Applied Biological Research 17(3): 250-258; (2015)
DOI: 10.5958/0974-4517.2015.00036.1

ESTIMATES OF GENETIC TRAITS IN SILKWORM (*Bombyx mori* L.) UNDER TEMPERATE CONDITIONS OF KASHMIR

Masarat Bashir*, Afifa. S. Kamili, M. Ashraf Bhat[1] and S.A. Mir[2]

Temperate Sericulture Research Institute, S.K. University of Agricultural Sciences & Technology of Kashmir (SKUAST-K), Mirgund, Baramulla, Jammu & Kashmir (India)
[1]Division of Genetics & Plant Breeding, [2]Division of Agri-Statistics, SKUAST-Kashmir, Shalimar, Srinagar - 190 025, Jammu & Kashmir (India)
*e-mail: *masarat.bashir4@gmail.com*

(Received 6 March, 2015; accepted 5 September, 2015)

ABSTRACT

The genetic parameters, trait association and path coefficient analysis between silkgland weight and its attributes of 10 silkworm genotypes were studied during spring and summer seasons of 2010-11 at TSRI, SKUAST-Kashmir (Mirgund). The genotypes exhibited wide range variability for all the traits studied. High heritability accompanied by moderate to high genotypic coefficient of variation and genetic gain were observed for filament length, shell ratio, single shell weight and filament size. Correlation studies indicated that during spring season, silkgland weight showed positive and significant correlation with shell ratio, while it showed significantly negative association with silkgland somatic index, while during summer season it showed significant positive association with all the traits except silk conversion index. The silkgland attributes exhibited varied magnitude of direct effects on silkgland weight during both spring and summer season. During summer season single shell weight showed the highest direct positive effect on silkgland weight which was followed by the filament length, while during spring season, highest positive direct effect on silkgland weight was exhibited by cocoon shell percentage(3.574) and single shell weight (3.346).

Key words: *Bombyx mori*, correlation, genetic advance, heritability, path coefficient analysis

INTRODUCTION

Silk is a functional term used to describe protein fibers that are secreted by arthropods. It is a natural protein fiber and is very soft, lustrous, smooth, strong and durable than any natural or artificial fibre (Shao and Vollrath, 2002). The growth and development of silkworm (*Bombyx mori* L) is greatly influenced by environmental conditions. The biological as well as cocoon related traits are influenced by ambient temperature, rearing seasons, and genetic constitution of silkworm strains (Rajesh and Elangovan, 2010). Different seasons affect the performance of silkworm. The seasonal differences in the environmental components considerably affect the genotypic expression in the form of phenotypic output such as cocoon weight, shell weight and cocoon cocoon shell percentage (Nagalakshmamma and Naga Jyothi, 2010). Among the different components of sericulture the breeds of silkworm play an important role in improving the productivity and quality of silk (Kumar *et al*., 2012). Genetic variability is a prerequisite for an effective selection of any economically important species, and a critical survey of genetic variability is essential aiming at developing high yielding breeds (Akanda *et al.,* 1998). In silkworm breeding numerous traits are considered important in enhancing the profit of silk producers and other sections of sericulture industry.

Correlation and heritability studies of quantitative traits are a pre-requisite for judicious selection and for genetic improvement of complex traits of economic importance. The success of selection is governed by the degree to which the desired traits are transmitted to the succeeding generation. The nature of selection is to be given due consideration at appropriate developmental stages for pursuing selection in desired direction while improving or evolving high productive breeds or hybrids of silkworm. Characters showing high heritability as well as high genetic advance respond better to simple phenotypic selection while those having low heritability and low genetic advance respond better to mass selection. Singh and Mohan (2011) reported that the characters showing high heritability and high genetic advance respond better to phenotypic selection. For selection under different environmental conditions, the quantitative and qualitative traits and heritability are most important tools in improving silkworm productivity (Naseema *et al.,* 2007; Reza *et al*., 2014). The present study was aimed to identify the variability, correlation and path coefficient estimates of economically important traits during spring and summer seasons and to determine the characteristics contributing to silkgland weight in silkworm.

MATERIALS AND METHODS

Ten popular pure races of silkworm (*Bombyx mori* L.) namely SK-6, Dun-22, SK-24, SK-34, SK-30. SK-1, SK-13, SK-28, CSR-2 and SK-31 were selected for the present study. These races were procured from the Germplasm Bank of Temperate Sericulture Research Institute, Mirgund, SKUAST-Kashmir whereas races CSR-2 and Dun-22 were procured from Central Sericultural Research and Training Institute, Pampore (Kashmir). The larvae were reared cellularly under standard rearing conditions (Krishnaswami, 1978) during spring and summer seasons of 2010-11. The experiment was laid out in a completely randomized block design with each treatment replicated three times. The data were recorded on eight traits *viz*., silk gland weight, single cocoon weight, single shell weight, shell ratio, filament length, filament size (denier), silkgland somatic index and silk conversion index. Standard statistical procedure were used for the analysis of variance, genotypic and phenotypic coefficients of variation (Burton, 1952), heritability (Hanson *et al*., 1956) and genetic advance (Johnson *et al*., 1955). The genotypic and phenotypic correlation coefficients were computed using genotypic and phenotypic variances and co-variances (Al-Jibouri *et al*., 1958). The path coefficient analysis was done by the method of Dewey and Lu (1959).

