	280 d EP-EW	-0.26	-0.33	-	-	-0.16

1	2	3	4	5	6	7	9
Prakashbabu *et al.*	1978	260 d EP-32 wk EW	-0.29	-	-	-	-0.01
			-0.54	-	-	-	-0.14
			-0.29	-	-	-	0.03
Poggenpoel and Erasmus	1978	275 d EP-14 mth EW	-0.23	-0.12	-0.18	-	-0.02
Trehan	1978	EP-EW	-0.50	-	-	-	-0.23
			-0.33	-	-	-	-0.17
Renganathan *et al.*	1979	260 d EP-EW	-	-	-	0.31	-
			-	-	-	-0.16	-
Kolstad	1980	42 wk EP-EW	-	-	-	-0.11	-0.11
Kotaiah and Renganathan	1980	40 wk. EP-EW	-0.52	-	-	-	-0.25
Trehan *et al.*	1980	40 wk EP-EW	-0.30	-	-	-	-0.06
Das	1982	280 d EP-EW	-0.40	-	-	-	-0.02
			-0.62	-	-	-	-0.07
Venkatramaiah	1982	280 d EP-EW	-0.54	0.20	-0.14	-	-0.04
Barua	1983	260 d EP-EW	-0.48	-0.33	-0.41	-	-0.09
			-0.16	0.12	-0.04	-	-0.12
Renganathan *et al.*	1983	40 wk EP-EW	0.07	-	-	-	0.03
Verma *et al.*	1983	260 d EP-EW(initial)	-	-	-	-0.23	-
Rodko *et al.*	1983	200 d EP-EW	-0.23	-0.95	-0.38	-	-
Zhang	1984	EP after 280 d-EW 36 wk	-	-	-	-0.53	-0.16

1	2	3	4	5	6	7	8
Thiyagasundaram	1984	EP upto 280 d-TM	-0.57	0.11	-0.10	-	0.01
			0.15	0.42	0.26	-	-0.04
			-0.90	0.01	-0.17	-	-0.06
			-2.56	0.11	-0.16	-	-0.02
Average			-0.34	-0.05	-0.11	-0.24	-0.09

Egg production and age at sexual maturity

The various reports on correlation between egg production and age at sexual maturity have been presented in Table 6. The averages of genetic correlation estimates are found to be -0.68, -0.72 and -0.40 from sire, dam and sire plus dam components respectively. The average phenotypic correlation (-0.47) although negative was smaller in magnitude than the estimate of genetic correlation. The higher estimates of rG from dam component of variance suggest the importance of maternal and/or dominance deviation effects involved in such genetic correlation between egg production and age at sexual maturity. The higher values from dam component of variance have also been reported by King (1961), Hale and Clayton (1965), Acharya *et al.* (1969), Quadeer *et al.* (1977), Poggenpoel and Erasmus (1978) and Rodke *et al.* (1983).

Table 6. Genetic and phenotypic correlation estimates between egg production and age at maturity

Authors	Year	Criterion	rG_S	rG_D	rG_{S+D}	rG pooled	rP
1	2	3	4	5	6	7	8
Krueger *et al.*	1952	Total EP-ASM	-	-	-	0.53	-
Dillard *et al.*	1953	EP-ASM	-	-	-	-0.22	-
Yamada	1955	Winter EP-ASM	-	-	-	-0.21	-
		Spring EP-ASM	-	-	-	0.19	-
Bray *et al.*	1960	EP-ASM	-	-	-	0.06	-
King	1961	EP to Jan. 1st-ASM	-0.15	-0.80	-0.25	-	-0.18
		72 wk % EP-ASM	-0.17	-1.07	1.73	-	-0.23
Hussaini and Singh	1964	EP-ASM	-0.54	-	-	-	-0.31
Baczkowska & Kaminska	1964	EP-ASM Sussex	-	-	-	-0.65	-
Hale and Clayton	1965	250 d EP-ASM	-0.47	-1.13	-	-	-
Kinney and Shoffner	1965	Rate of EP-ASM	-	-	-	-0.24	-
Krause *et al.*	1965	% EP-ASM	-	-	-	-0.45	-
		% EP-ASM	-	-	-	-0.33	-
Shibata	1965	EP-ASM	-	-	-	-0.75	-
Clayton and Robertson	1968	40 wk EP-ASM	-	-	-	-0.05	-

1	2	3	4	5	6	7	8
Kinney *et al.*	1968	40 wk % EP-ASM	-	-	-	-0.22	-
Acharya *et al.*	1969	70 d EP-ASM	-0.55	-0.27	-0.40	-	-0.08
Craig *et al.*	1969	260 d rate EP-ASM	-0.32	-	-	-	-
			-0.34	-	-	-	-
Ragab and Mossari	1969	EM to 1st Jan-ASM	-	-	-	-0.53	-
Mohapatra and Ahuja	1971	100 d EP-ASM	-0.75	-	-	-	-0.10
Anjaneyulu	1972	260 d EP-ASM	-0.73	-	-	-	-0.72
Kolstad	1972	EP-ASM	-	-	-	0.18	-
Singh *et al.*	1972	EP-ASM	-0.38	-	-	-	-0.19
Nanda	1973	100 d EP-ASM	-0.65	-	-	-	-0.3
Prakashbabu	1973	260 d EP-ASM	-0.72	-	-	-	-0.02
			-0.76	-	-	-	-0.34
			-0.65	-	-	-	-0.53
Vanchev *et al.*	1974	EP-ASM	-	-	-	-0.75	-
Choudhuri	1975	260 d EP-ASM	-1.47 to -0.79	-	-	-	-0.[illegible] to -0.75
Iqbaluddin *et al.*	1975	EP-ASM	-0.18	-	-	-	-0.2
Sivasamy *et al.*	1976	260 d EP-ASM	-0.36	-	-	-	-0.5
Singh *et al.*	1976	EP-ASM	-	-	-	-0.69	-

1	2	3	4	5	6	7	8
Chung	1977	EP-ASM	-	-	-	0.42	-
Murty	1977	260 d EP-ASM	-0.46	-	-	-	-0.01
			0.06	-	-	-	-0.01
Quadeer *et. al.*	1977	HH rate of lay-ASM	-0.16	-0.24	-0.22	-	-0.11
Sinha	1977	EP-ASM	-	-	-	-0.71	-1.00
			-	-	-	-0.81	-1.10
			-	-	-	-1.10	-0.20
Mishra *et. al.*	1978	280 d EP-ASM	-0.80	-0.86	-	-	-0.60
Poggenpoel and Erasmus	1978	275 d EP-ASM	-0.51	-0.75	-0.73	-	-0.55
Trehan	1978	40 wk EP-ASM	-0.85	-	-	-	-0.74
Reddy *et. al.*	1978	280 d EP-ASM	-	-	-	-0.21	-
			-	-	-	-1.00	-
			-	-	-	-1.00	-
			-	-	-	-0.15	-
Kolstad	1980	Winter EP-ASM	-	-	-	-0.52	-0.56
Kotaiah and Renganathan	1980	Winter EP-ASM	-0.83	-	-	-	-0.50
Jain *et. al.*	1980	EP-ASM	-	-	-	-	-0.24
Ahlawat *et. al.*	1980	90 d EP-ASM	-	-	-	-0.60	-
			-	-	-	-0.68	-
Das	1982	40 wk EP-ASM	-0.90	-	-	-	-0.60
			-0.97	-	-	-	-0.52

1	2	3	4	5	6	7	8
Venkatramaiah	1982	40 wk EP-ASM	-1.00	-0.99	-0.93	-	-0.68
Singh and Chaudhary	1982	EP-ASM	-	-	-	0.84	-
Barua	1983	260 d EP-ASM	-0.97	-0.84	-0.91	-	-0.73
			-1.02	-0.85	-0.95	-	-0.83
Renganathan *et al.*	1983	280 d EP-ASM	-0.77	-	-	-	-0.52
Verma *et al.*	1983	260 d EP-ASM	-	-	-	-1.16	-
Ahlawat *et al.*	1983	90 d EP-ASM	-	-	-	-0.61	-
Rodke *et al.*	1983	200 d EP-ASM	-0.11	-0.38	-0.37	-	-
Zhang Lao	1984	EP after 260 d-ASM	-	-	-	-0.73	-0.56
Thiyagasundarum	1984	EP-ASM	-1.04	-0.37	-0.62	-	-0.69
			-0.91	-1.28	-0.97	-	-0.56
			-1.29	-0.72	-0.76	-	-0.61
			-1.91	-0.98	-0.98	-	-0.64
Average			-0.68	-0.72	-0.48	-0.39	-0.47

Egg production and body weight

The genetic and phenotypic correlation between egg production and several measures of adult body weight have been presented in Table 7. Considerable variation both in direction and magnitude was noticed amongst the various reports for th genetic and phenotypic correlation between the two traits. This has however resulted since it involved not only the different populations but also measurements at different ages. The average of genetic correlation estimates are found to be 0.05, 0.21 and 0.12 from sire, dam and sire plus dam components respectively. Phenotypic correlation followed a similar trend to that of genetic correlation as the average of all the estimates reported in literature was 0.13. However, some reports revealed higher genetic correlation between these traits from sire component variance (King, 1961; Hale and Clayton, 1965; Mohapatra and Ahuja, 1971; Nanda et al., 1973; Das, 1982; Venkatramiah, 1982 and Thiyagasundaram, 1984), but phenotypic correlation estimates were mostly low in magnitude (King, 196 Nordskog et al., 1967; Prakashbabu, 1973; Trehan, 1973; Barua, 1976; Ranganathan, 1976; Sosamma and Singh, 1979; Das, 1982 and Barua, 1983).

Table 7. Genetic and phenotypic correlation estimates between egg production and body weight

Authors	Year	Criterion	rG_S	rG_D	rG_{S+D}	rG pooled	rP
1	2	3	4	5	6	7	8
Wyatt	1954	EP-165 d BW	-	-	-	-0.31	-
Yamada	1955	Winter EP-BW	-	-	-	0.17	-

1	2	3	4	5	6	7	8
Hogsett and Nordskog	1956	EP-March BW	-	-	-	0.29	-0.03
Jerome *et al.*	1956	4 month EP-March BW	-	-	-	-0.51	-
King	1961	Percent EP to Jan. 1st-32 wk BW	0.70	0.07	-0.26	-	0.13
Hussain and Singh	1964b	Part record EP-Mature body weight	-	-	-	-0.10	-0.13
Hale and Clayton	1965	250 d EP-Housing BW	0.73	0.08	-	-	
Kinney and Shoffner	1965	40 wk EP-32 wk BW	-	-	-	-0.19	-
Clayton and Robertson	1966	EP-Mature BW	-	-	-	0.00	-
Jaffe	1966	EP-Mature BW	-	-	-	-0.28	-0.01
Nordskog *et al.*	1967	9 mth EP-9 mth BW	-	-	-	-0.03	0.02
Kinney and Lowe	1968	40 wk EP-32 wk BW	-	-	-	-0.19	-
Kinney *et al.*	1968	40 wk % EP-32 wk BW	-	-	-	-0.07	
Craig *et al.*	1969	260 d EP-32 wk BW	-0.24	-	-	-	
			0.20	-	-	-	
Ragab and Hossari	1969	1st Jan. EP-BW at 1st	-	-	-	-0.54	
		egg BW at 12 M	-	-	-	0.29	
Mohapatra and Ahuja	1971b	100 d EP-mature BW	-0.92	-	-	-	

1	2	3	4	5	6	7	8
Kovalenko and Kocenko	1971	SP-[illegible]	-	-	-	-0.26 to 0.30	-
Anjaneyulu	1972	230 d LP-mature BW	-0.31	-	-	-	-0.05
Kolstad	1972	SP-BW	-	-	-	0.08	-
Nanda *et al.*	1973	200 d LP-mature BW	0.47	-	-	-	.23
Prakasham	1973	220 d SP-32 wk BW	0.09	-	-	-	0.35
			-0.42	-	-	-	0.20
Trehan	1973	10 wk SP-40 wk BW	0.47	0.63	0.20	-	.10
Nordskog *et al.*	1974	SP-[illegible]	-	-	-	-.10	-
Pangley *et al.*	1974	SP-F, 1st d	-	-	-	0.11	-
Choudhuri	1975	260 d LP-30 wk BW	0.01 to 0.53	-	-	-	0.27 to 0.37
		280 d LP-40 wk BW	-0.40 to 0.33	-	-	-	-0.01 to 0.18
Ignatov *et al.*	1975	SP-mature BW	-	-	-	-0.19	-
Varma	1976	260 d SP-32 wk BW	-0.36 to 0.35	-	-	-	-0.06 to -0.08
Rengarathan	1976	260 SP-40 wk BW	0.30 to 0.35	-	-	-	0.34 to 0.47
		260 SP-32 wk BW	0.13 to 0.26	-	-	-	0.06 to 0.11

1	2	3	4	5	6	7	8
Chung	1977	EP-40 wk BW	-	-	-	-0.01	-
Lionnavis	1977	260 EP- 18 wk BW	0.36	0.34	0.22	-	-
Murty	1977	260 EP- 20 wk BW	-0.13 to 0.13	-	-	-	0.00
		260 EP- 32 wk BW	-0.44 to 0.11	-	-	-	0.00
Sinha	1977	EP-[illegible]	-	-	-	0.27	0.22
Johari et al.	1977	300 d EP- 30 wk BW	-	-	-	-0.91	-
Roggenpool and Erasmus	1978	275 d EP- 500 d BW	-0.10	-0.09	-0.09	-	-0.01
Singh and Hussain	1978	90 d EP- mature BW	0.28	-	-	-	0.00
		300 d EP- mature BW	0.24	-	-	-	-0.01
Trehan	1978	40 wk EP- 20 wk BW	0.27	-	-	-	0.19
			0.16	-	-	-	0.12
		40 wk EP- 16 wk BW	-0.14	-	-	-0.24	0.07
			-0.24	-	-	-0.24	0.15
Taylor et al.	1978	100 d EP- FI ac AG	-	-	-	0.03	0.15
Reddy et al.	1978	300 d EP- 20 wk BW	-	-	-	-0.28	-
			-	-	-	0.16	-
			-	-	-	0.19	-
			-	-	-	0.10	-

1	2	3	4	5	6	7	8
Gonzaler *et al.*	1979	EP-133 d BW	-	-	-	0.64	-
		EP-308 d BW	-	-	-	0.55	-
Sosamma and Singh	1979	260 d EP-16 wk BW	-	-	-	0.06	0.13
Kotaiah and Renganathan	1980	40 wk EP-40 wk BW	-0.18	-	-	-	-0.02
Kolstad	1980	44 wk EP-44 wk BW	-	-	-	-0.04	0.02
Ahlawat *et al.*	1980	90 d EP-BW 24 wk	-	-	-	0.61	-
		BW ASM	-	-	-	0.59	-
		90 d EP-BW 12 wk	-	-	-	0.44	-
		BW 16 wk	-	-	-	0.72	-
		BW 24 wk	-	-	-	0.59	-
		BW ASM	-	-	-	0.71	-
Das	1982	40 wk EP-20 wk BW	0.37	-	-	-	0.28
			0.67	-	-	-	0.34
		40 wk EP-40 wk BW	-0.10	-	-	-	0.07
			-0.28	-	-	-	0.12
Venkatramaiah	1982	40 wk EP-20 wk BW	0.57	0.39	0.37	-	0.31
		40 wk EP-40 wk BW	0.05	0.10	0.18	-	0.08
Johari *et al.*	1982	200 d EN-20 wk BW	-0.36	-	-	-	0.32
Singh and Chaudhary	1982	EP-BW ASM	-	-	-	0.92	-

1	2	3	4	5	6	7	8
Barua	1983	260 d EN- 260 d BW	-0.37	0.04	-0.21	-	0.01
			-0.14	0.11	-0.03	-	0.04
Verma *et al.*	1983	260 d EP- 20 wk BW	-	-	-	0.34	-
Thiyagasundarum	1984	EP-BW 20 wk	1.34	0.39	0.47	-	0.32
			0.27	0.44	0.33	-	0.29
			-0.12	0.60	0.40	-	0.42
			-0.44	0.74	0.46	-	0.27
		EP-BW 40 wk	0.34	-0.02	-0.09	-	0.07
			-0.02	0.29	0.11	-	-0.03
			-0.01	-0.12	-0.07	-	0.07
			-2.31	0.19	-0.11	-	-0.03
Average			0.05	0.21	0.12	0.09	0.13

Age at sexual maturity and body weight

An optimum body weight requirement for the on-set of sexual maturity is a general phenomenon in votebrates. Under conditions of inferior nutrition, sexual maturity is delayed until females reach a body weight characteristic of well-fed animals at the onset of sexual maturity (Crichton *et al.*, 1959; Dickerson *et al.*, 1964; Kennedy and Mitra, 1963). There may be difference between stocks in their response to age at maturity in the sense that each stock might have different optimum age at maturity as suggested by Shanawany (1963).

The correlations available in the literature are summarised in Table 8. The average genetic correlation of these reported estimates were 0.16, -0.15 and -0.61 from sire, dam and sire plus dam components of variance, respectively and the phenotypic correlation was negative and low (-0.04) between these two traits.

Table 8. Genetic and phenotypic correlation estimates between age at sexual maturity and body weights

Authors	Year	Criterion	rG_S	rG_D	rG_{S+D}	rG pooled	rP
1	2	3	4	5	6	7	8
Hazel and Lamoreux	1947	ASM-32 wk BW	-	-	-	-0.44	-0.33
Lerner and Cruden	1951	ASM-Dec. BW	0.03	-	0.44	-	-0.03
Tanaka and Rosenberg	1952	ASM-BW	-	-	-	-0.01 to 0.32	.
Yamada	1955	ASM-Mature BW	-	-	-	0.003	-
		ASM-BW at ASM	-	-	-	-0.022	-
King	1961	ASM-BW	0.50	-0.08	-1.66	-	0.04
Daczkowska and Kaminska	1964	ASM-BW 31 June Sussex	-	-	-	0.57	-
		RIR	-	-	-	-0.51	-
Amer	1965	ASM-BW	-	-	-	0.50	-
Hale and Clayton	1965	ASM-BW housing					
		DLH	0.02	-0.22	-	-	-
		CS	0.05	-0.15	-	-	-

1	2	3	4	5	6	7	8
Clayton and Robertson	1966	ASM-BW 36 wk	-	-	-	-0.01	-
			-	-	-	-0.03	-
Kinney and Lowe	1968	ASM-BW 32 wk	-	-	-	0.10	-
Kinney *et al.*	1968	ASM-BW 32 wk	-	-	-	0.17	-
Sinha and Garowal	1970	ASM-BW	-	-	-	0.08	0.22
Mohapatra and Ahuja	1971b	ASM-BW	-	-	-	0.79	0.26
Reddy *et al.*	1972	ASM-BW	-	-	-	-	0.23
Nanda	1973	ASM-BW at ASM	-	-	-	0.52	0.19
Prakashbabu	1973	ASM-BW 32 wk					
		M	-	-	-	-0.13	0.01
		T	-	-	-	0.56	0.01
		V	-	-	-	0.65	0.37
Choudhuri	1975	ASM-BW 20 wk	-	-	-	0.09	-0.31
			-	-	-	0.08	-0.20
			-	-	-	-1.15	-0.30
		ASM-BW 40 wk	-	-	-	0.48	0.09
			-	-	-	0.75	0.06
			-	-	-	0.31	0.01
			-	-	-	-0.36	-0.04
Rongenathan	1976	ASM-BW 20 wk	-	-	-	-0.36	-0.38
			-	-	-	-0.65	-0.51

1	2	3	4	5	6	7	8
		ASM-BW 32 wk	-	-	-	0.18	0.02
			-	-	-	-0.57	0.00
Chung	1977	ASM-BW	-	-	-	-0.07	-
Murty	1977	ASM-BW 20 wk	-	-	-	0.04	-0.01
			-	-	-	0.02	-0.01
		ASM-BW 32 wk	-	-	-	0.32	0.01
			-	-	-	0.45	0.01
Johari *et al.*	1977	ASM-20 wk BW	-	-	-	-0.82	-
Reddy *et al.*	1978	ASM-BW 20 wk	-	-	-	-0.30	-
			-	-	-	-1.00	-
			-	-	-	-0.48	-
			-	-	-	0.68	-
Jain *et al.*	1980	ASM-BW	-	-	-	0.95	-
Singh and Chaudhary	1982	ASM-BW	-	-	-	1.00	-
Das	1982	ASM-20 wk BW	-	-	-	0.37	-0.03
			-	-	-	-0.27	-0.23
			-	-	-	-0.56	-0.54
		ASM-40 wk BW	-	-	-	0.15	0.24
			-	-	-	0.01	0.04
			-	-	-	-0.09	-0.18
Average			0.16	-0.15	-0.61	0.05	-0.04

Age at sexual maturity and egg weight

The reported estimates of genetic and phenotypic correlations between age at sexual maturity and egg weight are presented in Table 9. The estimates were mostly positive in direction but varied widely in magnitude. The averages of these estimates are 0.23, 0.01 and 0.13 from sire, dam, and sire plus dam components, respectively, whereas 0.15 for phenotypic correlation. The observed wide variation in these correlation estimates reported was probably due to population differences and egg weight measurements at various ages.

Table 9. Genetic and phenotypic correlations between age at sexual maturity and egg weight

Author	Year	Criterion	rG_S	rG_D	rG_{S+D}	rG pooled	rP
1	2	3	4	5	6	7	8
Lerner	1946	ASM-EW (early)	-	-	-	0.66 to 0.69	-
Lerner and Cruden	1951	ASM-EW (early)	0.67	-	0.75	-	0.50
		ASM-EW (Nov)	0.06	-	0.27	-	0.36
		ASM-EW (April)	0.12	-	0.41	-	0.32
Tanaka and Rosenberg	1952	ASM-EW (early)	-	-	-	0.17 to 0.67	-

1	2	3	4	5	6	7	8
King	1961	ASM-EW 32 wk	0.78	0.13	-	-	0.13
Hussain and Singh	1964b	ASM-EW	-	-	-	0.16	0.49
Baczkowska and Kaminska	1964	ASM-EW (RIR)	-	-	-	-0.52	-
Hale and Clayton	1965	ASM-Spring EW					
		BLWI	-	-	-	-0.24	-
		LS	-	-	-	-0.51	-
Clayton and Robertson	1966	ASM-EW 36 wk	-	-	-	0.14	-
			-	-	-	-0.26	-
Kinney and Lowe	1963	ASM-EW 32 wk	-	-	-	0.33	-
Kinney *et al.*	1968	ASM-EW 32 wk	-	-	-	0.46	-
			-	-	-	0.69	-
Kumar and Kapri	1968	ASM-EW	-	-	-	0.18	-
Mohapatra and Ahuja	1971b	ASM-EW early	-	-	-	0.79	0.11
Singh *et al.*	1972	ASM-EW	-	-	-	0.13	0.10
Prakashbabu	1973	ASM-EW	-	-	-	0.16	0.06
			-	-	-	0.31	0.06
			-	-	-	0.35	-0.03
Nanda	1973	ASM-EW	-	-	-	0.59	0.35
Choudhuri	1975	ASM-EW	-	-	-	0.63	0.21
			-	-	-	0.74	0.10
			-	-	-	-0.14	0.11
			-	-	-	0.16	0.05

1	2	3	4	5	6	7	8
Renganathan	1976	ASM-EW 32 wk	-	-	-	-0.28	0.04
			-	-	-	-0.60	0.02
Sivasamy *et al.*	1976	ASM-EW	-	-	-	0.40	0.59
Chung	1977	ASM-EW	-	-	-	0.18	-
Murty	1977	ASM-EW	-	-	-	0.18	-0.00
			-	-	-	0.00	-0.00
Quadeer *et al.*	1977	ASM-EW	0.04	-0.02	0.01	-	0.03
Rodke *et al.*	1983	ASM-EW	-0.31	-	-0.81	-	-
Das	1983	ASM-EW	-	-	-	-0.35	0.15
			-	-	-	-0.08	0.00
			-	-	-	0.15	0.03
Zhang Lao	1984	ASM-EW (1st)	-	-	-	0.66	0.11
Average			0.23	0.01	0.13	0.22	0.15

Egg weight and body weight

It was observed that the correlation between egg weight and body weights at different ages are positive and high (Lerner and Cruden, 1951; Hogsett and Nordskog, 1958; Hussain and Singh, 1964b; Hale and Clayton, 1963; Shibata, 1965; Barua, 1976; Prakashbabu *et al.*, 1978; Das, 1982 and Zhang, 1984). The averages of the genetic correlation estimates reported in literature are 0.33, 0.38, 0.75 from sire, dam and sire plus dam components respectively (Table 10). The average of the estimates of phenotypic correlation (0.37) was found to be similar in magnitude as observed for genetic correlation.

Table 10. Genetic and phenotypic correlation between egg weight and body weight

Author	Year	Criterion	rG_S	rG_D	rG_{S+D}	rG pooled	rP
1	2	3	4	5	6	7	8
Lerner and Cruden	1951	Early EW-Dec. BW	0.45	-	0.74	-	0.34
		Nov. EW-Dec. BW	0.46	-	0.94	-	0.54
		April EW-Dec. BW	0.51	-	0.96	-	-
Wyatt	1954	EW-BW housing	-	-	-	0.31	
		EW-BW March	-	-	-	0.30	-
Hogsett and Nordskog	1956	Mar. EW-Mar. BW	-	-	-	0.56	-
Hogsett and Nordskog	1958	Mar. EW-Mar. BW	-	-	-	0.61	0.37
King	1961	EW 32 wk-BW	0.33	0.57	1.05	-	0.40
Hussain and Singh	1964b	EW-BW at ASM	-	-	-	0.87	-
Baczkowska and Kaminska	1964	EW-BW	-	-	-	0.50	-
Hale and Clayton	1965	Spring EW-BW housing					
		WLH	0.33	0.57	-	-	-
		LS	0.61	0.36	-	-	-

1	2	3	4	5	6	7	8
Kawahara	1965	EW-Adult BW	-	-	-	0.54	-
Shibata	1965	EW-Adult BW	-	-	-	0.65	-
Clayton and Robertson	1966	36 wk EW-BW 20 wk	-	-	-	0.18	-
			-	-	-	0.51	-
		36 wk EW-BW 26 wk	-	-	-	0.30	-
			-	-	-	0.43	-
		36 wk EW-BW 36 wk	-	-	-	0.34	-
			-	-	-	0.44	-
		36 wk EW-BW 44 wk	-	-	-	0.30	-
			-	-	-	0.50	-
Orlov and Zlocevskaja	1967	EW-BW	-	-	-	-	0.21 to 0.63
Kinney and Lowe	1968	EW-BW 32 wk	-	-	-	0.30	-
Kinney *et al.*	1968	EW-BW 32 wk	-	-	-	0.47	-
			-	-	-	0.22	-
Mohapatra and Ahuja	1971b	EW-BW at ASM	-	-	-	1.17	0.12
Kovalenko and Kosenko	1971	BW-EW	-	-	-	0.26 to 0.72	-
Kolstad	1972	EW-BW	-	-	-	0.38	-
Reddy *et al.*	1972	EW-BW at ASM	-	-	-	-	0.26
Nanda	1973	EW-BW at ASM	-	-	-	0.36	0.58

1	2	3	4	5	6	7	8
Prakashbabu	1973	FW-BW 32 wk					
		M	-	-	-	0.31	0.06
		T	-	-	-	0.16	0.06
		V	-	-	-	0.35	-0.03
Poulouse and Sathe	1974	EW-BW	-	-	-	-	0.88
			-	-	-	-	0.99
			-	-	-	-	0.28
Nordskog *et al.*	1974	FW-BW	-	-	-	0.41	-
Arthur and Beck	1974	EW-BW	-	-	-	0.35	-
Choudhuri	1975	EW-BW 20 wk	-	-	-	0.62	0.25
			-	-	-	0.02	0.28
			-	-	-	0.00	0.22
			-	-	-	0.37	0.28
		EW-BW 40 wk	-	-	-	0.62	0.38
			-	-	-	0.18	0.36
			-	-	-	0.35	0.25
			-	-	-	0.55	0.42
Ignatov *et al.*	1975	EW-BW	-	-	-	0.31	-
Barua	1976	32 wk FW-32 wk BW	-	-	-	0.74	0.39
			-	-	-	0.16	0.43
Chung	1977	EW-BW	-	-	-	0.32	-
Lianmovia	1977	37 wk EW-18 wk BW	0.02	0.01	0.06	-	0.10

1	2	3	4	5	6	7	8
Murty	1977	32 wk EW-20 wk BW	-	-	-	0.64	0.01
			-	-	-	0.56	0.01
		32 wk EW-32 wk BW	-	-	-	0.46	0.01
			-	-	-	0.38	0.01
Nikolov and Belorechkov	1978	EW-BW	-	-	-	0.18	-
			-	-	-	0.12	-
Prakashbabu *et al.*	1978	32 wk EW-32 wk BW					
		M	-	-	-	0.44	0.34
		T	-	-	-	0.77	0.38
		V	-	-	-	0.29	0.24
Gonzalez *et al.*	1979	EW-308 d BW	-	-	-	-0.02	-
		EW-133 d BW	-	-	-	0.09	-
Das	1982	EW-20 wk BW	-	-	-	1.87	0.25
			-	-	-	0.22	0.29
			-	-	-	0.07	0.39
		EW-40 wk BW	-	-	-	0.41	0.43
			-	-	-	-0.21	0.42
			-	-	-	0.86	0.48
Verma *et al.*	1983	35 wk EW-20 wk BW	-	-	-	0.27	-
Zhang	1984	EW-BW 36 wk	-	-	-	0.94	0.53
		36 wk EW-BW 36 wk	-	-	-	0.55	0.25
Average			0.38	0.38	0.75	0.44	0.32

20 week and 40 week body weight

The several genetic and phenotypic correlations between 20 week and 40 week body weights as available in the literature are presented in Table 11. Both the genetic and phenotypic correlations were positive and high and the genetic correlations exceeded the phenotypic correlations in all instances. The average of the reported estimates were 0.78 for genetic correlation and 0.45 for phenotypic correlations.

Table 11. Genetic and phenotypic correlations between body weight at housing and adult body weight

Author	Year	Criterion	rG_S	rG_D	rG_{S+D}	rG pool	rP
1	2	3	4	5	6	7	8
Wyatt	1954	March BW–165 d BW	-	-	-	0.95	-
Yamada	1955	BW at ASM–Mature BW	-	-	-	0.77	-
Clayton and Robertson	1966	20 week BW–36 wk BW	-	-	-	0.92	-
Choudhuri	1975	20 wk BW–40 wk BW	-	-	-	0.85	0.57
			-	-	-	0.83	0.51
			-	-	-	0.20	0.41
			-	-	-	0.89	0.54
Renganathan	1976	20 wk BW–32 wk BW	-	-	-	0.75	0.61
			-	-	-	0.89	0.55

1	2	3	4	5	6	7	8
Murty	1977	20 wk BW- 32 wk BW	-	-	-	0.74	0.01
			-	-	-	0.43	0.01
Natarajan	1977	20 wk BW- 40 wk BW	-	-	-	0.84	0.37
Gonzalez *et al.*	1979	133 d BW- 303 d BW	-	-	-	0.90	-
Ahlawat *et al.*	1980	BW at ASM- BW at 20 wk	-	-	-	0.42	-
			-	-	-	0.66	-
		BW at ASM- BW 24 wk	-	-	-	0.72	-
			-	-	-	0.83	-
		BW at ASM- BW 16 wk	-	-	-	0.69	-
Das	1982	20 wk BW- 40 wk BW	-	-	-	1.28	0.63
			-	-	-	0.83	0.57
			-	-	-	0.94	0.65
Average			-	-	-	0.78	0.45

Effect of selection on parameter estimates

Heritability:

No significant change of heritability estimates, over generations in selected populations could be observed by some investigators (Lerner and Dempster, 1951; Falconer, 1955) and Nordskog *et al.*, 1974). But Yamada *et al.* (1958) and Morris (1963) reported decline of heritability values of egg production traits for populations under selection over generations.

Similarly Gowe (1970) and Poggenpoel and Erasmus (1978) noticed that the heritability estimates had turned negative over generations of selection.

Hill (1971) postulated that any change in genetic variance in the course of selection may be noticed due to inbreeding effect or the effects of major genes governing the trait. Further, selection for less than five generations may not show any change in genetic variance. However, Nordskog *et al.* (1974) suggested that the different populations may behave differently with respect to decline in the genetic variability due to selection.

Barua (1983) observed an increasing trend in heritability due to selection as that of Scosseroli (1957) for production trait, whereas Thiyagasundaram (1984) reported decreasing trend of heritability from sire component of variance.

Genetic correlation:

Pleiotropy and linkage are the main causes which give rise to negative genetic correlation while selecting for two or more traits (Lush, 1945; Lerner, 1950; Falconer, 1960 and Sheridan and Barker, 1974b).

Bohren *et al.* (1966) reported that the directional changes in correlations might be due to change in gene frequency resulting from random drift and selection.

Parker et al. (1969, 1970) observed that the genetic correlations did not decrease unless selection was intense and traits involved had high heritability. However, intense selection and small environmental variance did not lead the genetic correlation to zero until 30th generation of selection.

As a consequence of selection the genetic correlation between a metric trait and a fitness trait turned negative (Nordskog et al., 1974) and also between highly heritable traits (Nordskog et al., 1974 and Kolstad, 1980).

Thiyagasundarum (1984) noticed variation in genetic correlation estimates between generations. As the experiment was for short duration (3 generations only) and selection intensity was not very high, the author did not expect any time trend and suggested that pooled estimates would be more meaningful.

Some of the genetic correlation estimates reported were beyond the theoretical limits of -1 to +1. One of the factors responsible for such situation might be due to statistical sampling (Robertson, 1959). The estimates of genetic correlations may tend to go wild, rather than approaching zero, when the genetic variance of one of the correlated traits approaches zero (King, 1961). It was also shown that the genetic variance/covariance matrix of quantitative genetic theory measures developmental constraints due to internal selection and non-random mutation which may cause selection response to deviate from the optimal rate and direction as specified by the selection gradient (Cheverud, 1984).

Selection differential

The selection differential is the mean phenotypic value of the individuals selected as parents expressed as a deviation from the population mean, that is from the mean phenotypic value of all the individuals in the parental generation before selection was made. The magnitude of selection differential depends on proportion of population selected and the phenotypic standard deviation of the trait under selection. Selection differential expressed as standard deviation units of the selected trait is the intensity of selection. In practice since individual parents do not contribute equally to the offspring generation there is a need to distinguish between expected and effective (realised) selection differential.

The effective selection differential is the weighted mean deviation of the selected parents, the weight given to each parent or pair of parents depending on their proportionate contribution of effective offspring to the next generation. By weighting selection differential the joint effects of natural and artificial selection are measured together. A comparison of effective with the expected selection differential may exhibit the action of natural selection (Falconer, 1960).

Morris (1963) observed no difference in magnitude between expected and effective selection differentials in his selection experiment on short term egg production records.

Kinney *et al.* (1970) observed little difference in the two measures of the selection differentials in their sire family and two index selected lines. But in the line selected on dam family averages the realised selection differentials were constantly higher than expected indicating some correlation between the trait selected (short term rate of egg production) and reproductive fitness in that line.

Poggenpoel and Erasmus (1978) estimated the ratio of expected to effective selection differentials as 1.00 and 0.96 in their selection experiment.

Ayyagari *et al.* (1980, 1983); Venkatramaiah (1982); Barua (1983) and Thiyagasundarum (1984) did not observe any significant influence of natural selection for part record egg production in those selected lines.

Response to selection

It is defined as the difference of mean phenotypic value between the offspring of the selected parents and the whole of the parental generation before selection. Response to selection depends on (i) intensity of selection applied, (ii) degree of heritability of the concerned trait and (iii) generation interval (Dickerson, 1961).

Dickerson (1955) suggested that the non-additive gene effects included in the estimates of genetic parameters might be the possible cause for over-estimation of the expected response.

Clayton *et al.* (1957) postulated that the realised response was below the expected at lower intensities of selection but at higher intensities there was no difference between those two.

The generation means remain confounded with environmental effects, as such it was very difficult to assess the genetic and environmental changes separately. Hence use of a random-bred control was essential (Gowe *et al.*, 1959a, and King *et al.*, 1959).

Marks (1978) had reported that major genes were the first to be influenced by selection followed by the additive action of minor genes at the later stages of selection programme.

Hill (1980) differentiated short and long term selection experiments. Short term experiments were for maximum five generations through which genetic parameters were estimated, prediction of responses were checked and ~~for comparison of~~ rates of response in different breeding schemes were compared. Long term experiments were for measuring rate and direction of direct and correlated responses and to obtain specialised lines with different properties.

Selection for egg number

Gowe *et al.* (1959b) reported a significant response of 3.71 eggs per generation but when environmental effect was eliminated with the help of a control population the same response droped to 1.26 eggs per generation.

Morris (1963) observed responses for part period selection which ranged from 1.97 ± 0.39 to 3.03 ± 0.38 eggs per generation.

Cowe et al. (1973) observed significant responses from a selection experiment spread over 20 generations for egg number to 273 days of age using Osborne's index in two White Leghorn strains. Gowe (1974) further reported genetic gains of 1.1 and 1.5 eggs per generation for part year hen-housed egg production to 275 days of age in two strains from 22 and 21 generations of selection, respectively. Cowe (1977) also observed genetic gains of 4.8, 3.7 and 12.4 eggs in hen-housed egg number in 273 days of age from five generations of selection in three White Leghorn lines through I.D.S. selection.

Poggenpoel and Erasmus (1978) reported realised response of 3.04 eggs per generation through seven generations of selection for egg production to 273 days of age.

Ayyagari et al. (1980) reported genetic gains of 4.17, 3.59, 2.30 and 1.10 eggs per generation respectively in four White Leghorn populations which were under selection for four generations for egg number to 280 days of age. Mohapatra (1980) estimated genetic gains which were 4.84, 3.59, 2.99 and 2.30 eggs per generation in the same four populations and the phenotypic gains in five years of I.D.S. method of index selection which exceeded the genetic gains were 5.78, 4.54, 4.13 and 3.24 eggs respectively per generation.

Flock (1980) reported that the annual rate of progress due to selection appeared to be approximately 3.5 to 4.5 eggs per hen-housed.

Kolstad (1980) obtained a genetic response of 6.61 eggs per generation from the population which was under selection for egg number upto 42 weeks on I.D.S. method of selection.

Gowe and Fairfull (1980) in the largest non-commercial selection experiment at Ottawa involving six selected and two control lines, demonstrated that response to selection for either part year hen-housed egg number or part year hen-day rate of production continued even after many generations of selection. The authors reported genetic gains of 6.4, 7.6 and 17.6 eggs in three strains with a mean value of 10.6 eggs for hen-housed part record egg number to 275 days of age during the period from 1971 to 1978.

Liljedahl and Weyde (1980) estimated an average genetic response of 3.57 eggs per generation in white Leghorn population from four generations of selection on egg number to 42 weeks of age.

Venkatramaiah (1982) reported non-significant genetic responses which were 3.74, 2.02, 0.99 and 1.91 eggs per generation for egg production to 280 days age in four populations, whereas Ayyagari *et al.* (1983) reported the responses in different lines which varied from 2.03 to 4.55 eggs per generation.

Barua (1983) reported a non-significant genetic gain of 3.58 eggs per generation for egg number to 260 days of age in a two year selection experiment. Mohapatra et al. (1983) indicated significant realised genetic gains which ranged from 2.67 to 4.44 eggs in four White Leghorn populations subjected to selection for egg number to 40 weeks of age.

Singh and Kumar (1983) obtained genetic gain of 10.44 eggs (which was 74.25% of the predicted response) from two generations of selection for egg production upto 280 days of age. Thiyagasundarum et al. (1983) reported a non-significant genetic gain of 2.75 eggs per generation in a White Leghorn population through two generations of selection for egg production upto 280 days of age. When response was updated to third selected generation the average response was 2.40 eggs per generation which was still non-significant (Thiyagasundarum, 1984).

Zhou (1983) reported average increase of 3.1 eggs, where selection was based on egg production to 300 days of age. Zhang (1984) concluded that the selection over three generations had led to an increase in hen-housed egg production of 14 eggs per year.

Correlated response

The selection for a primary trait brings about simultaneous changes in correlated traits. The change of generation means in unselected traits concomitant to selection for a primary trait are estimates of correlated response to selection (Falconer, 1960). While the direct response is a function of selection intensity and heritability of the selected trait, the correlated response depends on the magnitude of response for the primary trait and the genetic correlation between the selected and unselected traits.

The selection studies may give rise to three types of correlated responses:

a- When secondary traits lose normality due to selection for non-correlated primary trait (Mather and Harison, 1949).

b- When secondary traits exhibit direct changes due to selection for correlated primary trait (Schoirman et al., 1959; Nordskog and Festing, 1962).

c- When secondary trait is a component of fitness, the correlated response would be irregular in direction which has been termed as "Genetic Homeostasis" (Lerner, 1950).

Jaap et al. (1932) suggested that the validity of the parameter estimates should be checked through observing responses and correlated responses.

There are two reasons for the low predictability and the inconsistency of correlated responses (Falconer, 1983).

a) Sensitivity of genetic correlations to gene frequency changes (Bohren et al., 1966). The genetic correlation and correlated response can change rapidly during the course of selection due to selection itself and random drift.

b) Low precision of estimates of the genetic correlation in the base population, resulting from large sampling errors.

Ideta and Siegal (1966) are of the view that such variations between predicted and realised correlated responses might be due to genotype-environmental interaction.

Correlated response to selection for egg number

The Leghorn lines did not exhibit changes either for body weight or egg weight in first generation of selection (Scheirman et al., 1959).

In a White Leghorn population, Morris (1963) observed that the egg size declined by 3 g, body weight by 270 g and age at first egg by 3.5-4 weeks during a period of 11 years (1948 to 1959).

Abplanalp et al. (1964) observed decline of egg weight and age at first egg as correlated response to selection for egg number. Osborne's index selection for part year egg production led to reduction of 0.07 lbs in body weight and 0.32 g egg weight per generation, as correlated response (Nordskog et al., 1967).

The realized genetic correlated responses per generation were, -0.06 week for age at first egg, -0.03 kg for 32 week body weight, -0.04 kg for 55 week body weight, and egg weight as -0.44 g and -0.82 g for 32 and 55 weeks of body weight for CC DDS line (Craig et al., 1969). The corresponding values for

HR IDS line were, 0.32 weeks, -0.03 kg, -0.04 kg, -0.24 g, -0.37 g respectively consequent on selection for rate of lay from first egg to 260 days of age.

Using Osborne's index selection for part period egg production, Kinney et al. (1970) observed non-significant decline of age at first egg and significant reduction of body weight and egg weight. The average realised correlated responses per generation were -0.68 weeks for age at first egg, -0.58 oz for 18 week body weight, 0.33 x 1/16 oz for 30 week egg weight and 2.42 per cent for rate of lay from first egg to end of recording (Osborne, 1970).

Poggenpoel and Erasmus (1978) reported 2.18 days decline in age at first egg and 0.79 g in egg weight as correlated response per generation to selection for egg production to 275 day of age.

Ayyagari et al. (1980) observed decline in age at first egg and egg weight which ranged from 1.01 to 3.27 days and 0.16 to 1.2 g per generation concomitant to selection for egg number to 280 days of age. Liljedahl and Weyde (1980a,b) noticed decline in age at first egg and egg weight concomitant to selection on part period egg production.

Positive correlated responses in egg weights (1.8 g and 1.6 g) were reported by Fairfull and Gowe (1980) due to selection for egg number both in hen-day and hen-housed selected lines, whereas age at first egg (0.9 and 2.8 days) and 365 days body weight (105 and 130 g) were reduced.

Kolstad (1980) obtained improvement of 2.3% in rate of lay, but significant reduction of age at first egg (4.2 days), and egg weight (0.29 g) per generation as correlated responses due to selection for egg production. Brah and Dev (1981) reported decline of 0.74 days for age at first egg, 36 g for 40 week body weight and very low decline in 20 week body weight per generation concomitant to selection for 280 days egg production in Pb-1 line. But in Pb-2 line, above traits had shown improvement besides improvement in livability.

Venkatramaiah (1982) noticed correlated response in egg weight (-0.67 to +0.38 g), age at sexual maturity (-2.05 to -4.37 days), 20 week body weight (-2.63 to -24.64 g) and 40 week body weight (-2.15 to 22.91 g) in four lines due to selection for 280 days part production for two generations. Although those were mostly non-significant, there were similarity between realized and predicted correlated responses.

Barua (1983) obtained significant reduction in age at first egg, egg weight but no definite trend for mature body weights during two generations of selection for egg production to 260 days of age. Realised and predicted correlated responses were comparable.

Mohapatra et al. (1983) reported results of eight generations of selection for egg production to 40 weeks of age. The correlated responses averaged over all the four lines, were -0.54 g for egg weight, -3.44 days for age at sexual maturity, 16.2 g for 20 week body weight and −4.35 g for 40 week body weight. Further there was close agreement between predicted and realised correlated responses.

Singh and Kumar (1983) through two generations of selection for part record egg production observed decline of age at first egg (6.30 d), egg weight (1.92 g) and 40 week body weight (102.60 g) but rate of lay was increased (6.28%).

Zhou (1983) reported decline of egg weight by one gramme per generation as correlated response to selection for egg production to 300 days of age. Rodko et al. (1983) observed decline of age at first egg by 9.17 days and egg weight by 0.81 g per generation through selection for egg production to 200 days of age.

Thiyagasundarum (1984) reported reduction of age at first egg (−0.41 d), egg weight (−0.41 g), 20 week body weight (−6.25 g) and 40 week body weight (−25.04 g) in egg number line as correlated response to selection for egg production to 280 days of age. But the corresponding values were 0.35 d, −0.06 g, 2.94 g, −3.65 g in egg mass line and −0.13 d, −0.51 g, −15.00 g, −42.22 g, in efficiency index line.

Effective population size and rate of inbreeding

The most simple way of dealing with any particular deviation from the idealised breeding structure is to consider the effective number of breeding individuals which is known as effective population size, Ne. This is the number of individuals that give rise to the calculated sampling variance or rate of inbreeding (Falconer, 1960).

Lerner and Hazel (1947) postulated that the forces causing genetic alteration in biological populations are selection, mutation, migration and genetic drift. The inbreeding coefficient would indicate the level of expected deterioration of the trait due to gene segregation and sampling between generations where the effective population size is finite.

The effective number of sires and dams (Nm and Nf) was defined as the number of whom progenies survive to breeding age and calculated by the formula

$$Ne = \frac{4\ Nm\ Nf}{(Nm + Nf)} \quad \text{(Wright, 1940)}$$

The difference between parents in reproductive ability would decrease the effective population size whereas deliberate balancing of offspring per parent would increase effective population size. However, it should be assumed that each parent had equal chance to contribute for the next generation but not necessarily equal number of offspring. The formula used for measuring rate of inbreeding (expected increase in inbreeding coefficient) in random mating population:

$$\Delta F = \frac{1}{8\ Nm} + \frac{1}{8\ Nf} \quad \text{(Wright, 1931)}$$

Stephenson *et al.* (1953) reported that every 1% increase in inbreeding would reflect as 0.3% depression in part-year egg production.

Gowe *et al.* (1959b) described the formula for estimating effective population size when unequal contribution of progenies were observed, by considering the variance of family size.

Nordskog *et al.* (1967) suggested that 12 per cent rate of inbreeding per generation should have effective number of parents as 40. Further 10 per cent increase in inbreeding would affect 20 g in body weight, 0.6 g in egg weight and 2.3 per cent in egg production due to inbreeding depression.

Ayyagari *et al.* (1980) estimated the effective population size of their experimental selected and control populations which ranged from 118 to 190 and the cumulative inbreeding varied from 1.63 to 1.71 per cent.

Nordskog and Hardiman (1980) observed the effect of inbreeding depression and natural selection in the course of selection. The authors opined that a line consisting of eight sires and six to eight dams per sire (Ne=20) would require one-fourth of a standard deviation in selection differential for high egg production trait to neutralize the inbreeding depression effects. But when Ne=250, the effect of inbreeding would be negligible and that would be proportional to Ne.

Bohren *et al.* (1981) could not notice much inbreeding depression on age at sexual maturity and the magnitude of inbreeding depression was similar, for selected as well as for control lines.

Thiyagasundarum (1984) calculated the effective population size using the method of Wright (1940) and Gowe et al. (1959b). The effective population size was 154.32 and 147.89 in egg number line and the rate of inbreeding was 1.3% in both methods. As such the inbreeding depression on various traits was considered to be not important.

Realized heritability

Ayyagari et al. (1980) reported realized heritabilities for part record egg production in four white Leghorn lines which were 0.366, 0.263, 0.254 and 0.118 and the corresponding pooled estimates over generations from sire component of variance were 0.331, 0.184, 0.127 and 0.187, respectively.

Venkatramaiah (1982) calculated the realized heritability for part record egg number in four strains from two generations of selection as 0.32, 0.20, 0.11 and 0.19.

Barua (1983) obtained realized heritability and pooled heritability from sire component of variance for egg production to 260 days of age which were close to each other (0.409 ± 0.077 and 0.40). But Thiyagasundarum et al. (1983) reported realised heritability to be 0.29 for egg number upto 40 weeks of age. Further Thiyagasundarum (1984) obtained similar magnitude of realized heritability (0.21) for egg number line through three generations of selection.

Materials and Methods

MATERIALS AND METHODS

History of the experimental populations

Data utilized in this study pertain to two single comb White Leghorn strains, IWN and IWP, which have been maintained as closed flocks with selection for egg number on part record since 1979 under All India Co-ordinated Research Project on Poultry Breeding at Kerala Agricultural University, Mannuthy. Both the populations were received from All India Co-ordinated Research Project, Rajendra Nagar, Hyderabad, A.P., in the year 1978. Data pertaining to the economic traits generated in five consecutive generations (1979-80 to 1983-84) were utilized for this investigation. Since then, populations were under selection and the five generations were designated as S_0, S_1, S_2, S_3 and S_4. The details about number of sires and dams used to reproduce progenies measured in each generation of both the strains are presented in Table 33.

Criterion of selection

The chicks hatched during 1979-80 hatching season constituted the foundation stock (base generation) in the present experiment. The mode of selection was a combined selection in which individuals were selected on the basis of an index that took into consideration individual's production and it's sire and dam family averages for pullets (inclusive index) but only sire and dam family averages for cockerels, with appropriate weights assigned to each of the components (Osborne, 1957a,b). The indices used for selection of pullets and cockerels were as follows:

$$I♀ = (P-\bar{P}) + b_2\ (F_D-\bar{P}) + b_3(F_S-\bar{P})$$

$$I♂ = (F_D-\bar{P}) + b_3(F_S-\bar{P})$$

where,

P is individual performance for the selected trait

$\bar{P}$ is the population mean

F_D is dam family mean to which the individual belongs

F_S is sire family mean to which the individual belongs

b_2 and b_3 are weighting factors of dam and sire family means respectively.

Following the criterion of selection, individuals of both sexes with high index scores were selected and mated interse to generate the subsequent generations. Within strain and generation the mating was random with the restrictions that no full or half-sib matings were permitted to hold inbreeding to a minimum.

Hatching and management

The experimental chicks of both strains were hatched between January-March, in three to six hatches in all the generations with an interval of ten days between two consecutive hatches. The matings were arranged in single sire breeding pens. The eggs were identified both for sire and dam through daily trapnesting.

As far as possible standard method of feeding and management was followed in each of the generations. Hatching eggs were collected, pedigreed and stored, following recommended procedures. Chicks were removed from the hatcher on 22nd day of the incubation and were wing banded to identify their pedigree both by sire and dam. Chicks of both the strains were brooded under infra red light on floor. The sexes were separated at day old stage itself and reared separately. All the available females and only two males per dam were saved to impose selection. The pullets were transferred to individual laying cages at 18 weeks of age.

The chicks were vaccinated with RDF vaccine against Ranikhet disease immediately after hatch. Dubbing and debeaking were also done on the first day. Fowl pox vaccination was done between 6-8 weeks of age and R_2B vaccination at 8-10 weeks of age. A booster dose of RD vaccine was given at 18 weeks of age. The feeding and managemental conditions were kept identical for both strains within generation. The birds were fed standard starter ration during 0-8 weeks, grower ration during 9-18 weeks and layer ration thereafter. Standard deworming procedures were carried out during growing period.

Traits measured

a) Egg production: Egg production was measured as number of eggs laid by each pullet upto 280 days of age.

b) Body weights: The body weight both at 20 and 40 weeks of age were measured to the nearest 10 g accuracy.

c) Age at sexual maturity: The age in days when first egg was laid without any consideration for percentage of egg production.

d) Egg weights: The average weight of four consecutive eggs laid between 38-40 weeks of age to the nearest one gram accuracy.

Statistical analysis

All the major statistical analyses were carried out on DCM [illegible] COMPUTER [illegible] at the Central Avian Research Institute, Izatnagar, (U.P.).

Correction for hatch effects

Since the experimental progenies were obtained in more than one hatch, the data were corrected for hatch effects by fitting least square constants (Harvey, 1966) within strain-generation basis.

The model used for correction of hatch effects was as follows:

$Yij = U + hi + eij$

where,

Yij = observation of the trait on the j^{th} bird of the i^{th} hatch

U = overall population mean

hi = effect of i^{th} hatch

eij = random error normally and independently distributed with mean zero and variance $\sigma^2 e$

Mean and standard errors

The mean, standard error and coefficient of variation for each trait were calculated as follows:

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

$$\text{S.E.} = \sqrt{S^2/n}$$

$$\text{C.V.}(\%) = \frac{S}{\bar{X}} \times 100$$

where,

$\bar{X}$ = mean

X_i = observation of a trait on i^{th} individual

n = number of individuals measured

$$S^2 = \text{variance} = \frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n-1}$$

S = Standard deviation

Estimation of heritability

The data generated by single progeny per dam and single dam's progeny per sire were omitted from the analysis. Heritabilities were calculated within each generation for each strai using variance component analysis. Due to unequal subclass numbers the method as described by King and Henderson (1954a) was used.

The linear statistical model used for the estimation of heritability was as follows:

$$Yijk = \mu + Si + dij + eijk$$

where,

Yij, is the measurement of a trait on k^{th} progeny of j^{th} dam mated to i^{th} sire.

μ, is the overall mean of the population

Si, is effect of the i^{th} sire

dij, is effect of j^{th} dam mated to the i^{th} sire

eijk, is the random environmental and genetic deviations attributed to individuals.

The analysis of variance table used for estimation of heritability is as follows:

Analysis of variance

Source of variation	d.f.	S.S.	M.S.	E.M.S.
Between sires	S-1	SS_S	MS_S	$\sigma^2_W + k_2\sigma^2_D + k_3\sigma^2_S$
Between dams within sires	D-S	SS_D	MS_D	$\sigma^2_W + k_1\sigma^2_D$
Between progenies, within dams within sires	n..-D	SS_W	MS_W	σ^2_W

where,

S = total number of sires

D = total number of dams

n.. = total number of progeny

σ^2_W = error component of variance

σ^2_D = dam component of variance

σ^2_S = sire component of variance

$$SS_S = \sum_i \frac{Y^2_{i..}}{n_{i.}} - \frac{Y^2_{...}}{n_{..}}$$

$$SS_D = \sum_i \sum_j \frac{Y^2_{ij.}}{n_{ij}} - \sum_i \frac{Y^2_{i..}}{n_{i.}}$$

$$SS_W = \sum_i \sum_j \sum_k Y^2_{ijk} - \sum_i \sum_j \frac{Y^2_{ij.}}{n_{ij}}$$

$$k_1 = \frac{1}{D-S}\left[n_{..} - \sum_i \frac{\sum_j n_{ij}^2}{n_{i.}} \right]$$

$$K_2 = \frac{1}{S-1}\left[\sum_i \frac{\sum_j n_{ij}^2}{n_{i.}} - \frac{\sum_i \sum_j n_{ij}^2}{n_{..}} \right]$$

$$K_3 = \frac{1}{S-1}\left[n_{..} - \frac{\sum_i n_{i.}^2}{n_{..}} \right]$$

$$\sigma^2_W = MS_W$$

$$\sigma^2_D = \frac{MS_D - MS_W}{K_1}$$

Since $K_1 \neq K_2$

$$\sigma^2_S = \frac{MS_S - MS_W - \frac{K_2}{K_1}(MS_D - MS_W)}{K_3}$$

$$\sigma^2_P = \sigma^2_S + \sigma^2_D + \sigma^2_W$$

The heritabilities were computed from sire, dam and sire plus dam components of variance as follows:

$$h^2_S = \frac{4\,\sigma^2_S}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

$$h^2_D = \frac{4\,\sigma^2_D}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

$$h^2_{S+D} = \frac{2(\sigma^2_S + \sigma^2_D)}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

The standard error for heritability was calculated as per Dickerson (1960).

$$\text{S.E. of } h^2_S = \frac{4\sqrt{\frac{2}{K_3^2}\left[\frac{MS_S^2}{S-1} + \frac{MS_D^2}{D-S}\right]}}{\sigma^2 S + \sigma^2 D + \sigma^2 W}$$

$$\text{S.E. of } h^2_D = \frac{4\sqrt{\frac{2}{K_1^2}\left[\frac{MS_D^2}{D-S} \quad \frac{MS_W^2}{n..-D}\right]}}{\sigma^2 S + \sigma^2 D + \sigma^2 W}$$

$$\text{S.E. of } h^2_{S+D} = \frac{2\sqrt{V(\sigma^2 S) + V(\sigma^2 D) + 2\,\mathrm{Cov}(\sigma_S\ \sigma_D)}}{\sigma^2 S + \sigma^2 D + \sigma^2 W}$$

where,

$$V(\sigma^2 S) = \frac{2}{K_3^2}\left[\frac{MS_S^2}{S-1} + \frac{MS_D^2}{D-S}\right]$$

$$V(\sigma^2 D) = \frac{2}{K_1^2}\left[\frac{MS_D^2}{D-S} + \frac{MS_W^2}{n..-D}\right]$$

$$2\,\mathrm{Cov}(\sigma_S\ \sigma_D) = 2\frac{K_2}{K_3}\left[V(\sigma^2 D) - \frac{2\ MS_W^2}{K_1^2(n..\ -D)}\right]$$

Pooled estimates of heritabilities were obtained by weighting each estimate by the inverse of the square of their respective standard errors, following the method of Enfield *et al.* (1966).

Estimation of correlations

The genetic and phenotypic correlations between the traits were estimated from variance and covariance component analysis as per Becker (1964). Variance component analysis was the same as used in the estimates of heritability. Covariance components were estimated from the following analysis of covariance table.

Analysis of covariance

Source of variation	d.f.	S.C.P.	M.C.P.	E.M.C.P.
Between sires	S-1	SCP_S	MCP_S	$Cov_W + K_2 Cov_D + K_3 Cov_S$
Between dams within sires	D-S	SCP_D	MCP_D	$Cov_W + K_1 Cov_D$
Between progenies within dams within sires	n.. -D	SCP_W	MCP_W	Cov_W

where,

$$SCP_S = \sum_i \frac{X_{i..}\, Y_{i..}}{n_{i.}} - \frac{X_{...}\, Y_{...}}{n_{..}}$$

$$SCP_D = \sum_i \sum_j \frac{X_{ij.}\, Y_{ij.}}{n_{ij}} - \sum_i \frac{X_{i..}\, Y_{i..}}{n_{i.}}$$

$$SCP_W = \sum_i \sum_j \sum_k X_{ijk}\, Y_{ijk} - \sum_i \sum_j \frac{X_{ij.}\, Y_{ij.}}{n_{ij}}$$

X and Y are the two traits whose correlation is to be estimated, K_1, K_2 and K_3 were the same as used for the estimation of variance components.

$$\mathrm{Cov}_W = \mathrm{MCP}_W$$

$$\mathrm{Cov}_D = \frac{\mathrm{MCP}_D - \mathrm{MCP}_W}{K_1}$$

$$\mathrm{Cov}_S = \frac{\mathrm{MCP}_S - \mathrm{MCP}_W - \frac{K_2}{K_1}(\mathrm{MCP}_D - \mathrm{MCP}_W)}{K_3}$$

The genetic correlations between traits X and Y were then estimated as follows (Becker, 1964).

a) From sire component of variance and covariance

$$r_{G(S)} = \frac{\mathrm{Cov}_S(XY)}{\sqrt{\sigma^2 S_{(X)}\ \sigma^2 S_{(Y)}}}$$

b) From dam component of variance and covariance

$$r_{G(D)} = \frac{\mathrm{Cov}_D(XY)}{\sqrt{\sigma^2 D(X)\ \sigma^2 D(Y)}}$$

c) From sire plus dam component of variance and covariance

$$r_{G(S+D)} = \frac{\mathrm{Cov}_S + \mathrm{Cov}_D}{\sqrt{\left[\sigma^2 S(X) + \sigma^2 D(X)\right]\left[\sigma^2 S(Y) + \sigma^2 D(Y)\right]}}$$

The standard error of genetic correlation was estimated as per Robertson (1959).

$$\mathrm{S.E.\ of\ } r_G = \frac{1-r_G^2}{\sqrt{2}} \sqrt{\frac{\mathrm{S.E.}h^2(X)\ \mathrm{S.E.}h^2(Y)}{h^2(X)\ h^2(Y)}}$$

The phenotypic correlations were calculated as detailed below (Becker, 1964).

$$r_p = \frac{Cov_W + Cov_S + Cov_D}{\sqrt{\sigma^2 w(X) + \sigma^2 s(X) + \sigma^2 D(X)}\ \sqrt{\sigma^2 w(Y) + \sigma^2 s(Y) + \sigma^2 D(Y)}}$$

The standard error of phenotypic correlations was calculated according to Goulden (1962). The formula used for estimation of SE of r_p is as follows.

$$S.E.\ of\ r_p = \sqrt{\frac{1-r^2 p}{n-2}}$$

The environmental correlation was estimated utilizing the following formula suggested by Becker (1964).

$$r_{E(xy)} = \frac{Cov_W - 2\ Cov_S}{\sqrt{\sigma^2 w_x - 2\ \sigma^2 s_x}\ \sqrt{\sigma^2 w_y - 2\ \sigma^2 s_y}}$$

Selection differential

The average superiority of the selected parents over the population mean from which they have been selected is known as the selection differential. It is the mean phenotypic value of the individuals selected as parents expressed as deviation from population mean (Falconer, 1960) and is designated as expected selection differential. The effective selection differential was calculated by weighting each parent by the number of progeny it contributed to the next generation.

The ratio of effective to expected selection differential was estimated to evaluate the effect of natural selection during the course of artificial selection (Falconer, 1960).

The intensity of selection (i) was calculated as per Falconer (1960) in the following way:

$$i = \frac{\text{Effective selection differential}}{\text{Phenotypic standard deviation of the trait}}$$

Effective population size and rate of inbreeding

The effective number of individuals (Ne) in each parental generation for the selected group was calculated as per Wright (1940) using the following formula:

$$Ne = \frac{4\ Nm\ Nf}{Nm + Nf}$$

where, Nm is the number of male parents

Nf is the number of female parents

Wright (1940) suggested the formula for calculation of effective population size, assuming equality of variance among the parents for the number of progeny contributed. But in real situations, each parent contributes different number of progeny, as such the variance in family size may not be same. Cowe et al. (1959b) suggested a modified formula for calculating effective population size by weighting the number of male and female parents with their respective variance in family size.

$$\frac{1}{Ne} = \frac{1}{4Me} + \frac{1}{4Fe}$$

where,

$$\frac{1}{Me} = \frac{1}{M} \left(1 + \frac{\sigma^2 m - \bar{n}_m}{\bar{n}_m^2}\right)$$

$$\frac{1}{Fe} = \frac{1}{F} \left(1 + \frac{\sigma_f^2 - \bar{n}_f}{\bar{n}_f^2}\right)$$

where,

$\bar{n}_m$ is the average number of progeny per sire

σ_m^2 is the variance in number of progenies per sire

$\bar{n}_f$ is the average number of progenies per dam

σ_f^2 is the variance in number of progenies per dam

The increase in inbreeding coefficient per generation was calculated using the formula of Wright (1931) which is as follows:

$$\Delta F = \frac{1}{8\,Nm} + \frac{1}{8\,Nf} = \frac{Nm + Nf}{8\,NmNf}$$

where,

Nm is the number of male parents which had progenies surviving upto 280 days of age.

Nf is the number of female parents which had progenies surviving upto 280 days of age.

Direct Response to selection

Phenotypic responses per generation for the selected trait were estimated by regressing generation mean on generation number.

Regression (b) of Y on X is:

$$b_{YX} = \frac{\Sigma XY - \frac{\Sigma X . \Sigma Y}{n}}{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}$$

where,

Y = Phenotypic generation mean

X = Generation number

n = Number of generation

The standard error of the regression coefficient was calculated using the following formula (Snedecor and Cochran, 1967).

$$SE(b) = \sqrt{\frac{\Sigma Y^2 - \frac{(\Sigma Y)^2}{n} - b(\Sigma XY - \frac{(\Sigma X)\ (\Sigma Y)}{n})}{(n-2)\left[\Sigma X^2 - \frac{(\Sigma X)^2}{n}\right]}}$$

Regression coefficients were tested for statistical significance using 't' test.

$t = \frac{b}{SE(b)}$ with $(n-2)$ degree of freedom, where there were 'n' pairs of observations.

Expected genetic gains

Since no control population was maintained, it is not possible to separate the genetic gains from the total gains, as genetic and environmental effects remain confounded. However as an exercise the expected genetic gains were computed and compared with the realized gains under the assumption that $E(G) = P$.

The average expected genetic gain through four generations of I.D.S. index selection was calculated using the following formula (Kinney *et al.*, 1970).

$$C_{T\text{♀}} \quad I\text{♂}\text{♀} = (\bar{I}\text{♂} + \bar{I}\text{♀}) \frac{h_{T\text{♀}} \; \sigma P_{T\text{♀}}}{2} \left[\frac{\bar{I}\text{♀}}{\bar{I}\text{♂} + \bar{I}\text{♀}} \; RG_{T\text{♀}} \; P_{I\text{♀}} \right.$$

$$\left. \frac{\bar{I}\text{♂}}{(\bar{I}\text{♂} + \bar{I}\text{♀})} \; RG_{T\text{♀}} \; P_{I\text{♂}} \right]$$

where,

$$RG_{T\text{♀}} \; P_{I\text{♀}} = h_T \left[\frac{(n-1)}{2n(2-h^2)} + \frac{(d-1) \quad (n+2)^2}{4nd\left[4+(n-2)h^2\right]} + \right.$$

$$\left. \frac{(s+1)\left[n(1+d)+2\right]}{4sdn\left[4+\left[n(1+d)-2\right]h^2\right]} \right]^{\frac{1}{2}}$$

$$RG_{T\text{♀}} \; P_{I\text{♂}} = \frac{h_T}{d} \left[\frac{n}{d} \left[\frac{(d-1)}{4+(n-2)h^2} + \frac{(s-1)(d-1)^2}{s(4+\left[n(d+1)-2\right]h^2)} \right] \right]^{\frac{1}{2}}$$

While using the above formula, the values of n, d, s, $I\text{♂}$ and $I\text{♀}$ were replaced with the values of $\bar{n}$, $\bar{d}$, $\bar{s}$, $\bar{I}\text{♂}$ and $\bar{I}\text{♀}$, over generations.

where, $\bar{n}$ = average number of progeny

$\bar{d}$ = average number of dams

$\bar{s}$ = average number of sires

$\bar{I}\text{♂}$ = average selection intensity of male parents

$\bar{I}\text{♀}$ = average selection intensity of female parents and pooled heritability estimates from sire component of variance was used for such estimations.

Expected drift variance and sampling error of measurement

Drift variance and measurement errors are the major causes of asymmetry response in a selection experiment and were estimated from information on population parameters as per Hill (1971, 1972a,b,c,d).

i) Drift variance ($\sigma^2 D$) = $\frac{h^2(1-h^2)}{Ne}\sigma^2$

ii) Sampling error measurement ($\sigma^2 e$) = $\frac{(1-h^2)}{M}\sigma^2$

where,

h^2 = heritability of trait selected.

σ^2 = phenotypic variance of the trait

Ne = effective population size

M = size of tested population per generation

The ratio of $\sigma^2 D/\sigma^2 e$ was also approximately estimated by M/Ne and was used as a relative estimate of the importance of either drift or sampling error in the course of selection studies (Nordskog _et_ _al_., 1974).

Correlated Response

The realized correlated response (phenotypic) per generation in unselected traits was derived by regressing respective generation mean on generation number and their standard error, in the same way as detailed under direct response.

The expected genetic response per generation in unselected traits was calculated as per Kinney *et al.* (1970). However this may be considered as an exercise since it was not possible to compare them due to lack of control population.

$$\Delta GY = h_X h_Y r_{G_{XY}} \; i_X \; \sigma_{PY} \; \frac{K_1 + K_2}{2}$$

ΔGY = expected correlated response in trait Y

h_X = square root of heritability of trait X (selected trait)

h_Y = square root of heritability of trait Y (unselected trait)

$r_{G_{XY}}$ = genetic correlation between X and Y

i_X = selection intensity of trait X

σ_{PY} = phenotypic standard deviation of trait Y.

Pooled parameter estimates of five generations derived from sire component of variance were used for hx, hy and $r_{G_{XY}}$. Average selection intensity of male and female parents over four selected generations and the average phenotypic standard deviation over four selected generations were used for i_X and σ_{PY} respectively.

K_1 = expected relative selection efficiency in males by using Osborne's selection index over mass selection

K_2 = expected relative selection efficiency in females by using Osborne's selection index over mass selection.

The values of K_1 and K_2 were calculated as follows:

$$K_1 = h_T \left[\frac{(n-1)}{2n(2-h^2)} + \frac{(d-1)\ (n+2)^2}{4nd\left[4+(n-2)h^2\right]} + \frac{(s-1)\ \left[n(1+d)+2\right]}{4sdn\ \left[4+\left[n(1+d)-2\right]h^2\right]} \right]^{\frac{1}{2}}$$

$$K_2 = \frac{h_T}{2} \left[\frac{n}{d} \left[\frac{(d-1)}{4+(n-2)h^2} + \frac{(s-1)\ (d+1)^2}{s(4+\left[n(d+1)-2\right]\ h^2)} \right]\right]^{\frac{1}{2}}$$

$\bar{n}$, $\bar{d}$, $\bar{s}$ were used for n, d and s for pooled estimations.

Standardized Responses

In order to observe the effect of selection, for both the strains in a more meaningful manner, the responses obtained in each strain were standardized for selection intensity and expressed in standard deviation units.

The results, thus obtained as response in standard deviation units per unit selection differential imposed were compared for their magnitude.

Realized heritability

Realized heritability was obtained as regression of response on cumulated selection differential for the selected trait (Falconer, 1960).

Standard error of realized heritability estimates were derived as per the formula described by Hill (1972a,b). Since the error variance due to regression estimation is biased downwards, a term including the number of generations and drift variance estimate were added to this as follows:

$$V_{(bc)} = U_{(bc)} + \frac{2(3t + 4)}{5\,\bar{S}^2 (t+1)\,(t+2)}\,\sigma^2 d$$

where,

$V_{(bc)}$ = Variance of realized heritability

$$U_{(bc)} = \frac{n\left[(X_i-\bar{X})^2 - bc\,\Sigma(S_i-\bar{S})\,(X_i-\bar{X})\right]}{(t-1)\,\Sigma(S_i-\bar{S})^2}$$

t = number of generations

$\sigma^2 d$ = estimate of drift variance

S_i, $\bar{S}$ = selection differential in each generation and mean S.D. respectively.

X_i, $\bar{X}$ = performance in each generation and mean performance over generations respectively.

Results and Discussion

RESULTS AND DISCUSSION

Hatch effects on economic traits

The experimental populations of both the strains were generated through three to six consecutive hatches in all the five generations under study and ten days interval between hatches was systematically maintained throughout the experimental period. Further the number of progenies in each hatch were unequal. The data were therefore corrected for hatch effects by using least square technique (Harvey, 1966). The analysis of variance was carried out on an intrastrain-generation basis. The hatch means along with standard errors and coefficient of variation for different traits of IWN and IWP are shown in Tables 12, 13 and the mean squares from analysis of variance in Tables 14, 15.

Hatch effects were observed to be significant in most instances (Tables 14, 15). In strain IWN the traits for which hatch effects were not found to be significant were age at first egg, 40 week body weight and egg number in S_0; 40-week body weight and egg weight in S_2 and egg number in S_3 generations. For strain IWP, traits such as 40 week body weight, egg weight in S_0 and 20 week body weight in S_3 generations were not affected by date of hatch.

There are several reports in the literature which suggest that production traits are affected by date of hatch in chicken

Table 12. Hatchwise mean ± SE and C.V. of various traits over generations in IWN strain

Generation Code (1)	Hatch No. (2)	No. of observations (3)	MEAN ± S.E. (C.V.) ASM (4)	MEAN ± S.E. (C.V.) 20 wk BW (5)	MEAN ± S.E. (C.V.) 40 wk BW (6)	MEAN ± S.E. (C.V.) Egg No. (7)	MEAN ± S.E. (C.V.) Egg wt. (8)
S_0	1	154	177.31 ± 1.30 (9.12)	1176.30 ± 10.14 (10.72)	1591.36 ± 16.17 (12.61)	57.54 ± 1.27 (26.95)	50.92 ± 0.33 (8.03)
	2	180	174.32 ± 1.40 (10.81)	1191.39 ± 9.69 (10.91)	1575.83 ± 13.48 (11.47)	58.26 ± 1.43 (32.83)	51.31 ± 0.25 (6.41)
	3	203	176.75 ± 1.29 (10.43)	1188.67 ± 9.56 (11.45)	1620.00 ± 11.23 (9.88)	61.20 ± 1.31 (30.47)	52.63 ± 0.23 (6.35)
	4	47	180.98 ± 2.36 (9.71)	1091.49 ± 13.02 (9.18)	1619.15 ± 21.70 (9.19)	56.36 ± 3.00 (36.55)	53.08 ± 0.49 (6.36)
S_1	1	191	164.60 ± 0.76 (6.42)	1099.01 ± 10.76 (13.53)	1362.25 ± 9.53 (9.56)	72.83 ± 1.35 (25.60)	51.33 ± 0.24 (6.46)
	2	215	159.87 ± 0.59 (5.43)	1183.40 ± 8.45 (10.48)	1382.95 ± 8.91 (9.45)	75.62 ± 1.37 (26.55)	51.40 ± 0.23 (6.45)
	3	283	159.68 ± 0.59 (6.19)	1247.90 ± 7.18 (9.68)	1400.87 ± 10.88 (13.07)	80.17 ± 1.03 (21.71)	51.81 ± 0.23 (7.31)
	4	169	161.20 ± 0.66 (5.29)	1105.41 ± 10.42 (11.42)	1361.60 ± 9.28 (8.86)	78.70 ± 2.47 (40.83)	50.95 ± 0.25 (6.39)
	5	211	160.13 ± 0.54 (4.90)	1209.05 ± 7.39 (8.88)	1417.96 ± 6.63 (6.79)	75.94 ± 1.14 (21.74)	51.60 ± 0.23 (6.59)
	6	253	162.27 ± 0.50 (4.86)	1153.87 ± 6.51 (8.98)	1429.72 ± 7.01 (7.80)	65.28 ± 1.26 (30.67)	51.95 ± 0.18 (5.62)

(contd.)

1	2	3	4	5	6	7	8
S_2	1	347	155.19 ± 0.55 (6.56)	1297.72 ± 5.70 (8.18)	1518.88 ± 8.16 (9.09)	92.10 ± 2.79 (56.50)	51.11 ± 0.25 (9.06)
	2	439	159.14 ± 0.54 (7.04)	1207.63 ± 4.48 (7.77)	1515.10 ± 7.79 (10.78)	81.45 ± 0.89 (22.36)	50.55 ± 0.19 (7.98)
	3	325	162.05 ± 0.65 (7.18)	1161.87 ± 4.25 (6.59)	1500.45 ± 8.90 (10.70)	81.22 ± 0.95 (21.05)	51.22 ± 0.19 (6.74)
	4	186	161.14 ± 0.65 (5.47)	1136.34 ± 5.72 (6.87)	1490.43 ± 9.69 (8.86)	87.70 ± 0.98 (15.28)	50.87 ± 0.21 (5.75)
S_3	1	366	168.61 ± 0.40 (6.76)	1093.99 ± 5.96 (10.39)	1552.73 ± 8.81 (10.85)	85.78 ± 0.78 (17.48)	51.24 ± 0.16 (5.34)
	2	490	165.49 ± 0.58 (7.71)	1094.18 ± 5.44 (11.01)	1461.73 ± 7.22 (10.93)	88.11 ± 0.80 (20.21)	50.95 ± 0.13 (5.61)
	3	414	161.56 ± 0.58 (7.35)	1125.92 ± 7.35 (13.11)	1418.07 ± 6.24 (8.95)	86.29 ± 0.83 (19.59)	49.70 ± 0.14 (5.68)
S_4	1	409	155.63 ± 0.61 (5.28)	1307.70 ± 4.61 (7.14)	1547.29 ± 6.29 (8.23)	94.58 ± 0.77 (16.45)	51.62 ± 0.14 (5.42)
	2	507	155.25 ± 0.42 (6.08)	1352.54 ± 4.90 (8.29)	1492.80 ± 6.09 (9.18)	90.44 ± 0.84 (21.02)	51.26 ± 0.14 (6.07)
	3	440	151.39 ± 0.60 (8.27)	1365.23 ± 5.73 (8.80)	1481.80 ± 6.24 (8.83)	96.59 ± 0.89 (19.38)	50.27 ± 0.15 (6.20)

Values in parentheses are CV

Table 13. Hatchwise Mean ± SE and C.V. of various traits over generations in IWP strain

Generation code	Hatch No.	No. of observation	Mean ± S.E. (C.V.)				
			ASM	20 wk BW	40 wk BW	Egg No.	Egg wt
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
S_0	1	313	170.27 ± 0.66 (6.88)	1190.99 ± 6.68 (9.93)	1705.65 ± 10.78 (11.18)	74.10 ± 0.83 (19.75)	51.73 ± 0.18 (6.28)
	2	68	187.03 ± 2.71 (11.93)	1117.50 ± 11.60 (8.56)	1669.12 ± 24.07 (11.89)	58.88 ± 2.21 (30.89)	51.29 ± 0.38 (6.10)
	3	47	176.91 ± 2.60 (10.07)	1181.91 ± 19.91 (11.55)	1669.15 ± 30.32 (12.45)	65.17 ± 3.04 (31.93)	52.37 ± 0.49 (6.41)
S_1	1	191	152.85 ± 0.64 (5.78)	1207.09 ± 9.52 (10.22)	1407.81 ± 11.20 (11.00)	90.87 ± 1.12 (17.07)	51.67 ± 0.26 (6.86)
	2	161	153.18 ± 0.74 (6.17)	1337.42 ± 8.61 (8.16)	1435.28 ± 10.23 (9.04)	88.99 ± 1.42 (20.21)	52.00 ± 0.25 (6.21)
	3	110	155.93 ± 0.99 (6.64)	1287.14 ± 12.78 (10.42)	1408.91 ± 11.91 (8.87)	86.39 ± 1.48 (17.95)	50.92 ± 0.32 (6.54)
	4	131	153.33 ± 0.92 (6.87)	1304.50 ± 10.89 (9.55)	1493.51 ± 17.12 (13.12)	83.50 ± 1.73 (23.72)	51.30 ± 0.28 (6.28)
	5	229	156.00 ± 0.61 (5.83)	1265.83 ± 7.72 (9.23)	1469.78 ± 11.47 (11.81)	79.43 ± 1.25 (23.74)	51.93 ± 0.21 (6.20)
	6	88	156.77 ± 1.09 (6.53)	1177.27 ± 11.51 (9.17)	1379.55 ± 15.24 (10.37)	66.25 ± 2.10 (29.48)	52.39 ± 0.34 (6.14)

(contd.)

1	2	3	4	5	6	7	8
S_2	1	388	151.59 ± 0.65 (5.91)	1317.58 ± 6.17 (9.22)	1718.40 ± 29.43 (23.42)	92.08 ± 0.77 (16.57)	52.49 ± 0.19 (6.95)
	2	423	154.62 ± 0.45 (5.94)	1249.27 ± 4.26 (7.01)	1710.90 ± 19.60 (23.56)	82.08 ± 0.97 (24.39)	51.59 ± 0.19 (7.65)
	3	402	157.78 ± 0.47 (6.03)	1166.32 ± 4.63 (7.91)	1554.45 ± 8.83 (11.39)	82.08 ± 0.87 (20.75)	52.75 ± 0.19 (7.39)
	4	178	160.57 ± 1.13 (9.40)	1158.92 ± 5.02 (6.70)	1593.00 ± 11.65 (9.75)	80.94 ± 1.49 (24.59)	51.85 ± 0.26 (6.71)
S_3	1	408	160.21 ± 0.57 (7.23)	1177.08 ± 5.11 (8.77)	1583.50 ± 8.16 (10.41)	89.72 ± 0.81 (18.15)	51.57 ± 0.15 (5.85)
	2	438	157.67 ± 0.56 (7.38)	1194.06 ± 5.07 (8.89)	1457.05 ± 6.57 (9.44)	88.61 ± 0.77 (18.15)	50.33 ± 0.13 (5.39)
	3	456	165.97 ± 0.61 (7.85)	1183.56 ± 5.00	1422.43 ± 6.14 (9.22)	76.31 ± 0.84 (23.53)	50.49 ± 0.13 (5.70)
S_4	1	427	156.76 ± 0.68 (6.30)	1367.92 ± 5.59 (8.45)	1586.23 ± 7.02 (9.14)	92.32 ± 0.78 (17.53)	52.81 ± 0.16 (6.27)
	2	498	151.25 ± 0.40 (5.83)	1413.26 ± 5.05 (7.98)	1620.98 ± 6.78 (9.33)	98.61 ± 0.69 (15.66)	52.32 ± 0.15 (6.19)
	3	427	149.49 ± 0.54 (7.46)	1405.87 ± 5.67 (8.33)	1546.91 ± 6.91 (9.23)	99.40 ± 0.77 (16.07)	51.38 ± 0.15 (6.15)

Values in parentheses are CV

Table 14. Mean squares of analysis of variance to test batch effects for various traits in IWN strain over generations

Generation	Source of variance	df	Mean squares age at 1st egg (d)	20-week body weight (g)	40-week body weight (g)	280 days egg prodn. (No.)	Egg weight (g)
1	2	3	4	5	6	7	8
S_0	Bet. hatches	3	636.67	135829.33**	71424.00	577.75	125.67**
	Error	580	321.35	16492.69	31388.03	331.02	12.55
S_1	Bet. hatches	5	751.20**	579532.81**	170086.41**	6957.80**	25.80*
	Error	1316	80.57	15056.63	18183.59	432.72	11.30
S_2	Bet. hatches	3	2970.67**	1479229.40**	46000.00	9674.33**	31.50
	Error	1293	115.51	8334.35	24149.14	935.81	15.46
S_3	Bet. hatches	2	4884.00**	141248.00**	1818752.00**	631.50	269.75**
	Error	1267	146.40	16421.08	23301.66	280.25	7.90
S_4	Bet. hatches	2	2126.00**	386560.00**	521728.00**	4686.50**	207.00**
	Error	1353	104.80	12014.41	17479.71	321.87	9.13

**, $P < 0.01$; *, $P < 0.05$

Table 15. Mean squares of analysis of variance to test hatch effects for various traits in [illegible] strain over generations

Generation	Source of variation	df	Mean squares Age at first egg (d)	 20-week body weight (g)	 40-week body weight (g)	 280 days egg prodn. (No.)	 Egg weight (g)
1	2	3	4	5	6	7	8
S_0	Bet. hatches	2	8126.00**	151200.00**	56128.00	7275.13**	15.69
	Error	425	213.43	13723.26	37591.04	256.35	10.52
S_1	Bet. hatches	5	434.80**	318796.81**	240819.20**	8057.40**	30.25*
	Error	904	92.65	14711.08	24087.04	320.27	10.91
S_2	Bet. hatches	3	4301.33**	1565781.40**	2533888.00**	9767.33**	123.42**
	Error	1387	103.54	9769.07	106700.02	321.28	14.39
S_3	Bet. hatches	2	8106.00**	31360.00	3042944.00**	24562.00**	184.13**
	Error	1299	147.30	11242.42	20902.73	282.93	8.24
S_4	Bet. hatches	2	6202.00**	263168.00**	630784.00**	6543.00**	221.83**
	Error	1349	99.00	13210.84	21510.83	251.17	10.48

**, $P < 0.01$; *, $P < 0.05$

(King and Henderson, 1954b; Skaller, 1954; Prakashbabu et al., 1975; Reddy, 1975; Sinha, 1977; Ayyagari, 1978; Das, 1982; Venkatramaiah, 1982; Barua, 1983 and Thiyagasunderam, 1984) The results realized in this study presented a similar trend.

Since hatch effects were found to be important, all data were corrected for hatch effects by fitting least square constants (Harvey, 1966) and all subsequent analyses were based on hatch corrected data only.

Heritability

The heritability estimates for the selected and unselected traits were estimated from sire, dam and sire plus dam components using variance component analysis (King and Henderson, 1954). Estimates were initially obtained within generation strain basis and then pooled over generations within strains following the method of Enfield et al. (1966) to obtain mean estimates.

The generation-wise and pooled heritability estimates based on sire, dam and sire plus dam components of variance along with their standard errors are presented in Tables 16-20.

The generation-wise heritability estimates for various traits for each of the two strains were found to be within theoretical limits. Considerably higher estimates of standard error associated with these estimates may be due to sampling error as opined by Robertson (1959). The pooled estimates of heritabilities which were obtained as per Enfield *et al.* (1966), were found to be more reasonable in magnitude and were having small standard errors. Kinney and Shoffner (1965) suggested that pooled estimates would be more reliable than single generation estimates due to large sample size and consequently more degrees of freedom. Most of the heritability estimations realized in the present investigation were within the theoretical limits except a few low negative values. This was probably due to sampling (Robertson, 1959). Negative estimates of heritability as obtained in this study are not uncommon in literature (King, 1961; Anjaneyulu, 1972; Prakashbabu, 1973; Natarajan and Rathnasabapathy, 1978a; Poggenpoel and Erasmus, 1978; Jain and Roberts, 1980; Marks, 1981; Venkatramaiah, 1982; Barua, 1983 and Thiyagasundaram, 1984).

Egg number

The heritability estimates from sire, dam and sire plus dam components of variance for egg number to 280 days of age are presented in Table 16. Within generation estimates ranged from 0.10 to 0.39, from sire component, -0.13 to 0.30 from dam component and 0.03 to 0.34 from sire plus dam component in IWN strain. The respective values in IWP strain ranged from 0.13 to 0.60, 0.08 to 0.26 and 0.20 to 0.33.

The pooled heritability estimates for part period egg number upto 280 days of age from sire, dam and sire plus dam component of variance respectively were 0.23 ± 0.04, 0.33 0.05 and 0.18 ± 0.03 in IWH; 0.26 ± 0.05, 0.14 ± 0.04 and 0.25 ± 0.03 in IWP strains. These estimates are in close agreement with the heritability values reported by Clayton and Robertson (1966), Jaffe (1966), Bohren *et al.* (1970), Iqbaluddin *et al.* (1975), Ranganathan (1976) and Ayyagari (1978) in other white Leghorn populations. The present results as well as those reported in the literature confirm that egg production in chicken is a trait having low heritability. Few workers like Gowe (1977), Poggenpoel and Erasmus (1978), Venkatramaiah (1982) and Thiyagasundaram (1984), however reported somewhat higher estimates than obtained in this study. Factors like specificity of the population, breeding history, family size have been known to affect the heritability estimates. As such it is presumed that the differences in the magnitude of heritability values in different reports might be due to one or several of those factors.

In the present experiment the heritability estimates from sire component in strain IWP was found to be higher than the estimate from the dam component, indicating involvement of sex-linked genes in the inheritance of egg production. The importance of sex-linked effects as observed in this investigation for IWP was also reported by Lerner and Cruden (1948) Anjaneyulu (1972), Ranganathan (1976), Poggenpoel and Erasmus (1978), Venkatramaiah (1982) and Barua (1983). On the other

Table 16. Generation-wise heritability estimates for egg number in IWN and IWP strains

Strain	Generation	Heritability		
		$h^2_S \pm SE$	$h^2_D \pm SE$	$h^2_{S+D} \pm SE$
IWN	S_0	0.33 ± 0.15	0.21 ± 0.17	0.27 ± 0.10
	S_1	0.10 ± 0.07	0.29 ± 0.10	0.19 ± 0.05
	S_2	0.23 ± 0.07	-0.18 ± 0.07	0.03 ± 0.05
	S_3	0.39 ± 0.12	0.30 ± 0.10	0.34 ± 0.07
	S_4	0.31 ± 0.10	0.14 ± 0.08	0.22 ± 0.06
	Pooled	0.23 ± 0.04	0.23 ± 0.05	0.18 ± 0.03
IWP	S_0	0.60 ± 0.22	0.06 ± 0.21	0.33 ± 0.13
	S_1	0.47 ± 0.17	0.17 ± 0.11	0.32 ± 0.08
	S_2	0.13 ± 0.06	0.26 ± 0.10	0.20 ± 0.05
	S_3	0.41 ± 0.12	0.09 ± 0.08	0.25 ± 0.07
	S_4	0.40 ± 0.12	0.14 ± 0.08	0.27 ± 0.07
	Pooled	0.26 ± 0.05	0.14 ± 0.04	0.25 ± 0.03

hand maternal effects in the inheritance of this trait were reported by King and Henderson (1954b), King (1961), Saadeh *et al.* (1968), Cuadsor *et al.* (1977), Mishra *et al.* (1978), Radke *et al.* (1983) and Thiyagasundaram (1984). However in IWN strain both sex-linked and maternal effects were equall balanced. Similar reports are available in literature (Oliver *et al.*, 1957; Clayton and Robertson, 1966; Jaffe, 1966; Singh *et al.*, 1972; Gowe *et al.*, 1973; Aksoly, 1982).

Age at first egg

The heritability estimates for age at first egg are given in Table 17. These estimates from sire, dam and sire plus dam components ranged from 0.04 to 0.55, -0.10 to 0.44 and 0.09 to 0.49 in IWN strain and from 0.21 to 0.62, -0.10 to 0.29 and 0.13 to 0.44 in IWP strain.

The pooled estimates of heritability for average age at first egg from sire, dam and sire plus dam components of variance were found to be 0.22 ± 0.04, 0.21 ± 0.05 and 0.25 ± 0.03 in IWN and 0.34 ± 0.06, 0.24 ± 0.05 and 0.27 ± 0.03 in IWP strain respectively.

The magnitude of these estimates were close to the reports of Jerome *et al.* (1956), Shibata (1965), Iqbaluddin *et al.* (1975), Renganathan (1976), Sinha (1977), Mishra *et al.* (1978), Venkatramaiah (1982), Barua (1983), Renganathan *et al.* (1983) and Zhang (1984).

Table 17. Generation-wise heritability estimates for age at first egg in IWN and IWP strains

Strain	Generation	Heritability		
		$h^2_S \pm SE$	$h^2_D \pm SE$	$h^2_{S+D} \pm SE$
IWN	S_0	0.28 ± 0.12	-0.10 ± 0.15	0.09 ± 0.08
	S_1	0.04 ± 0.06	0.32 ± 0.11	0.18 ± 0.05
	S_2	0.55 ± 0.14	0.44 ± 0.11	0.49 ± 0.09
	S_3	0.55 ± 0.16	0.25 ± 0.09	0.40 ± 0.09
	S_4	0.46 ± 0.12	0.05 ± 0.07	0.25 ± 0.07
	Pooled	0.22 ± 0.04	0.21 ± 0.05	0.25 ± 0.03
IWP	S_0	0.36 ± 0.17	-0.10 ± 0.21	0.13 ± 0.11
	S_1	0.42 ± 0.14	0.24 ± 0.12	0.33 ± 0.08
	S_2	0.21 ± 0.08	0.18 ± 0.09	0.19 ± 0.05
	S_3	0.62 ± 0.17	0.26 ± 0.09	0.44 ± 0.09
	S_4	0.48 ± 0.14	0.29 ± 0.09	0.38 ± 0.08
	Pooled	0.34 ± 0.06	0.24 ± 0.05	0.27 ± 0.03

Higher estimates from sire component of variance as compared to dam component suggested the importance of sex-linked genes in the inheritance of this trait in IWP. For IWN, the estimates from both components were of equal magnitude indicating absence of maternal and sex-linked effects or both these effects were equally balanced.

20-week body weight

The heritability estimates for 20 week body weight are presented in Table 10. In IWN strain, these estimates ranged from 0.24 to 0.65, 0.20 to 0.63 and 0.31 to 0.45 and in IWP strain from 0.56 to 0.75, 0.16 to 0.46 and 0.36 to 0.54 from sire, dam and sire plus dam components respectively.

The pooled heritability estimates from sire, dam and sire plus dam components of variance were 0.35 ± 0.06, 0.32 ± 0.05 and 0.37 ± 0.04 in IWN and 0.64 ± 0.08, 0.33 ± 0.05 and 0.49 ± 0.05 for strain IWP, respectively.

The results of the present study revealed that the estimate from sire component was higher in IWP strain as compared to strain IWN but the estimates from dam component were of similar magnitude in both strains.

Such moderate to high heritability estimates for 20 week body weights are consistent with the values reported in literature (Prakashbabu, 1973; Nordskog *et al.*, 1974; Iqbaluddin *et al.*, 1975; Sinha, 1977; Trehan, 1978 and Johari *et al.*, 1982).

Table 18. Generation-wise heritability estimates for 20 week body weight in IWN and IWP strains

Strain	Generation	Heritability		
		$h^2_S \pm SE$	$h^2_D \pm SE$	$h^2_{S+D} \pm SE$
IWN	S_0	0.28 ± 0.15	0.42 ± 0.19	0.35 ± 0.10
	S_1	0.35 ± 0.12	0.32 ± 0.19	0.34 ± 0.07
	S_2	0.24 ± 0.10	0.63 ± 0.13	0.44 ± 0.07
	S_3	0.65 ± 0.18	0.26 ± 0.09	0.45 ± 0.10
	S_4	0.41 ± 0.12	0.20 ± 0.09	0.31 ± 0.07
	Pooled	0.35 ± 0.06	0.32 ± 0.05	0.37 ± 0.04
IWP	S_0	0.56 ± 0.22	0.16 ± 0.22	0.36 ± 0.13
	S_1	0.75 ± 0.21	0.33 ± 0.12	0.54 ± 0.11
	S_2	0.56 ± 0.16	0.46 ± 0.10	0.51 ± 0.09
	S_3	0.66 ± 0.18	0.32 ± 0.09	0.49 ± 0.10
	S_4	0.70 ± 0.19	0.28 ± 0.09	0.49 ± 0.10
	Pooled	0.64 ± 0.08	0.33 ± 0.05	0.49 ± 0.05

Sex-linked effects appeared to be important in the inheritance of 20 week body weight for strain IWP as reported by Hogsett and Nordskog (1958), Clayton and Robertson (1966), Prakashbabu (1973), Trehan (1973), Chaudhuri (1975), Iqbaluddin et. al. (1975) and Sinha (1977). Either maternal or sex-linked effects however could not be demonstrated in IWN as reported earlier by Prakashbabu (1973) and Venkatramiah (1982).

40-week body weight

The heritability estimates for 40 week body weights are presented in Table 19. Both the generation-wise as well as pooled estimates ranged from low to high.

In IWN strain, heritability estimates ranged from 0.29 to 0.89, 0.29 to 0.43 and 0.31 to 0.63 and in IWP strain from 0.08 to 0.61, -0.001 to 0.73 and 0.30 to 0.46 from sire, dam and sire plus dam component of variance respectively.

The pooled estimates in IWN strain were 0.42 ± 0.06, 0.34 ± 0.05 and 0.40 ± 0.04 whereas in IWP strain these were 0.24 ± 0.05, 0.48 ± 0.06 and 0.38 ± 0.04 from sire, dam and sire plus dam components respectively. The magnitude of heritability estimates obtained in this study for 40 week body weight were consistent with the earlier reports of Shibata (1965), Clayton and Robertson (1966), Prakashbabu (1973), Brah (1977) and Ayyagari et al. (1983).

Sex-linked effects were found to be important in the inheritance of 40 week body weight for strain IWN whereas

Table 19. Generation-wise heritability estimates for 40 week body weight in IWN and IWP strains

Strain	Generation	Heritability		
		$h^2_S \pm SE$	$h^2_D \pm SE$	$h^2_{S+D} \pm SE$
IWN	S_0	0.29 ± 0.15	0.33 ± 0.18	0.31 ± 0.10
	S_1	0.33 ± 0.11	0.29 ± 0.10	0.31 ± 0.07
	S_2	0.37 ± 0.13	0.43 ± 0.11	0.40 ± 0.07
	S_3	0.89 ± 0.23	0.38 ± 0.10	0.63 ± 0.12
	S_4	0.77 ± 0.20	0.30 ± 0.09	0.53 ± 0.10
	Pooled	0.42 ± 0.06	0.34 ± 0.05	0.40 ± 0.04
IWP	S_0	0.61 ± 0.24	0.30 ± 0.23	0.46 ± 0.14
	S_1	0.60 ± 0.17	-0.001 ± 0.09	0.30 ± 0.09
	S_2	0.08 ± 0.07	0.73 ± 0.13	0.40 ± 0.06
	S_3	0.36 ± 0.12	0.49 ± 0.11	0.43 ± 0.08
	S_4	0.39 ± 0.11	0.33 ± 0.10	0.36 ± 0.07
	Pooled	0.24 ± 0.05	0.40 ± 0.06	0.38 ± 0.04

maternal effects were important for IWP. Such variation might be due to difference in genetic architecture of the two populations under study. The maternal as well as sex-linked effects as observed in this investigation were also reported by King (1961), Brah (1977), Anjaneyulu (1972), Trehan (1973), Venkatramaiah (1982) and Barua (1983).

However, while observing the pooled heritability estimates of IWN and IWP for 20 and 40-week body weights from sire and dam components, considerable changes could be noticed within each strain. The inheritance of 20-week body weight for strain IWP was influenced by sex-linked effects whereas at 40-week maternal effects were found to be involved. Similarly, for IWN strain sex-linked effects could be detected for 40-week body weight whereas for 20-week body weight neither sex-linked nor maternal effects could be identified. The above findings of the present study tend to suggest that the influence of either sex-linked or maternal effects in the inheritance 20 week and 40-week body weights is specific to different populations and such effects may change within each population even at different periods of age.

Egg weight

The heritability estimates of egg weight from various components of variance have been shown in Table 20. The results of the present study indicated that the trait egg-weight is moderate to highly heritable in chicken. King and Henderson

Table 20. Generation-wise heritability estimates for egg weight in IWH and IWP strains

Strain	Generations	Heritability		
		h^2_S ± SE	h^2_D ± SE	h^2_{S+D} ± SE
IWH	S_0	0.14 ± 0.14	0.70 ± 0.22	0.42 ± 0.10
	S_1	0.82 ± 0.22	0.40 ± 0.11	0.65 ± 0.11
	S_2	0.44 ± 0.14	0.54 ± 0.12	0.49 ± 0.08
	S_3	0.54 ± 0.16	0.46 ± 0.11	0.50 ± 0.09
	S_4	0.73 ± 0.19	0.30 ± 0.09	0.52 ± 0.10
	Pooled	0.46 ± 0.07	0.44 ± 0.05	0.51 ± 0.04
IWP	S_0	0.25 ± 0.30	0.26 ± 0.20	0.61 ± 0.17
	S_1	0.81 ± 0.22	0.27 ± 0.11	0.54 ± 0.12
	S_2	0.67 ± 0.13	0.47 ± 0.10	0.57 ± 0.10
	S_3	0.52 ± 0.15	0.36 ± 0.10	0.44 ± 0.09
	S_4	0.94 ± 0.24	0.27 ± 0.08	0.61 ± 0.12
	Pooled	0.71 ± 0.09	0.33 ± 0.05	0.52 ± 0.05

(1954 a,b) reported estimates of 0.30 to 0.70 with a mean of 0.58 and Kinney (1969) found the heritability for light breeds to be 0.45 for early egg weight and 0.49 for mature egg weight, which are in conformity with the present findings.

During five generations the heritability estimates ranged from 0.14 to 0.82, 0.30 to 0.70 and 0.42 to 0.65 in IWN and from 0.52 to 0.95, 0.26 to 0.47 and 0.44 to 0.61 in IWP fro sire, dam and sire plus dam components respectively. The estimates pooled over generations were found to be 0.46 ± 0.07, 0.44 ± 0.05 and 0.51 ± 0.04 for strain IWN and 0.71 ± 0.09, 0.33 ± 0.05 and 0.52 ± 0.05 for IWP from sire, dam and sire plus dam components, respectively.

The results of the present experiment are consistent with the earlier reports of Lerner and Cruden (1951), Hicks (1958 Nanda (1973), Prakashbabu (1973), Renganathan (1976), Prakashbabu (1978) and Venkatramaiah (1982).

The higher estimates derived from sire component than dam component in IWP strain indicated importance of sex-linked effects in the inheritance of egg weight as suggested by Hicks (1958), Renganathan (1976) and Venkatramaiah (1982). However, in IWN strain, both sex-linked and maternal effects were found to exert equal influence in the inheritance of thi trait.

Time trend in heritability estimates

Change in genetic variance due to selection is condition by the genetic constitution of base population. Time trend in heritability estimates serves the purpose of assessing the changes in genetic variability.

Yamada et al. (1958) found that the genetic variance of egg production decreased rapidly during the early years of selection and remained at a low level for the next few generations.

Morris (1963) too found evidence of a decline in the heritability of egg production due to selection. Nordskog et al. (1974) indicated that selection reduced the genetic variation in some lines. Gowe (1970) and Poggenpoel and Erasmus (1978) also reported negative trend in heritability estimates over generations due to selection. Lerner and Dempster (1951), Dempster et al. (1952), Falconer (1955) and Friars et al. (1962) however reported fairly constant heritability estimates over generations in selected populations. Scosseroli (1957) on the other hand reported a positive trend in heritability estimates as a result of selection.

The time trend (b ± SE) in heritability estimates of both the strains for the selected trait, egg production as number of eggs to 280 days of age are given in Table 21. For the other economic traits the change in parameter estimates were observed as a single deviation from the corresponding pooled estimates (Thiyagasundarum, 1984).

The results realised in the present study indicated that the heritability estimates for egg production obtained from

Table 21. Time trend in heritability estimates (b±SE) in part period egg production number

Strain	Components of variance		
	Sire	Dam	Sire + Dam
IWH	0.03 ± 0.04	-0.01 ± 0.07	0.01 ± 0.04
IWP	-0.05 ± 0.06	0.01 ± 0.03	-0.02 ± 0.02

All estimates were non-significant

sire component of variance showed an increasing trend and from dam component a decreasing trend in strain IWN and the reverse was the case in strain IWP. However the rate of change per generation, which were calculated as simple regression co-efficients were not significant consistently in both the strains under study. The results obtained in this study suggest that there were no significant changes in genetic variability for the primary trait viz., egg number, due to selection for four generations and the prediction of response consequent to selection would not be affected significantly if the pooled estimates of heritability are made use of.

The decreasing trend in heritability from sire component due to selection as seen for IWP strain is in agreement with the view of Morris (1953), Thiyagasundaram (1984) and the increasing trend from sire component as observed for strain IWN is consistent with the reports of Scossiroli (1957).

No specific time trend in heritability estimates could be noticed for the secondary traits.

Correlation

The genetic correlations in this experiment were estimated from sire, dam and sire plus dam components utilizing variance and covariance component analysis. The correlations were derived initially on intrastrain and intrageneration basis and then pooled over generations within strains to provide mean estimates. Pooling was done by weighing them with the inverse of the square of their respective standard errors (Enfield *et al.*, 1966). The phenotypic and environmental correlations were also calculated from sire variance and covariance component analysis as per Becker (1964). The genetic, environmental and phenotypic correlations among the various traits studied are summarised in Tables 22 to 31.

Egg number and egg weight

The genetic correlation estimates between egg number and egg weight from sire, dam and sire plus dam components ranged from 0.03 to -0.79, 0.00 to -0.37 and -0.03 to -0.50 in IWN and -0.04 to -0.50, 0.004 to -0.65 and -0.02 to -0.47 in IWP strains, respectively (Table 22).

The pooled estimates of genetic correlation from sire, dam and sire plus dam components respectively were found to be -0.57 ± 0.07, -0.22 ± 0.10 and -0.35 ± 0.07 for strain IWN and -0.28 ± 0.09, -0.59 ± 0.10 and -0.28 ± 0.07 for IWP.

Although intra-strain and inter-strain generation estimates of genetic correlations were uniformly negative varied considerably among generations and also between strains. However few positive estimates were also noticed, such as in S_3 generation from sire component, S_0 generation from dam component in strain IWN and in S_3 generation from dam component in IWP, which were extremely low in magnitude.

Besides those, few genetic correlation estimates wer found to be beyond the theoretical limits. Such erratic es mates of genetic correlation beyond the theoretical limits have also been reported by Saadeh et al. (1963) and Thiyagasundaram (1984). The reasons for such erratic estimation might be due to statistical sampling as described by Robertson (1959).

While comparing the genetic correlation estimates betw the two strains, the sire component estimate was found to be higher than the dam component estimate in IWN strain whereas the reverse situation was noticed in IWP. The genetic correlation estimates from various components in the present study are found to be higher than the average of the several values reported in the literature (see Table 5) except the estimate from sire component in IWP strain. However few authors observed negative genetic correlation of higher magnitude, than these realised in the present investigation.

The negative genetic correlation between egg number and egg weight of domestic fowl is well documented (Blyth, 1952; Wyath, 1954; Abplanalp, 1956; Abplanalp, 1957; Jerome et al.

Table 22. Genetic, phenotypic and environmental correlations between egg number and egg weight

Strain	Generation	$rG_S \pm SE$	$rG_D \pm SE$	$rG_{S+D} \pm SE$	$rP \pm SE$	re_S	re_D	$re_{(S+D)}$
IWN	S_0	-	0.00 ± 0.36	-0.40 ± 0.18	$-0.23 \pm 0.04^{**}$	-0.04	-0.28	-0.15
	S_1	-0.79 ± 0.11	-0.22 ± 0.19	-0.42 ± 0.12	$-0.10 \pm 0.03^{**}$	0.17	0.03	0.09
	S_2	-0.38 ± 0.12	-0.30 ± 0.19	-	$-0.07 \pm 0.03^{*}$	0.07	0.04	0.05
	S_3	0.03 ± 0.22	-0.11 ± 0.20	-0.03 ± 0.14	$-0.13 \pm 0.03^{**}$	-0.24	-0.18	-0.20
	S_4	-0.55 ± 0.14	-0.37 ± 0.26	-0.50 ± 0.12	$-0.20 \pm 0.03^{**}$	0.04	-0.11	-0.05
	Pooled	-0.57 ± 0.07	-0.22 ± 0.10	-0.35 ± 0.07	$-0.14 \pm 0.01^{**}$	-0.00	-0.10	-0.05
IWP	S_0	-0.32 ± 0.22	-	-0.02 ± 0.23	$-0.10 \pm 0.05^{*}$	0.08	-0.30	-0.17
	S_1	-0.07 ± 0.21	-0.29 ± 0.34	-0.13 ± 0.17	$-0.06 \pm 0.03^{*}$	-0.02	0.003	-0.01
	S_2	-0.16 ± 0.25	-0.65 ± 0.12	-0.41 ± 0.13	$-0.20 \pm 0.03^{**}$	-0.18	-0.02	-0.10
	S_3	-0.04 ± 0.21	0.004 ± 0.35	-0.03 ± 0.16	$-0.11 \pm 0.03^{**}$	-0.16	-0.15	-0.15
	S_4	-0.50 ± 0.14	-0.39 ± 0.25	-0.47 ± 0.12	$-0.25 \pm 0.03^{**}$	0.01	-0.17	-0.10
	Pooled	-0.29 ± 0.09	-0.59 ± 0.10	-0.28 ± 0.07	$-0.13 \pm 0.02^{**}$	-0.05	-0.13	-0.11

**, $P < 0.01$; *, $P < 0.05$

-, Values beyond theoretical limits

1956; Hicks, 1958; Waring et al., 1962; Clayton and Robertson, 1966; Nordskog et al., 1967; Craig et al., 1969; Kinney, 1969; Anjaneyulu, 1972; Prakashbabu, 1973; Trehan, 1973; Quadeer et al., 1977; Mishra et al., 1978; Poggenpoel and Erasmus, 1978; Liljedahl et al., 1979; Kolstad, 1980; Kotaiah and Ranganathan, 1980; Venkatramaiah, 1982; Barua, 1983 and Thiyagasundarum, 1984). The results obtained in the present study as well as those reported in literature suggest that selection for egg number would bring about decline in egg weight.

The phenotypic correlation estimates of different generations ranged from -0.07 to -0.23 in IWN and -0.06 to -0.25 in IWP strain. The pooled over generation estimates were -0.14 ± 0.01 and -0.13 ± 0.02 for IWN and IWP strains respectively. All the phenotypic correlation estimates between egg number and egg weight in different generations as well as pooled estimates were found to be statistically significant for both the strains. The environmental correlations were extremely low in magnitude.

<u>Egg number and age at first egg</u>

The genetic correlation estimates between egg number and age at first egg from sire, dam and sire plus dam components of variance and covariance respectively ranged from -0.03 to -0.93, -0.87 to 0.11 and -0.73 to -0.84 for IWN and -0.57 to -0.81, -0.12 to -0.94 and -0.39 to -0.74 for IWP strain (Table 23). The estimates pooled over generations were -0.87 ± 0.03, -0.91 ± 0.05 and -0.81 ± 0.03 in IWN and -0.74 ± 0.05,

−0.91 ± 0.04 and −0.70 ± 0.04 in IWP strain from sire, dam and sire plus dam components respectively.

The genetic correlation estimates of both the strains as well as for all generations/components were found to be negative except for strain IWN from dam component in base generation which was low and positive (0.11). Mostly the magnitude of these negative genetic correlation estimates varied from moderate to high except few low estimates such as in S_1 generation (rGs) of IWN and S_0 and S_2 generation (rGD) of IWP strain (Table 23). The pooled estimates from various components of both the strains were negative and high in magnitude. These estimates fairly agreed with the averages of the several reported results (see Table 6). As such it may be concluded that the age at first egg would decline concomitant to selection for egg number upto 280 days of age. Similar results were reported by Abplanalp (1957), Abplanalp *et al.* (1964), Hussain and Singh (1964), Acharya *et al.* (1969), Anjaneyulu (1972), Quadeer *et al.* (1977), Kotaiah and Renganathan (1980), Kolstad (1980), Boh-ron *et al.* (1981), Venkataramaiah (1982), Barua (1983), Thiyagasundarum (1984) and Shang (1984).

Some genetic correlation estimates were observed to be beyond the theoretical limits which might be due to statistical sampling as suggested by Robertson (1959).

The phenotypic correlations between egg number and age at

Table 23. Genetic, phenotypic and environmental correlations between age at first egg and egg number

Strain	Generation	$rG_S \pm SE$	$rG_D \pm SE$	$rG_{S+D} \pm SE$	$rP \pm SE$	re_S	re_D	$re_{(S+D)}$
IWH	S_0	-0.93 ± 0.04	0.11 ± 0.77	-0.84 ± 0.12	$-0.61 \pm 0.03^{**}$	-0.53	-0.63	-0.58
	S_1	-0.03 ± 0.69	-0.87 ± 0.06	-0.73 ± 0.09	$-0.40 \pm 0.03^{**}$	-0.38	-0.27	-0.33
	S_2	-0.61 ± 0.13	-0.58 ± 0.14	$-$	$-0.27 \pm 0.03^{**}$	-0.09	-0.11	-0.10
	S_3	-0.87 ± 0.05	-0.81 ± 0.08	-0.84 ± 0.04	$-0.60 \pm 0.02^{**}$	-0.42	-0.49	-0.45
	S_4	-0.69 ± 0.11	$-$	-0.74 ± 0.09	$-0.52 \pm 0.02^{**}$	-0.44	-0.46	-0.45
	Pooled	-0.87 ± 0.03	-0.81 ± 0.05	-0.81 ± 0.03	$-0.51 \pm 0.01^{**}$	-0.37	-0.39	-0.38
IWP	S_0	$-$	-0.12 ± 1.87	$-$	$-0.69 \pm 0.04^{**}$	-0.46	-0.62	-0.55
	S_1	-0.73 ± 0.11	-0.76 ± 0.17	-0.74 ± 0.08	$-0.45 \pm 0.03^{**}$	-0.27	-0.34	-0.31
	S_2	-0.57 ± 0.20	-0.26 ± 0.29	-0.39 ± 0.16	$-0.40 \pm 0.02^{**}$	-0.39	-0.43	-0.41
	S_3	-0.81 ± 0.07	-0.44 ± 0.31	-0.71 ± 0.08	$-0.59 \pm 0.02^{**}$	-0.48	-0.59	-0.54
	S_4	-0.60 ± 0.13	-0.94 ± 0.04	-0.70 ± 0.08	$-0.50 \pm 0.02^{**}$	-0.41	-0.40	-0.41
	Pooled	-0.74 ± 0.05	-0.91 ± 0.04	-0.70 ± 0.04	$-0.48 \pm 0.01^{**}$	-0.40	-0.48	-0.44

**, $P < 0.01$; *, $P < 0.05$

–, Values beyond theoretical limits

first egg in all generations as well as pooled estimates for both the strains were found to be significantly ($P < 0.01$) negative and varied from moderate to high in magnitude. Similarly the environmental correlations were also negative and moderate in magnitude.

Egg number and 20-week body weight

The genetic correlation estimates between egg number and 20 week body weight ranged from -0.53 to 0.59, -0.30 to 0.76 and -0.03 to 0.71 for IWN and 0.31 to 0.66, -0.02 to 0.32 and 0.29 to 0.80 for IWP strains from sire, dam and sire plus dam components respectively (Table 24). The estimates pooled over generations were 0.25 ± 0.09, 0.57 ± 0.07 and 0.38 ± 0.07 for IWN and 0.30 ± 0.07, 0.22 ± 0.13 and 0.52 ± 0.06 for IWP from sire, dam and sire plus dam components, respectively.

The results of this study revealed that the correlation between egg number and 20 week body weight were moderately positive. This observation was consistent in both populations as well as in all the generations.

Few erratic estimates beyond the theoretical limits as observed in base generation (S_0) for strain IWP is in conformity with finding of Kinney and Shoffner (1965) and might be due to statistical sampling.

The results of the present study were in agreement with the average values of several reports (see Table 7) in direction

Table 24. Genetic, phenotypic and environmental correlations between 20-week body weight and egg number

Strain	Genera-tion	$rG_S \pm SE$	$rG_D \pm SE$	$rG_{(S+D)} \pm SE$	$rP \pm SE$	rE_S	rE_D	$rE_{(S+D)}$
IWN	S_0	0.59±0.23	0.40±0.36	0.49±0.17	0.39±0.04**	0.33	0.38	0.36
	S_1	-0.53±0.23	0.76±0.10	0.27±0.15	0.26±0.03**	0.37	0.16	0.26
	S_2	-0.09±0.25	0.46±0.16	0.71±0.19	0.09±0.03*	0.09	-0.04	0.03
	S_3	0.59±0.14	0.35±0.21	0.50±0.11	0.32±0.03*	0.14	0.26	0.21
	S_4	0.10±0.21	-0.30±0.33	-0.03±0.17	0.35±0.03**	0.35	0.36	0.35
	Pooled	0.25±0.09	0.57±0.07	0.38±0.07	0.25±0.01**	0.26	0.22	0.24
RIP	S_0	0.39±0.23	-	0.80±0.10	0.35±0.05**	0.18	0.06	0.11
	S_1	0.66±0.12	0.32±0.31	0.56±0.11	0.26±0.03**	-0.13	0.16	0.04
	S_2	0.50±0.20	0.21±0.20	0.33±0.14	0.13±0.03**	0.02	0.07	0.05
	S_3	0.40±0.17	-0.02±0.37	0.29±0.15	0.21±0.03**	0.11	0.23	0.18
	S_4	0.31±0.18	0.30±0.28	0.31±0.14	0.23±0.03**	0.17	0.20	0.19
	Pooled	0.50±0.07	0.22±0.13	0.52±0.06	0.22±0.01**	0.07	0.14	0.11

**, $P < 0.01$; *, $P < 0.05$

-, Values beyond theoretical limits

but were found to be much higher in magnitude. The magnitude of estimates obtained in the present study however were consistent with the findings of Clayton and Robertson (1966), Trehan (1978), Venkatramaiah (1982) and Thiyagasundaram (1984). A positive correlation for light breeds and negative correlation for heavier breeds of egg type chicken were reported by Krueger et al. (1952) and Wyatt (1954).

The phenotypic correlation estimates between these two traits in different generations ranged from 0.09 to 0.39 in IWN and 0.13 to 0.35 in IWP strains. The pooled estimates were found to be 0.25 ± 0.01 in IWN and 0.22 ± 0.01 in IWP strain. All the phenotypic correlation estimates were statistically significant. The environmental correlation estimates were found to be positive but low in magnitude. But the estimates in IWN strain were relatively higher than IWP.

Egg number and 40-week body weight

The genetic correlation estimates between egg production and 40-week body weight from sire, dam and sire plus dam components ranged from -0.84 to 0.12, -0.52 to 0.37 and -0.57 to 0.10 in IWN and -0.13 to 0.50, -0.73 to 0.15 and -0.20 to 0.39 in IWP strains respectively (Table 25). The pooled over generation estimates from sire, dam and sire plus dam components were -0.51 ± 0.08, 0.06 ± 0.01 and -0.07 ± 0.08 in IWN and 0.14 ± 0.10, -0.03 ± 0.13 and 0.06 ± 0.07 in IWP strains respectively.

Table 25. Genetic, phenotypic and environmental correlations between 40-week body weight and egg number

Strain	Generation	$rG_S \pm SE$	$rG_D \pm SE$	$rG_{(S+D)} \pm SE$	$rP \pm SE$	re_S	re_D	$re_{(S+D)}$
IWN	S_0	0.12±0.33	-0.52±0.34	-0.18±0.23	0.06±0.04	0.10	0.22	0.16
	S_1	-0.84±0.10	0.37±0.21	-0.07±0.16	0.08±0.03*	0.19	0.02	0.11
	S_2	-0.41±0.19	0.05±0.22	-0.57±0.28	-0.01±0.03	0.11	0.02	0.06
	S_3	0.10±0.20	0.10±0.21	0.10±0.14	-0.04±0.03	-0.25	-0.14	-0.18
	S_4	-0.34±0.20	-0.10±0.29	-0.09±0.10	0.12±0.03**	0.29	0.22	0.25
	Pooled	-0.51±0.30	0.05±0.01	-0.07±0.08	0.04±0.01**	0.09	0.07	0.08
IWP	S_0	-0.11±0.27	-	0.31±0.23	0.22±0.05**	0.33	0.01	0.16
	S_1	0.50±0.16	-0.73±2.58	0.32±0.17	0.03±0.03	-0.29	-0.03	-0.14
	S_2	-0.04±0.47	0.13±0.18	0.09±0.14	-0.08±0.03**	-0.11	-0.21	-0.15
	S_3	-0.18±0.22	0.15±0.21	-0.06±0.15	-0.05±0.03	-0.004	-0.09	-0.04
	S_4	-0.09±0.23	-0.40±0.24	-0.20±0.15	-0.004±0.03	0.05	0.10	0.06
	Pooled	0.14±0.10	-0.03±0.13	0.06±0.07	-0.01±0.01	0.01	-0.06	-0.02

**, $P < 0.01$; *, $P < 0.05$

-, Values beyond theoretical limits

Table 26. Genetic, phenotypic and environmental correlations between age at first egg and 20-week body weight

Strain	Generation	$rG_S \pm SE$	$rG_D \pm SE$	$rG_{(S+D)} \pm SE$	$rP \pm SE$	rE_S	rE_D	$rE_{(S+D)}$
IWH	S_0	-0.67±0.19	-0.83±0.18	-1.01±0.01	-0.39±0.01**	-0.42	-0.40	-0.41
	S_1	-	-0.68±0.12	-0.29±0.16	-0.31±0.03**	-0.50	-0.26	-0.39
	S_2	0.43±0.20	-0.60±0.10	-0.17±0.12	0.26±0.03**	-0.54	-0.13	-0.34
	S_3	-0.67±0.11	-0.41±0.21	-0.59±0.10	-0.68±0.03**	-0.32	-0.46	-0.40
	S_4	-0.10±0.20	0.77±0.24	0.06±0.17	-0.35±0.03**	-0.53	-0.50	-0.52
	Pooled	-0.41±0.08	-0.55±0.06	-0.30±0.06	-0.29±0.01**	-0.46	-0.35	-0.41
IWP	S_0	-0.27±0.28	-	-0.81±0.14	-0.35±0.05**	-0.31	-0.16	-0.22
	S_1	-0.52±0.16	-0.18±0.28	-0.41±0.14	-0.33±0.03**	-0.15	-0.30	-0.24
	S_2	-0.21±0.22	-0.11±0.22	-0.26±0.15	-0.25±0.03**	-0.29	-0.26	-0.28
	S_3	-0.48±0.15	-0.28±0.21	-0.42±0.12	-0.37±0.03**	-0.27	-0.37	-0.33
	S_4	-0.54±0.14	-0.12±0.22	-0.40±0.12	-0.33±0.03**	-0.18	-0.35	-0.28
	Pooled	-0.40±0.08	-0.23±0.11	-0.46±0.06	-0.32±0.01**	-0.24	-0.29	-0.27

**, $P < 0.01$; *, $P < 0.05$

-, Values beyond theoretical limits

The genetic correlation estimates of different generations for both the strains fluctuated considerably in magnitude and direction during the course of this experiment. The estimates pooled over generations were found to be low in magnitude except the sire component estimate in IWN (rGs) which was found to be moderately negative. The pooled estimates from dam component were low in magnitude than the sire component values. Further, while the sire component estimate in IWN was negative the same was positive in IWP. Similarly the dam component estimate was found to be positive in IWN whereas it was negative in IWP strain.

From the above trend in directions of the genetic correlations it can be suggested that there is scope to reduce 40-week body weight due to selection for egg number in strain IWN whereas improvement in 40-week body weight is expected in IWP. Such situation might be due to the difference in genetic make up of the two populations and the previous selection history.

The negative genetic correlation (rGs) as found in the present study for IWN strain was reported by several investigators (Craig _et al._, 1969; Mohapatra and Ahuja, 1971b; Anjaneyulu, 1972; Prakashbabu, 1973; Choudhuri, 1975; Trehan, 1978; Kotaiah and Renganathan, 1980; Das, 1982; Barua, 1983 and Thiyagasundaram, 1984). Further the positive genetic correlation as obtained in present study for IWP was in agreement with the reports of King (1961), Hale and Clayton (1965), Craig *et al.* (1969), Nanda *et al.* (1973), Trehan (1973), Choudhuri (1975), Renganathan (1976) and Venkatramaiah (1982).

The phenotypic correlation between these two traits ranged from -0.04 to 0.12 for IWN and -0.08 to 0.22 for IWP strain in the different generations. Few of the estimates were found to be significant (Table 25) while others were non-significant. The pooled over generation phenotypic correlation estimates were 0.04 ± 0.01 for IWN and -0.01 ± 0.01 for strain IWP. The environmental correlations were very small in magnitude.

Age at first egg and 20-week body weight

The genetic correlations between age at first egg and 20-week body weight from sire, dam and sire plus dam components respectively ranged from -0.67 to 0.43, -0.83 to 0.77 and -1.01 to 0.06 for IWN and -0.54 to -0.21, -0.31 to -0.12 and -0.81 to -0.26 for IWP strain during five generations of study (Table 26). The estimates pooled over generations from sire, dam and sire plus dam components were found to be -0.41 ± 0.08, -0.55 ± 0.06 and -0.30 ± 0.06 for IWN and -0.40 ± 0.08, -0.23 ± 0.11 and -0.46 ± 0.06 for IWP strains respectively.

Most of the genetic correlation estimates between these two traits in both the strains were found to be negative and varied from moderate to high in magnitude except a few positive estimates in IWN strain. There were also few erratic genetic correlation estimates for generation S_1 in IWN (rGs) and for generation S_0 in IWP (rGD).

Pooled estimates of genetic correlation from different components between age at first egg and 20-week body weight (secondary traits) were found to be negative. The pooled estimates of this investigation were higher in magnitude than the average of the estimates from several reports compiled from literature (see table 8). However the present results are close to the findings of Hazel and Lamoreux (1947), Baczkowska and Kaminska (1964), Renganathan (1976), Reddy *et al.* (1978) and Das (1982).

The phenotypic correlation estimates between age at first egg and 20 week body weights ranged from -0.68 to 0.26 in IWN and -0.37 to -0.25 in IWP strain and the respective pooled over generation estimates were -0.29 ± 0.01 and -0.32 ± 0.01. All these estimates were found to be statistically significant. The environment correlation estimates in both the strains between those two traits were moderate in magnitude and negative in direction. The phenotypic and environmental correlations in general showed similar trend both in magnitude and direction as reported by Choudhari (1975), Renganathan (1976) and Das (1982).

values on generation number. The results of both the strains from different components are presented in Table 32.

The genetic correlation between egg number and egg weight estimated from sire component of variance and covariance increased over the years due to selection for part period egg production. The estimates from dam component however showed a decline. The respective values were 0.11 ± 0.17, -0.06 ± 0.04 and 0.01 ± 0.10 in IWN and -0.03 ± 0.07, 0.04 ± 0.15 and -0.08 ± 0.06 in IWP from sire, dam and sire plus dam components respectively. However, all these estimates were small in magnitude and statistically non-significant.

The genetic correlations between egg number and age at first egg decreased at a non-significant rate of -0.04 ± 0.13, -0.25 ± 0.17 and 0.02 ± 0.03 in IWN and -0.02 ± 0.09, -0.13 ± 0.09 and -0.02 ± 0.03 in IWP strain from sire, dam and sire plus dam components respectively, due to selection for egg number.

The genetic correlation between egg number and 20-week body weight in general declined due to selection for part period egg production. The change in time which were calculated as regression coefficients were 0.01 ± 0.17, -0.10 ± 0.09 and -0.08 ± 0.09 in IWN and -0.04 ± 0.04, -0.03 ± 0.08 and -0.13 ± 0.04 in IWP from sire, dam and sire plus dam components, respectively. None of these regression coefficients however were significantly different from zero.

Table 32. Time trend (b±SE) of genetic and phenotypic correlations between various traits over four generations of selection for egg number

Between traits (1)	Strain (2)	b ± S.E. rG_S (3)	 rG_D (4)	 rG_{S+D} (5)	 rP (6)
Egg number and Egg weight	IWN	0.11±0.17	-0.06±0.04	0.01±0.10	0.003±0.02
	IWP	-0.03±0.07	0.04±0.15	-0.02±0.06	-0.04±0.02
Egg number and Age at first egg	IWN	-0.04±0.13	-0.25±0.17	0.02±0.03	-0.002±0.05
	IWP	-0.02±0.09	-0.13±0.09	-0.02±0.08	0.02±0.04
Egg number and 20-week body weight	IWN	0.01±0.17	-0.18±0.09	-0.08±0.09	-0.02±0.04
	IWP	-0.04±0.04	-0.03±0.08	-0.13±0.04	-0.03±0.02
Egg number and 40-week body weight	IWN	0.06±0.15	0.04±0.11	0.04±0.08	0.002±0.02
	IWP	-0.06±0.09	0.10±0.22	-0.15±0.03	-0.05±0.03

None of the estimates were significant

The change in genetic correlation between egg number and 40-week body weight did not produce any consistent trend o the years in two populations. While the trend was positive in IWN, it was negative from sire and sire plus dam component in IWP strain. The magnitude of changes were 0.06 ± 0.15, 0.04 ± 0.11 and 0.04 ± 0.08 in IWN and -0.06 ± 0.09, 0.10 ± 0.22 and -0.15 ± 0.03 in IWP from sire, dam and sire plus dam components respectively. None of these estimates were statistically significant.

The change in phenotypic correlations between selected trait (egg number) and several unselected traits like (egg weight, age at first egg, 20 week body weight and 40 week body weight) were found to be extremely low in magnitude and all were statistically non-significant. Further, the time trend estimates in phenotypic correlations in both strains were in similar direction as observed for genetic correlation from sire component except between egg number and age at first egg in IWP; between egg number and 20 week body weight in IWN.

The genetic and phenotypic correlations between several traits which did not show any significant time trend due to selection for egg number, in this study were consistent with the view of Thiyagasundarum (1984). Majority of the genetic and phenotypic correlation estimates in this study were consistent with the several values reported in literature.

Some of the changes in genetic correlations as observed in this study between egg number and egg weight, egg number and age at first egg, etc. might have been generated as a consequence of selection as reported by Hogsett and Nordskog (1958). Lerner (1950), Falconer (1960) and Sheridan and Barker (1974b) suggested that pleiotropic genes were responsible for generation of genetic correlation during selectio which were not found in the beginning. Parker *et al.* (1969, 1970) examined the effects of selection for a primary trait on the genetic correlation with a secondary trait over 30 generations in simulated populations and found that genetic correlations remained constant near initial correlations when the proportion of offspring saved for breeding was as large as one half. Genetic correlations did not decrease until t selection was as intense as 20%. The decrease was most rapid with high heritability and after 15th generation of selection. Even at intense selection and small environmental variance, genetic correlations did not reach zero even after 30 gener tions.

The results of the present study suggest that utilizing genetic correlation estimates pooled over generations betwee primary and secondary traits is not likely to affect the prediction of correlated response significantly as this is a sh term selection experiment and at the same time no significan time-trend for genetic correlations could be observed for both populations.

Response to selection

Response realized from four generations of IDS method of index selection for egg number upto 280 days of age in two white Leghorn strains was evaluated in the present study. The essential features of the response to selection are shown in Tables 33 to 42 and Figures 1 to 3.

Effective population size and rate of inbreeding

The number of sires and dams that contributed to the sampling variance among the progenies and the number of individuals measured in each generation are presented in Table 33.

The average number of pullets with complete records, upto 280 days of age were 1165.8 in IWN and 1076.6 in IWP strains respectively per generation. The number of sires, which effectively contributed progeny, averaged over the generations were 40 for IWN and 39.8 in IWP. The effective number of dams per generation were 238.4 and 232.2 in IWN and IWP strains respectively.

The increase in the rate of inbreeding is primarily dependent upon breeders from less numerous sex (Falconer, 1960). The effective number of males were adequate enough to minimise the increase in inbreeding coefficient (ΔF) is evident from the results presented in table 33.

Restriction in the size of parental population would lead to increase in homozygosity of the progeny over and above that was present in the base population. This would lead to drift in gene frequencies because of sampling a smaller number of genes in each generation. Gowe *et al.* (1959b) suggested that such sampling effect due to restriction in parental population size can be seen from the magnitude of effective number of parents (Ne) derived utilising the formula as suggested by Wright (1940). This formula is based on the assumption that each parent has an equal chance of contributing progeny to the next generation implying that the actual distribution of progeny number per parent will be of poisson type. However, differences among parents in reproductive ability or family differences in survival to maturity would lead to a decrease in effective number of parents. To overcome such situations, a term for variance of family size has to be used to estimate effective population size (Gowe *et al.*, 1959b). Nordskog (1978) reported that the rate of inbreeding estimated on the basis of effective population size (Ne) by such formula (Gowe *et al.*, 1959b) would be closer to the rate of inbreeding obtained from actual pedigree.

In this experiment, effective population size in each strain/generation was calculated by using both the formulae i.e. of Wright (1940) and Gowe *et al.* (1959b) and the results are presented in Table 33. It was observed that average Ne values over generations using Wright (1940)'s formula were 136.62, 135.33 and as per Gowe *et al.* (1959b)'s the respective

Table 33. Effective number of sires, dams, number of progeny, effective population size and expected ΔF in two strains

Strain	Generations	No. of sires (Nm)	No. of dams (Nf)	No. of progeny	Wright (1940)		Gowe *et al.* (1959b)	
					Ne	ΔF	Ne	ΔF
TWI	S_0	40	183	534	131.30	0.004	117.35	0.004
	S_1	40	219	1322	135.29	0.004	118.42	0.004
	S_2	40	279	1297	139.94	0.004	133.88	0.004
	S_3	40	272	1270	139.49	0.004	130.69	0.004
	S_4	40	232	1356	137.06	0.004	134.90	0.004
	Average	40	238.4	1165.8	136.62	-	127.03	-
	Cumulative	-	-	-	-	0.020	-	0.020
INP	S_0	40	174	428	130.09	0.004	125.00	0.004
	S_1	39	197	910	130.22	0.004	120.40	0.004
	S_2	40	294	1391	140.84	0.004	138.95	0.004
	S_3	40	257	1302	138.45	0.004	130.77	0.004
	S_4	40	239	1352	137.06	0.004	133.34	0.004
	Average	39.8	232.2	1076.6	135.33	-	129.69	-
	Cumulative	-	-	-	-	0.020	-	0.020

values were 127.03, 129.69 in IWN and IWP strains respectively. The smaller differences in the Ne values derived from both the methods suggest that the variance of the family size was not very large. The very small reduction in effective population size by considering family size variance is consistent with the reports of Gowe *et al.* (1959b), Brah and Dev (1981), Barua (1983) and Thiyagasundaram (1984). Brah and Dev (1981) reported that the effective population size calculated as per Gowe *et al.* (1959b) was more efficient to measure increase in rate of inbreeding at every generation. But the present results revealed absolutely no difference in ΔF in any generation/strain (Table 33) by using both the methods. The cumulative inbreeding for both the strains under study was found to be 2%. This was considered as the upper limit since sib matings were deliberately avoided in each strain under selection.

Shoffner (1948), Wilson (1948), Morris (1963), Kolstad (1972) and Nordskog *et al.* (1974) reported about the effect inbreeding on economic traits in poultry. Nordskog *et al.* (1974) indicated that 0.1% increase in inbreeding would depress rate of egg production by 0.23 ± 0.04%. Nordskog and Hardiman (1980) examined the importance of inbreeding depression and natural selection during artificial selection and reported that metric traits are less subjected to inbreeding depression than reproductive traits. Dempster *et al.* (1952) and Gowe *et al.* (1973) indicated that with large effective population size the effect of natural selection and inbreeding depression on high level egg production are negligible. Thiyagasundaram (1984) observed very marginal increase (1.3%) in inbreeding due to three generations of IWJ selection for egg production upto 280 days of age and did not consider a correction for inbreeding depression with reference to reported results.

In the present study the effective population size was large and Δ F was small. Hence the inbreeding depression on various economic traits was assumed to be negligible and correction of data for inbreeding effects was considered to be unnecessary.

Selection differentials

The expected and effective selection differentials along with selection intensities and phenotypic standard deviations are shown in Tables 34, 35. Although selection was practised only for egg number, selection differentials were also calculated for the secondary traits to assess the degree and magnitude of selection pressure imposed in those traits due to selection for primary trait (Tables 34, 35).

Primary selection differential (egg number)

The effective selection differential for egg number upto 280 days of age averaged over four generations were 10.73 and 12.03 eggs in IWN and IWP strains, respectively. The corresponding expected selection differentials were 10.66 in IWN and

Table 34. Expected and effective selection differentials, selection intensity for selected and unselected traits in strain IWJ

Traits	Generation	Males		Females		Average M+F		Eff./Exp.	Phenotypic S.D. σp	Selection intensity (I)
		Exp. S.D.	Eff. S.D.	Exp. S.D.	Eff. S.D.	Exp. S.D.	Eff. S.D.			
1	2	3	4	5	6	7	8	9	10	11
<u>Selected</u>	S_1	6.34	7.76	12.85	11.66	9.60	9.71	1.01	18.15	0.5350
280 days egg production number	S_2	10.67	10.24	14.02	14.25	12.35	12.25	0.99	20.76	0.5901
	S_3	8.88	8.76	12.11	12.73	10.50	10.75	1.02	30.55	0.3519
	S_4	7.97	7.82	12.38	12.73	10.18	10.28	1.01	16.73	0.6145
	Av.	8.47	8.65	12.84	12.84	10.66	10.75	1.01	21.55	0.4988
<u>Unselected</u>										
Age at first egg (d)	S_1	-4.27	-5.17	-7.13	-6.53	-5.70	-5.85	1.03	17.88	-0.3272
	S_2	-3.37	-3.21	-3.39	-3.60	-3.38	-3.41	1.01	8.93	-0.3819
	S_3	-4.65	-4.47	-5.43	-5.96	-5.04	-5.22	1.04	10.74	-0.4860
	S_4	-3.95	-3.98	-7.59	-7.72	-5.77	-5.85	1.01	12.09	-0.4839
	Av.	-4.06	-4.21	-5.89	-5.95	-4.97	-5.08	1.02	12.41	-0.4094

(contd.)

Table 34 contd.

1	2	3	4	5	6	7	8	9	10	11
20-week body weight (g)	S_1	49.24	59.11	45.87	41.48	47.56	50.30	1.06	128.09	0.3927
	S_2	35.83	33.35	37.65	41.72	36.84	37.54	1.02	122.46	0.3066
	S_3	19.32	20.99	37.03	40.49	28.10	30.74	1.09	91.33	0.3366
	S_4	13.09	15.40	60.37	62.57	36.73	38.99	1.06	128.13	0.3043
	av.	29.37	32.21	45.28	46.57	37.33	39.39	1.06	117.50	0.3352
40-week body weight (g)	S_1	-14.34	-17.63	7.86	2.31	-3.24	-7.66	2.36	176.70	-0.0434
	S_2	3.08	3.95	-0.74	1.45	1.17	2.70	2.31	134.47	0.0201
	S_3	-4.12	1.29	3.30	1.45	-0.41	1.37	-3.34	155.14	0.0088
	S_4	-21.51	-16.13	19.77	20.90	-0.87	2.39	-2.75	152.57	0.0157
	Av.	-9.22	-7.13	7.55	6.53	-0.84	-0.30	0.36	154.72	-0.0019
Egg weight (g)	S_1	-0.36	-0.47	-0.53	-0.30	-0.45	-0.39	0.87	3.53	-0.1105
	S_2	-0.59	-0.63	-0.97	-0.91	-0.78	-0.77	0.99	3.36	-0.2292
	S_3	-0.40	-0.26	0.26	0.50	-0.07	0.12	-1.71	3.93	0.0305
	S_4	-0.78	-0.75	1.05	1.08	0.14	0.17	1.21	2.81	0.0605
	Av.	-0.53	-0.53	-0.05	0.09	-0.29	-0.22	0.76	3.41	-0.0645

Table 35. Expected and effective selection differentials, selection intensity for selected and unselected traits in strain RIR

Traits	Generation	Males		Females		Average M+F		Eff./Exp.	Phenotypic standard deviation P	Selection intensity $(\bar{I})$
		Exp. S.D.	Eff. S.D.	Exp. S.D.	Eff. S.D.	Exp. S.D.	Eff. S.D.			
1	2	3	4	5	6	7	8	9	10	11
Selected										
280 days egg production number	S_1	12.67	12.96	11.47	12.37	12.07	12.67	1.05	15.97	0.7934
	S_2	12.40	12.32	11.98	11.58	12.19	12.20	1.00	17.85	0.6835
	S_3	10.43	10.24	13.90	14.32	12.17	12.28	1.01	17.90	0.6860
	S_4	9.30	9.72	12.20	12.20	10.75	10.96	1.02	16.81	0.6520
	Av.	11.20	11.44	12.39	12.62	11.80	12.03	1.02	17.10	0.7023
Unselected										
Age at first egg (d)	S_1	-9.56	-9.81	-9.55	-10.17	-9.56	-9.99	1.04	14.88	-0.6852
	S_2	-2.91	-2.86	-3.17	-2.89	-3.04	-2.88	0.95	9.58	-0.3006
	S_3	-1.87	-1.57	-4.93	-5.42	-3.40	-3.50	1.03	10.17	-0.3442
	S_4	-5.03	-5.22	-5.68	-5.31	-5.36	-5.27	0.98	12.12	-0.4348
	Av.	-4.84	-4.87	-5.83	-5.95	-5.34	-5.41	1.01	11.61	-0.4650

(contd.)

Table 35 contd.

1	2	3	4	5	6	7	8	9	10	11
20-week body-weight (g)	S_1	33.74	40.81	38.31	54.41	36.03	47.61	1.32	116.89	0.4073
	S_2	49.26	50.98	41.69	41.13	45.48	46.06	1.01	120.93	0.3809
	S_3	32.97	26.95	38.93	48.66	35.95	37.81	1.05	98.59	0.3835
	S_4	15.27	14.93	34.76	32.45	25.02	23.69	0.95	105.87	0.2238
	Av.	32.81	33.42	38.42	44.16	35.62	38.79	1.09	110.57	0.3508
40-week body weight (g)	S_1	-0.92	2.52	37.13	57.32	18.11	29.92	1.65	193.45	0.1547
	S_2	47.52	47.87	14.70	15.93	31.11	31.90	1.03	157.59	0.2024
	S_3	19.44	14.69	-11.86	-8.16	3.79	3.27	0.86	326.42	0.0100
	S_4	-0.77	-1.53	12.12	16.45	5.68	7.46	1.31	144.34	0.0517
	Av.	16.32	15.89	13.02	20.39	14.67	18.14	1.24	205.45	0.0883
Egg weight (g)	S_1	-0.73	-0.45	0.03	0.12	-0.35	-0.17	0.49	3.23	-0.0526
	S_2	-0.62	-0.65	-0.28	-0.13	-0.45	-0.39	0.87	3.29	-0.1185
	S_3	-0.82	-0.92	0.20	0.43	-0.31	-0.25	0.81	3.79	-0.0560
	S_4	-0.07	-0.14	1.01	1.12	0.47	0.49	1.04	2.87	0.1707
	Av.	-0.56	-0.54	0.24	0.39	-0.16	-0.08	0.50	3.30	-0.0242

11.80 eggs in IWP. The ratio of effective to expected selection differential was almost unity. The respective values were 1.01 for IWN and 1.02 for IWP. Within generation comparison presented similar trend and it was consistent in both the strains under study. This suggested that natural selection was not antagonistic to the intended selection criterion as reported by earlier workers (Morris, 1963; Kinney et al., 1970; Ayyagari et al., 1980; Das, 1982; Venkatramaiah, 1982; Ayyagari et al., 1983; Barua, 1983; Mohapatra et al., 1983 and Thiyagasundarum, 1984).

The selection intensities (standardised selection differential) averaged over generations for the selected trait were 0.4989 S.D. for IWN and 0.7023 S.D. for IWP. Thus selection was relatively more intense in IWP as compared to IWN strain.

Secondary selection differentials

The selection differentials in the unselected traits, which have been presented in tables 34 and 35, were computed to assess the influence of selection criterion (egg number upto 280 days of age) on secondary unselected traits.

Age at first egg

The respective expected and effective secondary selection differentials for average age at first egg averaged over four generations were -4.97 and -5.08 days in IWN strain; -5.34 and -5.41 days in IWP. The ratio of effective to expected selection differential were 1.02 in IWN and 1.01 in IWP. This trend was almost similar as observed for egg number, the principal trait. The results were also consistent with the reports of Kinney et al. (1970), Ayyagari et al. (1983), Mohapatra et al. (1983) and Thiyagasundarum (1984). The intensity of selection (standardised secondary selection differentials) for this trait due to selection for egg number were -0.4094 S.D. for IWN and -0.4660 S.D. for IWP and were close to the reports of Thiyagasundarum (1984). These selection intensities were comparatively of higher magnitude, which is only possible when the selected and unselected traits are correlated favourably as in this case. The generation-wise selection intensities ranged from -0.3272 S.D. to -0.4860 S.D. in IWN and -0.3006 S.D. to -0.6852 S.D. in IWP. The above results indicate that direct selection for egg number would bring about concomitant reduction in age at first egg.

20-week body weight

The expected and effective secondary selection differentials averaged over four generations for 20 week body weight were 37.33 and 39.39 grammes in IWN and 35.62 and 38.79 grammes in IWP strain. The ratio of effective to expected secondary selection differentials averaged over generation were 1.06 and 1.09 in IWN and IWP strains respectively. The results suggest that natural selection favoured the artificial selection for 20 week body weight in the two populations under study.

The selection intensities ($\bar{I}$) for 20 week body weight due to selection for part period egg number were 0.3352 S.D. in IWN and 0.3508 S.D. in IWP. These estimates were found to be relatively higher than the report of Thiyagasundarum (1984) in egg number line (0.2440 S.D.). The generation-wise selection intensities ranged from 0.3043 S.D. to 0.3927 S.D. in IWN and 0.2238 S.D. to 0.4073 S.D. in IWP strain. The positive selection differentials and a moderate intensity of selection for 20 week body weight would suggest that the 20 week body weight would improve in both populations(IWN, IWP) consequent upon selection for egg number upto 280 days of age.

40 week body weight

The secondary expected and effective selection differentials averaged over generations, were found to be -0.04 and -0.30 grammes in IWN and 14.67 and 18.14 grammes in IWP strains respectively (Tables 34, 35). The ratio of effective to expected selection differentials over generations were 0.36 in IWN and 1.24 in IWP. The results suggested that natural selection was operating in favour of 40-week body weight in IWP strain, but was against the indirect effect of selection for 40 week body weight in IWN. This trend however is undesirable since selection for part period egg number would increase mature body weight and hence higher feed consumption in IWP strain, but natural selection would decrease the mature body weight in IWN which is desirable. However while examining the realized correlated response per generation in IWP strain for 40-week body weight (Table 39), decline of mature body weight was noticed (-13.80 g) which is desirable although increasing trend was expected. As such it tends to suggest that the effect of natural selection was masked by the indirect effect of the selection on 40-week body weight in IWP strain in the course of four generations.

The standardized secondary selection differentials averaged over generation were -0.0019 S.D. in IWN and 0.0883 S.D. in IWP strains.

Egg weight

The secondary expected and effective selection differentials over generations were found to be -0.29 and -0.22 grammes in IWN and -0.16 and -0.08 grammes in IWP strains (Tables 34, 35). The ratio of effective to expected selection differentials which were 0.76 for IWN and 0.50 for IWP indicated that natural selection was acting against the indirect artificial selection for egg weight. The standardized secondary selection differentials averaged over generations were found to be -0.0645 S.D. and -0.0242 S.D. in IWN and IWP strains respectively.

Realized response to selection

The least square means along with standard errors for the principal and correlated traits have been summarised in Tables 36 and 37 and Figures 1-3. The average phenotypic response

Table 36. Generationwise mean along with standard error of various traits in IWN strain

Generation	No. of observation	Mean ± SE (c.v.)				
		Age at first egg (d)	20-week body weight (g)	40-week body weight (g)	Egg prodn. (no.)	Egg weight (g)
Base (S_0)	584	177.34±0.74 (10.08)	1161.96±5.30 (11.02)	1601.59±7.31 (11.03)	58.34±0.75 (31.11)	51.99±0.15 (6.80)
S_1	1322	161.30±0.25 (5.54)	1179.77±3.37 (10.38)	1392.57±3.70 (9.66)	74.76±0.57 (27.77)	51.51±0.09 (6.51)
S_2	1297	159.38±0.30 (6.74)	1200.88±2.54 (7.61)	1506.22±4.31 (10.30)	85.62±0.85 (35.69)	50.94±0.11 (7.71)
S_3	1270	165.22±0.34 (7.32)	1104.69±3.60 (11.60)	1477.51±4.28 (10.33)	86.73±0.47 (19.29)	50.63±0.08 (5.54)
S_4	1356	154.09±0.28 (6.61)	1341.82±2.97 (8.16)	1507.29±3.59 (9.76)	93.87±0.49 (19.09)	51.05±0.08 (5.92)

Age at first egg and 40-week body weight

The genetic correlation estimates between age at first egg and 40 week body weight ranged from -0.09 to 0.60, -0.57 to -0.18 and -0.33 to 0.46 for IWN and -0.26 to 0.31, -0.91 to 0.39 and -0.15 to 0.19 for IWP strain from sire, dam and sire plus dam components respectively in different generations (Table 27). The estimates pooled over generations from sire, dam and sire plus dam components were found to be 0.33 ± 0.09, -0.23 ± 0.11 and 0.19 ± 0.07 in IWN and 0.09 ± 0.11, -0.21 ± 0.09 and 0.07 ± 0.07 in IWP strains respectively.

The results of genetic correlations between these two traits revealed that the estimates from sire component were positive and varied from low to moderate in both the strains under study, whereas estimates from dam component were mostly negative although of similar magnitude. The average values of the several estimates reported in the literature were consistent with the present findings both in magnitude and direction, except the estimates from sire plus dam components. The estimates of this study for IWP strain is in agreement with the reports of Lerner and Cruden (1951), Hale and Clayton (1965) and Das (1982) whereas the magnitude of genetic correlation obtained in strain IWN is close to the results of Tanaka and Rosenberg (1952), Choudhuri (1975) and Murty (1977).

Considering the reliability of the pooled estimates from sire component it is expected that selection for egg number

Table 27. Genetic, phenotypic and environmental correlations between age at first egg and 40-week body weight

Strain	Generation	$rG_S \pm SE$	$rG_D \pm SE$	$r_{G(S+D)} \pm SE$	$r_P \pm SE$	re_S	re_D	$re_{(S+D)}$
IMB	S_0	−0.03±0.33	−0.57±0.43	−0.33±0.34	−0.14±0.04**	−0.14	−0.07	−0.10
	S_1	–	−0.27±0.22	0.25±0.16	−0.01±0.03	−0.17	0.01	−0.09
	S_2	0.60±0.14	−0.18±0.17	0.22±0.12	0.04±0.03	−0.26	0.06	−0.10
	S_3	−0.09±0.19	−0.20±0.21	−0.12±0.14	−0.02±0.03	0.11	0.07	0.09
	S_4	0.36±0.16	–	0.46±0.13	0.08±0.03**	−0.24	−0.10	−0.15
	Pooled	0.33±0.09	−0.23±0.11	0.19±0.07	0.01±0.02	−0.14	−0.01	−0.07
IMP	S_0	0.17±0.30	−0.91±0.15	−0.16±0.35	−0.15±0.05**	−0.29	−0.07	−0.17
	S_1	−0.26±0.20	–	−0.15±0.19	−0.02±0.03	0.12	−0.02	0.04
	S_2	0.31±0.37	−0.11±0.21	−0.01±0.15	−0.02±0.03	−0.06	−0.01	−0.03
	S_3	0.27±0.20	−0.00±0.20	0.15±0.13	0.03±0.03	−0.12	0.004	−0.05
	S_4	0.02±0.23	0.39±0.18	0.19±0.14	0.07±0.03*	0.05	−0.05	−0.001
	Pooled	0.09±0.11	−0.21±0.09	0.07±0.07	0.001±0.01	−0.06	−0.03	−0.04

**, $P < 0.01$; *, $P < 0.05$

–, Values beyond theoretical limits

would bring down the age at first egg and 40 week body weight. The phenotypic correlation between these two traits ranged from -0.14 to 0.08 in IWN and -0.15 to 0.07 in IWP strain, out of which only the estimates of S_0 and S_4 generations in both strains were observed to be significant. However, estimates pooled over generations were non-significant and extremely low in magnitude (0.01 ± 0.02, IWN; 0.001 ± 0.01; IWP). The environmental correlations for both the strains were negative and low in magnitude.

Age at first egg and egg weight

The genetic correlation estimates between age at first egg and egg weight in several generations from sire, dam and sire plus dam components ranged from -0.25 to 0.86, -0.18 to 0.56 and -0.19 to 0.63 in IWN and -0.39 to 0.23, -0.24 to 0.33 and -0.22 to 0.18 in IWP strain respectively (Table 28). The pooled estimates were 0.39 ± 0.06, 0.02 ± 0.10 and 0.11 ± 0.06 for IWN and -0.04 ± 0.09, 0.04 ± 0.11 and -0.04 ± 0.07 for IWP strain from sire, dam and sire plus dam components respectively.

Mostly the pooled genetic correlations were low in magnitude between these two traits in both strains from various components except for IWN from sire component. The intra generation estimates also varied widely in magnitude as well as in direction. The estimates of the present study are close to the average values calculated from the several reported

Table 28. Genetic, phenotypic and environmental correlations between age at first egg and egg weight

Strain	Generation	rG_S±SE	rG_D±SE	$rG_{(S+D)}$±SE	rP±SE	re_S	re_D	$re_{(S+D)}$
IW1	S_0	0.34±0.12	0.28±0.45	0.63±0.20	0.16±0.04**	0.01	0.08	0.04
	S_1	0.06±0.11	-0.18±0.13	0.12±0.15	0.06±0.03*	-0.07	0.14	0.04
	S_2	0.08±0.21	0.09±0.16	0.08±0.12	0.05±0.03	0.02	0.02	0.02
	S_3	-0.25±0.19	-0.11±0.21	-0.19±0.13	0.05±0.03	0.33	0.19	0.25
	S_4	0.23±0.18	0.56±0.33	0.27±0.15	0.11±0.03**	-0.02	0.04	0.01
	Pooled	0.39±0.06	0.02±0.10	0.11±0.06	0.08±0.01**	0.05	0.09	0.07
IW2	S_0	0.21±0.26	-	-0.08±0.34	0.04±0.05	-0.02	0.19	0.11
	S_1	-0.39±0.18	0.18±0.31	-0.22±0.16	-0.07±0.03*	0.20	-0.07	0.04
	S_2	0.23±0.21	-0.14±0.23	0.07±0.16	0.05±0.03	-0.01	0.09	0.04
	S_3	-0.16±0.19	-0.24±0.21	-0.19±0.14	0.02±0.03	0.21	0.16	0.18
	S_4	0.12±0.19	0.33±0.19	0.18±0.14	0.15±0.03**	0.18	0.10	0.12
	Pooled	-0.04±0.09	0.04±0.11	-0.04±0.07	0.04±0.01**	0.11	0.09	0.10

**, $P < 0.01$; *, $P < 0.05$

-, Values beyond theoretical limits

results (see table 9). The results as obtained in this investigations are similar to the reports of Quadeer *et al.* (1977) and Das (1983).

The phenotypic correlation estimates ranged from 0.05 to 0.16 in IWN and -0.07 to 0.15 in IWP in different generations. The pooled over generation estimates were found to be 0.08 ± 0.01 and 0.04 ± 0.01 for IWN and IWP respectively. Both these estimates are statistically significant. The phenotypic correlation obtained in this study are consistent with the reports of Prakashbabu (1973), Ranganathan (1976) and Das (1983). The environmental correlations were observed to be very low in magnitude.

Egg weight and 20-week body weight

The genetic correlations between the egg weight and 20 week body weight ranged from -0.54 to 0.52, 0.17 to 0.61 and 0.09 to 0.48 in IWN and -0.08 to 0.60, 0.11 to 0.91 and 0.14 to 0.53 in IWP from sire, dam and sire plus dam component respectively in various generations. The pooled estimates wer 0.32 ± 0.09, 0.39 ± 0.07 and 0.33 ± 0.06 in IWN and 0.41 ± 0.0 0.54 ± 0.07 and 0.39 ± 0.65 in IWP strains from sire, dam and sire plus dam components respectively.

Most of the genetic correlation estimates were found to be moderately positive. Few negative estimates obtained were only from sire component i.e. from S_0 (rGs), S_2 (rGs) of IWN and S_0 (rGs) of IWP strain. However, all the estimates were

Table 29. Genetic, phenotypic and environmental correlations between 20-week body weight and egg weight

Strain	Generation	rG_S±SE	rG_D±SE	$rG_{(S+D)}$±SE	rP±SE	re_S	re_D	$re_{(S+D)}$
LN	S_0	−0.54±0.36	0.38±0.23	0.13±0.18	0.03±0.04	0.09	−0.18	−0.03
	S_1	0.52±0.15	0.31±0.17	0.43±0.11	0.16±0.03**	−0.18	0.004	−0.00
	S_2	−0.05±0.26	0.17±0.14	0.09±0.12	0.09±0.03**	0.13	0.03	0.09
	S_3	0.45±0.16	0.53±0.15	0.48±0.11	0.14±0.03**	−0.23	−0.12	−0.17
	S_4	0.28±0.18	0.61±0.16	0.38±0.13	0.18±0.03**	0.05	0.04	0.05
	Pooled	0.32±0.09	0.39±0.07	0.33±0.06	0.13±0.01**	−0.03	−0.05	−0.03
IWP	S_0	−0.08±0.25	0.91±0.12	0.14±0.22	0.18±0.05**	0.52	0.09	0.24
	S_1	0.27±0.18	0.11±0.27	0.23±0.14	0.19±0.03**	0.08	0.20	0.16
	S_2	0.42±0.16	0.19±0.15	0.32±0.11	0.13±0.03**	−0.19	0.01	−0.03
	S_3	0.60±0.13	0.43±0.16	0.53±0.10	0.24±0.03**	−0.13	0.06	−0.02
	S_4	0.44±0.25	0.53±0.15	0.46±0.11	0.23±0.03**	−0.26	0.05	−0.06
	Pooled	0.41±0.07	0.54±0.07	0.39±0.05	0.20±0.01**	0.004	0.00	0.05

**, $P < 0.01$; *, $P < 0.05$

within the theoretical limits. The estimates of IWP were relatively higher than those for the strain IWN. However there was not much variation among the estimates obtained from various components in both strains. The results obtained in the present study are close to the average values calculated from the several reported in the literature (see Table 10), and were in agreement with the findings of Kinney *et al.*(1968), Kalstad (1972), Nanda (1973), Prakashbabu (1973) and Choudhuri (1975).

The phenotypic correlation estimates ranged from 0.03 to 0.18 in IWN and 0.13 to 0.24 in IWP and all were statistically significant except in S_6 generation of IWN strain. The pooled estimates of phenotypic correlation were also significant and were 0.13 ± 0.01 in IWN and 0.20 ± 0.01 in IWP strains. The environmental correlations were small and negative in IWN whereas they were small and positive in IWP strain.

Egg weight and 40-week body weight

The genetic correlation estimates between egg weight and 40 week body weight in different generations varied widely and ranged from 0.27 to 0.74, 0.27 to 0.65 and 0.29 to 0.65 in IWN and 0.01 to 0.77, -0.08 to 0.50 and -0.02 to 0.52 in IWP strains from sire, dam and sire plus dam components respectively (Table 30). The pooled estimates of genetic correlation from sire, dam and sire plus dam components were 0.54 ± 0.08, 0.32 ± 0.06 and 0.49 ± 0.05 for IWN and 0.46 ± 0.08,

Table 30. Genetic, phenotypic and environmental correlations between egg weight and 40-week body weight

Strain	Generation	$rG_S \pm SE$	$rG_D \pm SE$	$rG_{(S+D)} \pm SE$	$rP \pm SE$	re_S	re_D	re_{S+D}
IWN	S_0	0.46±0.39	0.65±0.17	0.56±0.13	0.16±0.04**	0.02	-0.18	-0.07
	S_1	0.74±0.10	0.53±0.14	0.65±0.08	0.26±0.03**	-0.17	0.03	-0.06
	S_2	0.31±0.21	0.27±0.15	0.29±0.12	0.21±0.03**	0.14	0.15	0.15
	S_3	0.39±0.17	0.61±0.11	0.46±0.10	0.23±0.03**	0.09	0.07	0.08
	S_4	0.27±0.17	0.50±0.16	0.33±0.12	0.25±0.03**	0.18	0.16	0.17
	Pooled	0.54±0.08	0.52±0.06	0.49±0.05	0.24±0.01**	0.05	0.05	0.05
JAP	S_0	0.01±0.25	-0.08±0.53	-0.02±0.21	0.19±0.05**	0.61	0.36	0.44
	S_1	0.03±0.19	-	0.13±0.18	0.17±0.03**	0.31	0.15	0.21
	S_2	0.77±0.14	0.03±0.14	0.20±0.11	0.06±0.03*	-0.14	0.004	-0.07
	S_3	0.36±0.19	0.45±0.14	0.40±0.11	0.25±0.03**	0.16	0.13	0.14
	S_4	0.58±0.14	0.50±0.15	0.52±0.10	0.33±0.03**	0.16	0.23	0.19
	Pooled	0.46±0.08	0.31±0.08	0.33±0.06	0.20±0.01**	0.22	0.17	0.18

**, $P < 0.01$; *, $P < 0.05$

-, Values beyond theoretical limit

0.31 ± 0.08 and 0.33 ± 0.06 for IW strains respectively.

In general, the genetic correlation estimates from various components were found to be positive and moderate in both strains under study except few negative estimates such as the rG_D and rG_{S+D} in S_0 generation of IWP strain. The results of the present study were consistent with the average values calculated from several reports in the literature (see Table 10), and similar to the reports of Nordskog _et al._ (1974), Choudhuri (1975), Murty (1977), Prakashbabu _et al._ (1978) and Zhang (1984).

The phenotypic correlations between these two traits in different generations ranged from 0.16 to 0.29 in IWN and 0.06 to 0.33 in IWP strain and all the estimates were found to be significant statistically. The pooled estimates were 0.24 ± 0.01 and 0.20 ± 0.01 in IWN and IWP strains respectively, and were statistically significant. The environmental correlations were all positive but the estimates were relatively higher in IWP than IWN strain.

<u>Body weight at 20 and 40-weeks of age</u>

The genetic correlation estimates between body weights of both the ages ranged from 0.75 to 0.83, 0.61 to 0.82 and 0.71 to 0.79 in IWN and 0.63 to 0.94, 0.40 to 0.78 and 0.57 to 0.93 in IWP strains from sire, dam and sire plus dam components, respectively (see Table 11) in different generations. The pooled estimates from sire, dam and sire plus dam components

Table 31. Genetic, phenotypic and environmental correlations between 20-week and 40-week body weight

Strain	Generation	$rG_S \pm SE$	$rG_D \pm SE$	$rG_{S+D} \pm SE$	$rP \pm SE$	re_S	re_D	$re_{(S+D)}$
IWN	S_0	0.83±0.12	0.71±0.18	0.76±0.09	0.50±0.04**	0.38	0.38	0.38
	S_1	0.81±0.08	0.61±0.14	0.71±0.07	0.42±0.03**	0.25	0.31	0.28
	S_2	0.76±0.11	0.80±0.06	0.77±0.05	0.52±0.02**	0.39	0.29	0.34
	S_3	0.75±0.08	0.74±0.10	0.74±0.06	0.39±0.03**	-0.28	0.13	-0.02
	S_4	0.77±0.08	0.82±0.08	0.79±0.06	0.58±0.03**	0.43	0.48	0.46
	Pooled	0.78±0.04	0.77±0.04	0.75±0.03	0.48±0.01**	0.23	0.32	0.29
IWP	S_0	0.74±0.13	0.40±0.59	0.64±0.14	0.57±0.04**	0.45	0.58	0.53
	S_1	0.84±0.06	-	0.93±0.03	0.55±0.03**	0.19	0.40	0.32
	S_2	0.94±0.04	0.56±0.10	0.57±0.08	0.37±0.03*	0.23	0.16	0.20
	S_3	0.63±0.13	0.78±0.07	0.68±0.07	0.52±0.02**	0.42	0.38	0.40
	S_4	0.70±0.11	0.68±0.11	0.66±0.08	0.56±0.02**	0.50	0.50	0.50
	Pooled	0.87±0.03	0.70±0.05	0.83±0.02	0.52±0.01**	0.36	0.49	0.39

**, $P < 0.01$; *, $P < 0.05$

-, Values beyond theoretical limits

were found to be 0.78 ± 0.04, 0.77 ± 0.04 and 0.75 ± 0.03 in IWN and 0.87 ± 0.03, 0.70 ± 0.05 and 0.83 ± 0.02 in IWP strains respectively.

The genetic correlation values obtained in this study were all positive and high in both the strains and in all generations. This suggested that the body weights at both the ages are more governed by the same sets of genes. The estimates derived in the present study were close to the average values of the several reported estimates (see Table 11) and are consistent with the reports of Clayton and Robertson (1966), Chaudhuri (1975), Ranganathan (1976), Murty (1977), Natarajan (1977), Gonzaler (1978) and Das (1982). All the phenotypic correlation were positively high and significant. The estimates in various generations ranged from 0.39 to 0.58 in IWN and 0.37 to 0.57 in IWP strain and the respective pooled estimates were 0.48 ± 0.01 and 0.52 ± 0.01 and are consistent with the results of Chaudhuri (1975), Ranganathan (1976) and Das (1982). The environmental correlations were also positive and moderate.

Time trend of genetic and phenotypic correlation

Time trends in genetic and phenotypic correlations between various traits due to selection for egg production (number) upto 280 days were studied for the primary and secondary traits in the two populations under study. The time trend estimates (b ± SE) were calculated by regressing generation correlation

Table 37. Generationwise mean along with standard error of various traits in IWP strain

Generation	No. of observation	Mean ± S.E. (c.v.)				
		Age at first egg (d)	20-week body weight (g)	40-week body weight (g)	Egg prodn. (no.)	Egg weight (g)
Base (S_0)	428	178.07±0.70 (8.19)	1263.47±5.65 (10.05)	1681.30±9.35 (11.51)	66.05±0.77 (24.18)	51.80±0.16 (6.24)
S_1	910	154.68±0.32 (6.20)	1276.56±4.01 (9.47)	1432.48±5.22 (11.00)	82.67±0.59 (21.59)	51.70±0.11 (6.37)
S_2	1391	156.14±0.27 (6.52)	1228.03±2.64 (8.03)	1644.43±8.75 (19.85)	84.29±0.48 (21.24)	52.12±0.10 (7.27)
S_3	1302	161.28±0.34 (7.51)	1184.91±2.93 (8.94)	1427.67±4.90 (9.70)	84.88±0.47 (19.90)	50.80±0.08 (5.64)
S_4	1352	153.50±0.27 (5.52)	1395.68±3.13 (8.24)	1564.71±3.98 (9.24)	96.73±0.43 (16.36)	52.17±0.09 (6.20)

per generation in the selected trait calculated from regression of generation means on generation numbers were 8.30 eggs for IWH and 6.37 eggs for IWP. Both the regression coefficients were significantly different from zero. How much of this improvement is due to genetic causes i.e. due to selection alone however was not possible to ascertain due to lack ofa suitable control population. Hill (1972a,b) reported that the drift variance (6 ^{2}d) and sampling error in measurements (6 ^{2}e) may bias the evaluation of response in short duration selection experiments. Therefore the drift variance (6 ^{2}d) and sampling error measurements (6 ^{2}e) were calculated as per the method suggested by Hill (1972b). The ratio of drift variance to sampling variance (6 ^{2}d/6 ^{2}e) revealed that the drift variance was unimportant in the present selection experiment for all traits and strains except in IWP for 20 week body weight and egg weight (Table 40).

<u>Direct response in egg number</u>

The least square means along with standard errors and coefficient of variation for egg production number to 280 days of age have been presented in table 36 and 37. The total phenotypic responses realized from four generations of IDS method of index selection for egg number to 280 days of age were 35.53 eggs in IWH and 30.73 eggs in IWP strain. The average response per generation was 8.30 ± 1.60 eggs in IWH and 6.37 ± 1.60 eggs in IWP strain which were found to be significant at 1% and 5% levels, respectively (Table 38).

The analysis of variance (Table 41) revealed differences between generations for part record egg production consistently in both the strains under study. Pairwise comparison of generation means using Duncan's Multiple Range Test (Table 42) revealed significant differences among generations except between S_2 and S_3 in IWP as well as in IWI.

There was a spectacular and sudden jump in mean egg number from S_0 to S_1 generations in both the strains. This might be due to the improvements in test environment of the two selected populations as compared to the prevailing environment in base generation. Similar situations may also be encountered in case of epistatic characters of the genes affecting egg production (Mohapatra, 1980). Marko (1978) ascribed this to the favourable effects of major genes during the first generation of selection and the effect of minor genes in subsequent generation. Positive response for part record egg production upto 280 days of age has been widely reported in literature and well documented (Gowe *et al.*, 1959b; Morris, 1963; Gowe *et al.*, 1973; Gowe, 197, Gowe, 1977; Poggenpoel and Erasmus, 1978; Ayyagari *et al.*, 1980 Mohapatra, 1980; Flock, 1980; Kolstad, 1980; Gowe and Fairfull, 1980; Liljedahl and Weyde, 1980; Venkatramaih, 1982; Ayyagari *et al.*, 1983; Barua, 1983; Mohapatra, *et al.*, 1983; Singh and Kumar, 1983; Thiyagasundarum *et al.*, 1984; Thiyagasundarum, 1984; Zhou, 1983 and Zhang, 1984).

Table 39. Realized gains per generation for the strains

Traits	b ± S.E.	
	IW1	IW2
280 days egg number (s)	8.30±1.60**	6.37±1.60*
Age at first egg (d)	-4.26±2.03	-4.45±2.76
20 week body weight (g)	28.46±27.65	37.28±25.97
40 week body weight (g)	-10.37±26.67	-13.80±38.19
Egg weight (g)	-0.28±0.11	-0.02±0.2

(s) selected trait

**, $P < 0.01$; *, $P < 0.05$

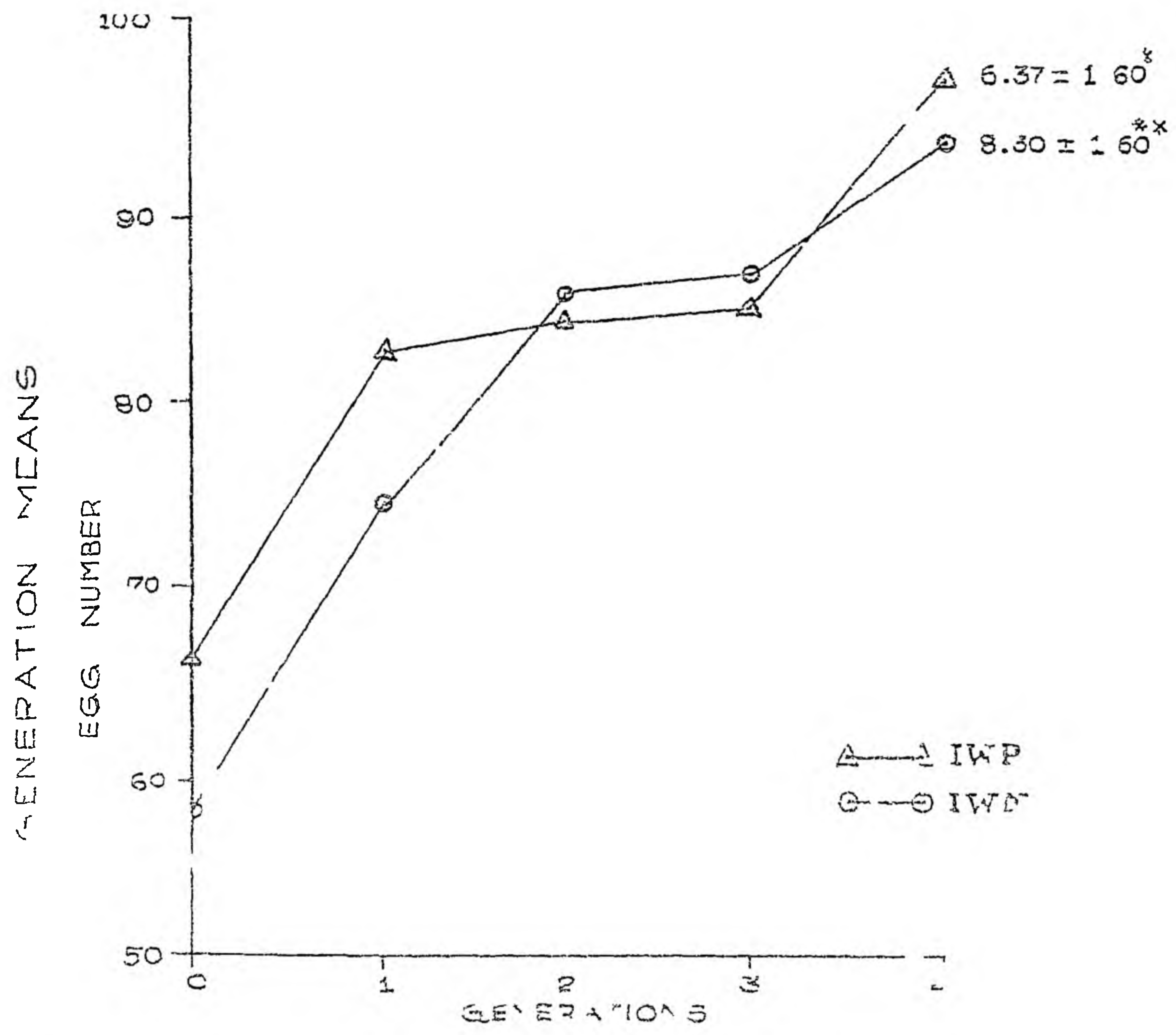

FIG 1. DIRECT RESPONSE IN EGG NUMBER

The results of the present study when verified in conjunction with the documented evidences clearly indicate that genetic improvement for egg production is a slow process.

Correlated response to selection

The least square means for the unselected traits are shown in tables 36 and 37 and figures 2 and 3. The realised correlated responses per generation were calculated in similar manner as that of selected trait i.e. from regression of generation means on generation numbers.

Age at first egg

The least square means along with standard errors and coefficient of variation for age at sexual maturity are presented in tables 36 and 37 and figure 2. The age at sexual maturity declined from generation to generation as a correlated response to selection for egg number. The average response per generation was found to be -4.26 ± 2.03 days in IWN and -4.45 ± 2.76 days in IWP (Table 38). The average response, which was calculated as simple regression coefficients, was found to be statistically non-significant. The analysis of variance revealed significant differences between generations in both strains (Table 41). The generation means for age at first egg also differed significantly from each other as evident from Duncan's multiple range Test. Gowe *et al.* (1959b), Morris (1963), Kinney *et al.* (1970), Osborne (1970), Mohapatra

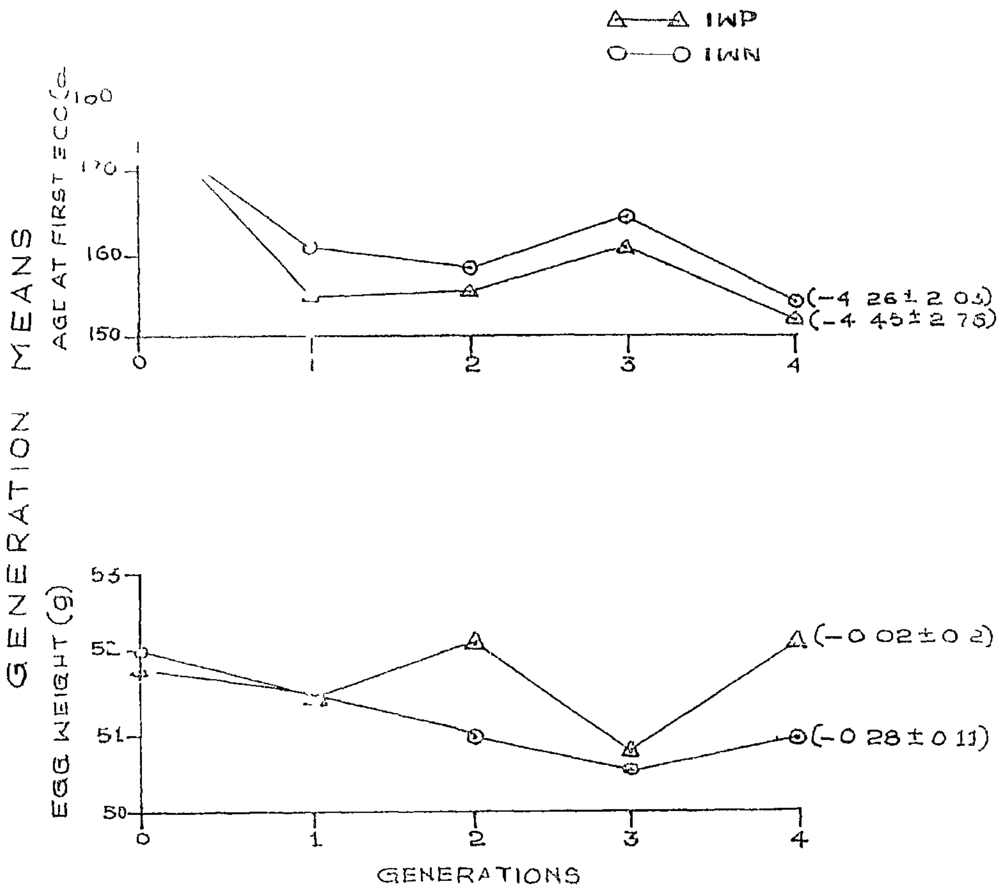

FIG. 2: CORRELATED RESPONSE IN AGE AT FIRST EGG AND EGG WEIGHT

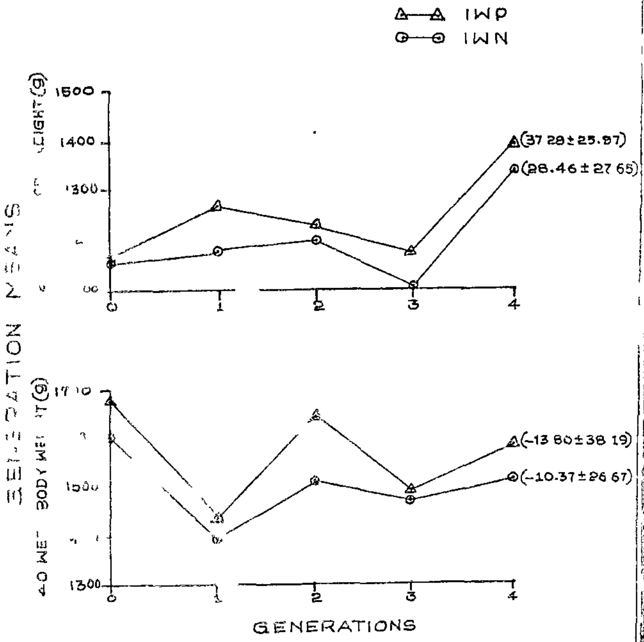

FIG. 3: CORRELATED RESPONSE IN 20 AND 40 WEEK BODY WEIGHTS

and Ahuja (1971), Gowe *et al.* (1973), Gowe (1974), Poggenpoel and Erasmus (1978), Ayyagari *et al.* (1980, 1983), Kolstad (1980), Brah and Dev (1981), Venkatramaiah (1982), Barua (1983) and Thiyagasundarum (1984) also have reported decline in age at first egg due to selection for part period egg production as observed in this study.

20-week body weight

The least square means for 20 week body weight along with standard errors and coefficient of variation have been presented in Tables 36, 37. There was gradual increase in body weight as the generation of selection advanced. The analysis of variance (Table 41) showed significant ($P < 0.01$) generation effects in both strains. Generation means were also significantly different from each other in both the strains(Table 42). The results of this study suggest that selection for part period egg number would result in concomitant increase in 20 week body weight due to positive correlation between these two traits. The mean 20 week body weights were 1342 g in IWN and 1396 g in IWP in S_4 generation compared to 1162 g in IWN and 1164 g in IWP for base population. Average response per generation (Table 38) calculated from regression of generation means on generation number was 28.46 ± 27.65 g in IWN and 37.28 ± 25.97 g in IWP. None of these regression coefficients were however significantly different from zero.

A non-significant positive change in 20-week body weight concomitant to selection on part record egg production as observed in this study was also reported by Venkatramaiah (1982), Ayyagari et al. (1983) and Mohapatra et al. (1983). Contrary to this Gowe et al. (1959a), Nordskog et al. (1967), Kinney et al. (1970), Poggenpoel and Erasmus (1978) and Thiyagasundaram (1984) reported non-significant decline in body weight due to selection on part period egg production.

40-week body weight

The least square means for 40 week body weight along with standard errors and coefficient of variation are presented in Tables 36 and 37 and Figure 3. The realized responses per generation for 40 week body weights due to selection for part period egg number were negative and non-significant in both the strains under study (Table 38). The respective values were -10.37 ± 26.67 g and -13.80 ± 38.19 g in IWN and IWP strains. The analysis of variance revealed highly significant generation effects (Table 41) both in IWN and IWP strains. Generation means for 40 week body weight also differed significantly from each other in both the strains as evident from Duncan's Multiple Range Test, except between S_2-S_4 in IWN

A non-significant decline in 40-week body weight as observed in this study was also reported by earlier workers (Gowe and Fairfull, 1980; Kolstad, 1980; Brah and Dev, 1981; Ayyagari et al., 1983; Barua, 1983 and Thiyagasundaram, 1984).

Egg weight

The least square means for egg weight along with standard errors and coefficient of variation have been summarized in tables 36, 37. The realised correlated responses per generation for egg weight due to selection for egg number were -0.28 ± 0.11 g and -0.02 ± 0.20 g in IWN and IWP strains respectively (Table 38). None of these regression coefficients were found to be statistically significant. Generation effects for egg weight were found to be significant from analysis of variance. Generation means were also found to be significantly different from each other except for S_2 and S_3, and S_2 and S_4 in IWN. Similar trend was also observed for IWP except that the mean of S_0 generation was not significantly different from S_1 and that of S_2 from S_4. Decline in egg weight due to selection for egg number was expected as egg number and egg weight are negatively correlated. Decline in egg weight as observed in this study due to selection for part period egg number was reported by Abplanalp (1956), Jerome et al. (1956), Claytor and Robertson (1966), Craig et al. (1969), Kinney (1969), Quadeer et al.(1977), Ayyagari et al. (1980, 1983), Kolstad (1980), Marks (1981), Venkatramaiah (1982), Mohapatra et al. (1983), Barua (1983)and Thiyagasundarum (1984).

Prediction of direct and correlated responses

Accuracy of prediction of response is dependent upon the reliable estimates of genetic parameters. The parameter estimates from sire components of variance pooled over generations are supposed to be more accurate and reliable than individual generation estimates (Kinney *et al.*, 1970). Hence pooled estimates were utilized for prediction of genetic response in this study. As the selection in the present study was based on Osborne's index, the formula suggested by Kinney *et al.* (1970) was used for prediction of direct and correlated responses.

The predicted and the realized gains for the selected and correlated traits are presented in Table 39. Where predicted gains are genetic gains, the realized gains are the realized phenotypic gains. As there was no means of separating genetic gains from total phenotypic gains due to want of a control population the comparison between predicted genetic gains with realized phenotypic gain is based on the assumption that environmental deviations cancel out each other over the years and hence the response calculated from regression of generation means on generation numbers is an estimate of realized genetic gains. Since its validity is questionable in short duration experiments, this part of the thesis may be considered as a theoretical exercise than actual happenings in selection experiments.

The predicted gains for egg number were 2.12 eggs in IWN and 2.49 in IWP strain (Table 39). The corresponding phenotypic realized responses were 8.30 and 6.37 eggs and were 3.92 and 2.56 times higher than the predicted responses.

The realized correlated responses followed a similar trend as far as direction is concerned with predicted genetic correlated responses for all the unselected traits under study i both strains except for 40-week body weight in IWP strain, where it was in opposite direction to the predicted gains. Further the realised correlated responses were several times higher than the predicted values due to similar reasons as stated earlier under direct response for the principal trait. The egg weight in IWP strain is the only instance of the realized responses, which was less than the predicted genetic response. The close agreement in direction between expected and realized direct responses in both the strains under study was in agreement with the findings of Kolstad (1980), Ayyagari et al. (1980, 1983), Barua (1983) and Thiyagasundaram (1984) In the studies of those workers, realised responses were also higher than the predicted even though control population was used to separate out the environmental trend.

Realized responses, however, were much smaller than predicted in the study of Poggenpoel and Erasmus (1978) and Venkatramaiah (1982).

Bohren et al. (1966) and Kinney and Shoffner (1965) expressed the view that predicted correlated responses were likely to be less accurate than the prediction of direct response itself. Poggenpoel and Erasmus (1978) observed that realised correlated response agreed well with the predicted in case of age at sexual maturity but was 13.17 times higher than the predicted for egg

Table 39. Realized and predicted gains per generation for selected and unselected traits in the strains

Strain	IWN			IWP		
Traits	Realized value	Predicted genetic gain	Realized/predicted	Realized value	Predicted genetic gain	Realized/predicted
Selected						
280 days egg production (No.)	8.30^{**}	2.12	3.92	6.37^{*}	2.49	2.56
Unselected						
Age at first egg (d)	-4.26	-0.56	7.61	-4.45	-0.91	4.89
20-week body weight (g)	28.46	2.23	12.76	37.28	9.84	3.79
40-week body weight (g)	-10.37	-6.99	1.48	-13.80	2.28	-6.05
Egg weight (g)	-0.28	-0.19	1.47	-0.02	-0.18	0.11

**, $P < 0.01$; *, $P < 0.05$

Table 40. Drift variance (σ_D^2), sampling error measurement (σ_e^2) and the relative importance (σ_D^2/σ_e^2) between σ_D^2 and σ_e^2 in the course of selection for various traits in the strains

Strain	Variances	EN	ASM	20 wk BW	40 wk BW	EW
IWN	σ_D^2	0.60	0.19	22.99	42.63	0.021
	σ_e^2	1.28	0.43	32.23	49.87	0.023
	$\frac{\sigma_D^2}{\sigma_e^2}$	0.47	0.44	0.71	0.86	0.91
IWP	σ_D^2	0.42	0.22	20.81	56.89	0.017
	σ_e^2	0.80	0.33	16.13	117.94	0.012
	$\frac{\sigma_D^2}{\sigma_e^2}$	0.53	0.67	1.29	0.48	1.42

Table 41. Analysis of variance between generations within strain

Strain	Source of variance	DF	Mean squares				
			EN	ASM	20 wk BW	40 wk BW	EW
IWH	Between generation	4	157672.23**	61074.54**	10025646.26**	5138944.4**	248.95**
	Error	5024	474.25	131.77	13267.87	21712.39	11.09
IWD	Between generation	4	65760.51**	60535.58**	9462055.35**	9659426.45**	400.35**
	Error	5378	288.23	119.53	12100.23	45137.86	11.00

**, P < 0.01

Table 42. Duncan's multiple range test between generations within strain

Traits	Strain	Means					Level of significance
		S_0	S_1	S_2	S_3	S_4	
Egg number in 280 days	IWN	58.34^a	74.76^b	85.62^c	86.73^c	93.87^d	**
	IWP	66.05^a	82.67^b	84.29^c	84.88^c	96.78^d	**, *, S_1-S_2
Age at first egg	IWN	177.34^a	161.30^b	159.38^c	165.22^d	154.09^e	**
	IWP	178.07^a	154.68^b	156.14^c	161.20^d	152.50^e	**, *, S_1-S_2
20-week body weight	IWN	1161.96^a	1179.77^b	1200.88^c	1104.69^d	1341.82^e	**
	IWP	1163.47^a	1276.56^b	1228.03^c	1184.91^d	1395.68^e	**
40-week body weight	IWN	1601.59^a	1392.57^b	1506.22^c	1477.51^d	1507.29^c	**
	IWP	1681.30^a	1432.48^b	1644.43^c	1407.67^d	1584.71^e	**
Egg weight	IWN	51.99^a	51.51^b	50.94^{cd}	50.63^d	51.05^c	**; *, S_3-S_4
	IWP	51.80^a	51.70^a	52.12^b	50.80^c	52.17^b	**; *, S_0-S_2

Horizontal means with common superscript don't differ significantly

**, $P < 0.01$; *, $P < 0.05$

weight at 14 months as a correlated response to selection [illegible] part period egg number.

Ayyagari et al. (1980, 1983) compared the predicted and realised responses in selected and correlated traits from five generations of IDS method of index selection and found that predicted and realized genetic gains were comparative in magnitude and direction in most of the traits studied.

Barua (1983) reported comparable predicted and realized selection responses in selected trait (egg number) and correlated traits. Similarly Thiyagasundaram (1984) noticed close agreement between realized and predicted direct and correlated responses both in magnitude and direction.

Realised heritability

Realized heritability estimates for the principal trait provides the most empirical description of the effectiveness of selection. In the absence of non-genetic cause of resemblance between offspring and parents and natural selection, the ratio of response to selection differential is equal to the heritability of the trait (Falconer, 1960). In selection experiments involving several generations the realised heritability is obtained by regressing cumulative response on cumulated selection differential.

Realized heritability estimates would be biased unless control deviation data are being used so as to eliminate th systemic changes due to environmental trends, inbreeding depression and random drift (Falconer, 1960). In the present experiment the inbreeding and genetic drift were found to be unimportant. But in absence of control strain, environmental trend could not be eliminated in the present study to obtain unbiased estimates of genetic gains. Hill (1972b) developed the formula for estimation of realized heritability in the absence of a control population with the assumption that common environmental variance is absent i.e. $\sigma_c^2 = 0$. But the author mentioned that when $\sigma_c^2 > 0$, in directional selection experiments without a control population, the realized heritability estimate immediately becomes less efficient.

Good agreement between estimated and realized heritabilities is not uncommon in literature (Festing and Nordskog, 1967; Carwood et al., 1978; Ayyagari et al., 1980; Venkatramaiah, 1982; Barua, 1983 and Thiyagasundarum, 1984).

In the present study the realized heritabilities were found to be 0.76 ± 0.11 in IWN and 0.53 ± 0.10 in IWP strains for the principal trait under selection (Table 43). The corresponding estimates from sire component variance pooled over generations were 0.23 ± 0.04 in IWN and 0.26 ± 0.05 in IWP strains.

Comparatively higher realized heritability values as compared to estimated values obtained in the present study suggest that the environmental trends had considerable influence over the responses realised through selection.

Table 43. Realized heritability along with standard error for egg number in IWH and IWP strains

Strain	Realized $h^2 \pm SE$ (Hill, 1972b)
IWH	0.76 ± 0.11
IWP	0.53 ± 0.10

Inter strain variation

The performances of both the strains (IWN and IWP) for various economic traits were compared by using analysis of variance in each generation to assess the interstrain tion.

The least square means along with standard errors and coefficient of variations for each strain and generation are presented in tables 36, 37. The analysis of variances between strains in each generation/trait are shown in Table 44.

Egg number

The least square means for egg number upto 280 days of age were 58.34 ± 0.75, 74.76 ± 0.57, 85.62 ± 0.85, 86.73 ± 0.47 and 93.87 ± 0.49 for IWN and 66.05 ± 0.77, 82.67 ± 0.39, 84.29 ± 0.4 84.68 ± 0.47 and 96.78 ± 0.43 for IWP strains in S_0, S_1, S_2, S_3 and S_4 generations respectively (Tables 36, 37). The respective coefficients of variation were 31.11, 27.77, 35.69, 19.29 and 19.09 percentages in IWN and 24.18, 21.59, 21.24, 19.80 and 16.3 percentages in IWP strain during S_0, S_1, S_2, S_3 and S_4 generations respectively. The c.v.s between strains in each generation were fairly similar except S_0 and S_2 of IWN which were higher than the IWP.

The mean comparison in each generation through analysis of variance revealed highly significant ($P < 0.01$) differences between strains IWN and IWP, in all the generations except in

S_2 generation where no significant difference could be observed.

Age at first egg

The least square means for age at first egg were 177.34 ± 0.74, 161.39 ± 0.25, 159.38 ± 0.30, 165.22 ± 0.34 and 154.09 ± 0.28 days for IWN and 178.07 ± 0.70, 154.60 ± 0.32, 156.14 ± 0.27, 161.28 ± 0.34 and 152.50 ± 0.27 days for IWP strain in S_0, S_1, S_2, S_3 and S_4 generations respectively. The respective coefficient of variation estimates were 10.08, 8.54, 6.74, 7.32, and 6.61 for IWN and 8.19, 6.20, 6.52, 7.51 and 6.52 for IWP strain in S_0, S_1, S_2, S_3 and S_4 generations. The magnitude of coefficient of variations in each generation was similar in both the strains. The analysis of variance indicated highly significant differences between the strains IWN and IWP in all generations except in S_0 generation, where no significant difference could be noticed.

20 week body weight

The mean 20 week body weights in grammes were 1161.96 ± 5.30, 1179.77 ± 3.37, 1200.88 ± 2.54, 1104.69 ± 3.60 and 1341.82 ± 2.97 for IWN and 1163.47 ± 5.65, 1276.56 ± 4.01, 1228.03 ± 2.64, 1184.91 ± 2.93 and 1395.68 ± 3.13 for IWP strain in S_0, S_1, S_2, S_3 and S_4 generations respectively. The coefficient of variation ranged from 7.61 to 11.60 in IWN and 8.03 to 10.05 in IWP strain in various generations, which were fairly close in magnitude in both populations under study. The analysis of variance indicated highly significant strain differences in all generations except in S_0 generation. The mean 20-week body weights were found to be consistently higher for IWP than the strain IWN.

40 week body weight

The least square means of 40 week body weight were 1601.59 ± 7.31, 1392.57 ± 3.70, 1506.22 ± 4.31, 1477.51 ± 4.28 and 1507.29 ± 3.59 g for IWN and 1631.30 ± 9.35, 1432.48 ± 5.22, 1644.43 ± 8.75, 1487.67 ± 4.00 and 1584.71 ± 3.98 g for IWP strain in S_0, S_1, S_2, S_3 and S_4 generations respectively. The coefficient of variation estimates ranged from 8.76 to 11.03 in IWN and 9.24 to 19.85 in IWP strain. The mean comparison through analysis of variance revealed highly significant differences between strains IWN and IWP in all generations except in S_3. The 40 week body weight of the IWP was higher than the strain IWN in all the generations of this study.

Egg weight

The least square means for egg weight were 51.99 ± 0.15, 51.51 ± 0.09, 50.94 ± 0.11, 50.63 ± 0.08 and 51.05 ± 0.08 for IWN and 51.80 ± 0.16, 51.70 ± 0.11, 52.12 ± 0.10, 50.80 ± 0.08 and 52.17 ± 0.09 for IWP strains in S_0, S_1, S_2, S_3 and S_4 generations respectively. The coefficient of variation in different generations ranged from 5.54 to 7.71 in IWN and 5.64 to 7.27 in IWP and were similar in magnitude in both the strains.

The results of analysis of variance (Table 44) indicated

Table 44. Analysis of variance between strains within generation

Generation	Source of variation	DF	Mean squares				
			EP	ASM	20 wk	40 wk	EW
S_0	Between strain	1	14681.99^{**}	131.62^{NS}	563.15^{NS}	1560284.62^{**}	3.92^{NS}
	Error	1010	297.93	274.41	15247.06	33844.08	11.60
S_1	Between strain	1	33723.42^{**}	23620.80^{**}	5049390.37^{**}	858503.57^{**}	19.46^{NS}
	Error	2230	385.18	84.65	14844.06	20834.63	11.10
S_2	Between strain	1	1187.25^{NS}	7045.76^{**}	494740.57^{**}	12820848.73^{**}	931.55^{**}
	Error	2686	616.43	109.18	9054.71	66752.49	14.89
S_3	Between strain	1	2200.33^{**}	9980.13^{**}	4137224.18^{**}	66363.79^{NS}	10.58^{NS}
	Error	2570	281.25	146.54	13780.45	22340.61	8.07
S_4	Between strain	1	5732.89^{**}	1711.52^{**}	1963904.74^{**}	4057631.92^{**}	849.23^{**}
	Error	2706	285.91	101.42	12604.31	19445.15	9.81

**, $P < 0.01$; *, $P < 0.05$

Table 45. Standardized realized response and correlated responses (in S.D. units) per generation in IWN and IWP over four generations of selection for egg number

Traits	Strain	
	IWN	IWP
Egg number in 280 days	0.39	0.37
Age at first egg (d)	-0.34	-0.38
20 week body weight (g)	0.24	0.34
40 week body weight (g)	-0.07	-0.07
Egg weight (g)	-0.08	-0.01

that the mean egg weights of IWP strain were higher than strain IWN in all the generations except in base generation. But the difference between two was significant only in S_2 and S_4 generations but not in S_0, S_1 and S_3 generations.

The standardized realized gains per generation (Table 45) in selected and unselected traits due to selection for egg number indicated that IWN was relatively more sensitive to IDS method of selection than IWP strain for improving egg number and reducing egg weight. Selection was however more effective in IWP strain for reducing age at first egg and improving 20 week body weight. However for 40 week body weight IDS method of selection was equally effective in both strains.

The interstrain variation as observed in this study between IWN and IWP strains for several selected and unselected traits were in agreement with the earlier reports of Poulose (1973), Jha (1975), Tripathy *et al.* (1975).

Summary

SUMMARY

The investigation reported in this thesis was undertaken with the following objectives.

1. To evaluate the response from four generations of IDS method of index selection for egg production upto 280 days of age.
2. To measure the associated changes in the unselected but correlated traits due to selection for part record egg production.
3. To estimate the genetic and phenotypic parameters for selected and unselected traits in the populations under study.
4. To measure the time trend in genetic parameters such as heritability, genetic and phenotypic correlations, and
5. To measure the interstrain variation for some of the economic traits.

In order to achieve these objectives, data collected over a period of five generations including base generation, on two single comb white Leghorn flocks maintained under All India Co-ordinated Research Project on Poultry Breeding, Kerala Agricultural University, Mannuthy, Trichur were utilised.

The chicks hatched from these two populations during 1979-80 hatch year constituted the foundation stock (base generation) for this investigation. They were subjected to four generations of IDS index method of selection for egg number upto 280 days of age, where weighted combination of individual production, sire and dam family averages were considered for selection of pullets and sire, dam family averages only for selection of cockerels.

Uniform standard managemental practices were followed throughout the experimental period.

The traits measured in each strain were egg production as number of eggs upto 280 days of age, age at first egg in days, body weight at 20 and 40-weeks of age to the nearest 10 g accuracy and average egg weight in grammes of the eggs laid between 38-40 week of age. The effective number of male and female breeders per generation were 40 and 230.4 in IWN and 39.8 and 232.2 in IWP strain respectively. The average number of pullets with complete records were 1165.8 for IWN and 1076.6 for IWP per generation. The effective population size averaged over the generations were 136.62 in IWN and 135.33 in IWP strains.

The coefficient of inbreeding increased by two per cent in both populations over four generations of selection. This, however, would be the upper limit since full and half-sib matings were intentionally avoided.

As progenies were generated in more than one hatch in each generation and most of the traits showed significant hatch effects, all the data were corrected for hatch effects before analysis by fitting least square constants.

Heritability for each of the traits and genetic, phenotypic and environmental correlations among them were estimated initially intra-generation-strain basis following variance and covariance component analysis and then pooled over generations within strain to provide mean estimates. Pooling was done as per the method suggested by Enfield *et al.* (1966).

The pooled heritability values from sire, dam and sire plus dam components of variance were 0.23, 0.23 and 0.18 for egg number, 0.22, 0.21 and 0.25 for age at first egg, 0.35, 0.32 and 0.37 for 20 week body weight, 0.42, 0.34 and 0.40 for 40 week body weight, 0.46, 0.44 and 0.51 for egg weight in IWH strain. The respective values in IWP strain were 0.26, 0.14 and 0.25 for egg number, 0.34, 0.24 and 0.27 for age at first egg, 0.64, 0.33 and 0.49 for 20-week body weight, 0.24, 0.48 and 0.38 for 40-week body weight, 0.76, 0.33 and 0.52 for egg weight. In IWP strain, sex-linked effects appeared to be important in the inheritance of egg number, 20wk body weight, egg weight and age at first egg. Maternal effects were seen to be involved in the inheritance of 40wk body weight. 40-week body weight was the only trait in IWH for which sex-linked effects appeared to be important.

The pooled genetic correlations from sire, dam, sire plus dam components and phenotypic correlation respectively were -0.57, -0.22, -0.35 and -0.14 between egg number and egg weight; -0.87, -0.81, -0.81 and -0.51 between egg number and age at first egg; 0.25, 0.57, 0.38 and 0.25 between egg number and 20-week body weight; -0.51, 0.06, -0.07 and 0.04 between egg number and 40-week body weight; -0.41, -0.55, -0.30 and -0.29

between age at first egg and 20-week body weight; 0.33, -0.23, 0.19 and 0.01 between age at first egg and 40 week body weight; 0.39, 0.02, 0.11 and 0.08 between age at first egg and egg weight; 0.32, 0.39, 0.33 and 0.13 between 20-week body weight and egg weight; 0.54, 0.52, 0.49 and 0.24 between 40 week body weight and egg weight; 0.78, 0.77, 0.75 and 0.48 between 20-week and 40-week body weights in IWH strain. The respective values in IWP strain were -0.28, -0.59, -0.28 and -0.13 between egg number and egg weight; -0.74, -0.91, -0.70 and -0.48 between egg number and age at first egg; 0.59, 0.22, 0.52 and 0.22 between egg number and 20-week body weight; 0.14, -0.03, 0.06 and -0.01 between egg number and 40-week body weight; -0.40, -0.23, -0.46 and -0.32 between age at first egg and 20-week body weight; 0.09, -0.21, 0.37 and 0.001 between age at first egg and 40-week body weight; -0.04, 0.04, -0.04 and 0.04 between age at first egg and egg weight; 0.41, 0.54, 0.39 and 0.20 between 20 week body weight and egg weight; 0.46, 0.31, 0.30 and 0.20 between 40 week body weight and egg weight; 0.87, 0.70, 0.83 and 0.52 between 20 week and 40 week body weights.

The time trend of the heritability estimates from the sire component for egg production was positive for IWH whereas it was negative for IWP strain. However, reverse trends were observed from the dam component.

Similarly the rate of change in genetic correlations from sire component between different traits revealed positive trend for IWN except between egg number - age at first egg whereas negative trends were observed for IWP strain. But from dam component IWN showed negative trends in genetic correlations except for egg number - 40 week body weight whereas IWP strain indicated positive trends except for egg number - age at first egg and egg number - 20 week body weight. The phenotypic correlations followed similar trend as that of genetic correlation from sire component except in IWP between egg number - age at first egg and in IWN between egg number - 20 week body weight. None of these regression values were statistically significant. The results indicated that the genetic parameter estimates did not show any significant change due to four generations of selection in both the populations under study.

The selection intensity averaged over generations were 0.50 S.D. and 0.70 S.D. for egg number, -0.41 S.D. and -0.37 S.D for age at first egg, 0.34 S.D. and 0.35 S.D. for 20 week body weight, -0.002 S.D. and 0.080 S.D. for 40 week body weight, -0.06 S.D. and -0.02 S.D. for egg weight in IWN and IWP strains respectively. Comparison of the effective and expected selection differentials revealed that natural selection was unimportant for egg number, age at first egg, 20 week body weight for the two strains under study. However, for 40-week body weight and egg weight natural selection was operating against artificial selection, for strain IWN but only for egg weight in case of strain IWP.

The least square means for egg number were 58.34, 74.76, 85.62, 86.73 and 93.87 for IWN and 66.05, 82.67, 84.29, 84.88 and 96.78 for IWP strains in S_0, S_1, S_2, S_3 and S_4 generations respectively. The realized phenotypic response per generation obtained from regression of generation means on generation numbers were 8.30 ± 1.60 eggs in IWN and 6.37 ± 1.60 eggs in IWP strains. Both the regression coefficients were significantly different from zero. The average correlated response per generation for age at first egg, 20 and 40 week body weights and egg weight due to selection for part period egg number were -4.26 d, 28.46 g, -10.37 g, -0.28 g in IWN strain and -4.45 d, 37.28 g, -13.80 g, -0.02 g in IWP strain.

Although similar in direction, the predicted response for egg number fell short of the realized response and this was consistent in both the populations under study. Realized gains for egg number were found to be 3.92 and 2.49 times higher than the predicted responses in IWN and IWP strain respectively. The realized gains in unselected traits agreed well with the predicted responses in direction but not in magnitude, except for 40 week body weight of IWP strain which was in opposite direction. For all traits the realized gains were found to be higher than the predicted gains except egg weight of IWP strain which was less than the predicted response.

The realized heritability estimates for egg number were 0.76 ± 0.11 in IWN and 0.33 ± 0.10 in IWP strains. These estimates were substantially higher than the estimated values.

Differences were highly significant between the two strains for all the traits under study in all the generations except S_2 for egg number, S_0 for age at first egg and 20 week body weight, S_3 for 40 week body weight and S_0, S_1 and S_3 for egg weight.

The results of the presented study can be summarised in the following manner.

a) The genetic parameters like heritabilities, genetic and phenotypic correlation estimates were consistent with the several earlier reports.

b) The heritabilities, genetic and phenotypic correlations did not show any significant time trend due to four generations of selection for part record egg number.

c) The realized phenotypic gains per generation due to IDS method of index selection for egg number in both the strains were statistically significant.

d) The realized phenotypic responses per generation in unselected traits due to selection for part period egg number were in the desirable direction in both strains but none of those correlated responses were statistically significant.

e) The realized direct and correlated responses in both strains were in agreement with the predicted values in direction but not in magnitude.

f) The realized values were higher than the predicted values due to confounding effect of genotype and environment.

g) Analysis of variance within generation revealed significant interstrain variation for almost all the traits. The standardised realised gains indicated higher effectiveness of the index method of selection in IWH than IWP strain for improving egg production upto 280 days of age.

From the various results obtained in the present study it can be concluded that significant improvement in egg number upto 280 days of age with decline in age at first egg and improvement in 20 week body weight without affecting significantly the 40-week body weight and egg weight could be obtained. On the basis of these results the following suggestions can be made.

a) The present selection system should be continued till genetic variabilities for egg production are completely exhausted.

b) The decline in egg weight observed in both the strains has to be effectively checked and steps initiated to improve egg weight in subsequent generations. This may be achieved by incorporating egg weight component to the present single trait multisource (TMS) selection index or as an alternative independent culling level for egg weight may be imposed along with the present selection system.

c) A suitable random bred control population is felt as mandatory in order to assess the trends in test environments so that actual genetic gains can be quantified.

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SELECTION STUDIES IN CHICKEN FOR EGG NUMBER ON PART RECORDS

BY

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ABSTRACT

All India Co-ordinated Research Project on Poultry Breeding for egg located at Kerala Agricultural University, Mannuthy, Trichur is maintaining two strains of White Leghorn which are subjected to selection for high egg production since 1978. The criterion of selection has been the method of index selection by combining the information on sire and dam family averages with the individual's performance, for egg number upto 280 days of age.

The present investigation was planned with the following objectives.

- To evaluate the response of intrapopulation selection for part period egg production.
- To estimate the genotypic and phenotypic parameters for different traits.
- To evaluate the correlated responses in unselected traits.
- To measure the time trend in genetic parameters.
- To measure the interstrain variation for some economic traits.

To achieve these objectives data collected over a period of five generations, including base generation, on the experimental populations were utilized.

Chicks hatched during 1979-80 hatching year of each strain constituted the foundation stock (G_0). Thereafter both strains were subjected to four generations of selection.

Standard managemental practices were followed uniformly throughout the experimental period.

The traits measured were egg number upto 280 days of age (EP), age at first egg in days (AFE), body weight in grammes at 20 and 40 weeks of age (20 wk-40 wk BW) and egg weight (EW) in grammes at 38-40 weeks of age.

The average effective number of male breeders, female breeders and progenies with complete records were 40, 230.4 and 1165.8 in IWH and 39.8, 232.7 and 1076.6 in IWP strains, respectively, over generations.

The effective population size over generations were 135.62 in IWH and 135.33 in IWP strains. The coefficient of inbreeding increased by two per cent in both populations over four generations of selection which would be the upper limit due to intentional avoidance of sib matings.

Since hatch effects were significant for most of the traits, data were corrected for hatch effects before analysis by fitting least square constants.

The heritability of each trait and correlations between traits were estimated initially intra generation - strain basis following variance and covariance component analysis and then pooled over generations within strain to provide mean estimates.

The heritability estimates of various traits obtained in this study were consistent with several earlier reports. Sex-linked effects appeared to be important in the inheritance of EP, 20WK BW, EW and ASM in IWP strain whereas maternal effects were important for 40WK BW. But sex-linked effects for 40 week BW appeared to be important in IWN.

The genetic and phenotypic correlations of the present study were close to several earlier reports both in direction and magnitude.

The genetic parameter estimates did not show any significant time trends due to four generations of selection in both populations. The realised phenotypic response per generation obtained from regression of generation means on generation number were 8.30 ± 1.60 eggs in IWN and 6.37 ± 1.60 eggs in IWP strains, which were significantly different from zero.

The correlated responses per generation for ASM, 20 wk BW, 40 wk BW and EW due to selection for part period egg number were -4.26 d, 28.46 g, -10.32 g, -0.28 g in IWN and -4.45 d, 37.28 g, -13.80 g, -0.02 g in IWP strains, respectively.

The realised gains in selected and unselected traits agreed well with the predicted responses in direction but not in magnitude, except 40 wk BW in IWP which was in opposite direction. For all the traits the realized gains were found to be higher than the predicted gains except [illegible] of the [illegible] which was less than the predicted response.

Differences were not significant between the two selection for all the traits under study in the generations except S_2 for [illegible]; S_0 for [illegible], 20 wk wt; S_3 for 40 wk wt; S_0, S_1 and S_3 for [illegible].