Correlation coefficients

Correlation coefficients were calculated phenotypic (r_p), genotypic (r_g) and environmental (r_e) level using the formulae suggested by Al-Jibourie *et al*. (1958).

$$r_{p12} = \frac{Cov_{p12}}{\sqrt{\text{var}_{p11}\ x\ \text{var}_{p22}}}$$

Where, Cov_{p12} = Phenotypic covariance of character X_1 and X_2; Var_{p11} = Phenotypic variance of character X_1; and Var_{p22} = Phenotypic variance of character X_2

$$r_{g12} = \frac{Cov_{g12}}{\sqrt{\text{var}_{g11}\ x\ \text{var}_{g22}}}$$

Where, Cov_{g12} = Genotypic covariance of character X_1 and $X_{2;}$ Var_{g11} = Genotypic variance of character $X_{1;}$ Var_{g22} = Genotypic variance of character X_2

$$r_{e12} = \frac{Cov_{e12}}{\sqrt{\text{var}_{e11}\ x\ \text{var}_{e22}}}$$

Where, Cov_{e12} = Error covariance of character X_1 and $X_{2;}$ Var_{e11} = Error variance of character $X_{1;}$ Var_{e22} = Error variance of character $X_{2.}$

Path coefficient analysis

The estimates of direct and indirect contribution of various characteristics to silkgland weight were calculated through path coefficient analysis as suggested by Wright (1921) and elaborated by Dewey and Lu (1959). The following set of simultaneous equation was formed and solved for estimating various direct and indirect effects:

$r_{1y} = P_{1y} + r_{12}\ P_{2y} + r_{13}\ P_{3y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots + r_{11}\ P_{iy}$
$r_{2y} = P_{2y} + r_{21}\ P_{1y} + r_{23}\ P_{3y} \ldots\ldots\ldots\ldots\ldots\ldots\ldots + r_{21}\ P_{iy}$
$r_{iy} = r_{11}\ P_{1y} + r_{12}\ P_{2y} + r_{13} + P_{3y} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + r_1\ P_{iy}$

Where, r_{1y} to r_{iy} = Coefficients of correlation between casual factors 1 to i and dependent character y.
r_{12} to $r_{1\text{-}1}$ = Causal factors
P_{1y} to P_{iy} = Direct effect of characters 1 to i on character y.

Then direct effects were calculated as follows:

$P_{1y} = \Sigma_1 = 1$ $C_{11}\ r_{iy}$
$P_{2y} = \Sigma_1 = 1$ $C_{21}\ r_{iy}$
$P_{iy} = \Sigma_1 = 1$ $C_{11}\ r_{iy}$

Residual effect which measures the constitution of the characters not considered in the causal scheme was obtained as:

Residual effect (PRY) = 1-R_2

Where, R2 = $\sum pp_{iy}^2 + 2\sum_i\sum_j P_{iy} P_{jy} r_{ij}$; i = 1; i = $\dot{j}y$; i < $\dot{j}$; P= Number of characters

RESULTS AND DISCUSSION

The improvement via breeding programme is dependent on the availability of information on genetic variability. The observed variability is normally due to the variation in qualitative and quantitative heritability fractions influenced considerably by prevailing environmental condition. It is, therefore, desirable to study the nature of exhibited variability and to exploit same in the breeding programmes. Pooled analysis of variance for studied traits has been presented in Table 1. The effect of genotype, environment and genotype environment interaction were highly significant and revealed broad spectrum of variability in the experimental material. Similar results on varietal diversity have been earlier reported by Darmand *et al.* (2011) and Ahsan and Rahman (2008). Variability in population, especially with respect to the characters for which improvement is sought, is prerequisite for successful breeding programme. The estimates of phenotypic coefficient of variation (PCV) in general were higher than the estimates of genotypic coefficient of variation

(GCV) for all the traits studied, which suggested that the apparent variation is not only due to the genotypes but also due to the influence of environment. The estimates of genotypic coefficient of variation ranged from 8.74 to 25.43 (Table 2). The value was highest for single shell weight (25.43) followed by filament size (17.66), cocoon shell percentage (14.31) and filament length (14.06). This is indicative of less amenability of these traits to environmental fluctuations and hence greater emphasis should be given to these characters while breeding from the present material. The lowest genotypic coefficient of variance was recorded in single cocoon weight (8.74) followed by silkgland

Table 1: Pooled analysis of variance for silkgland weight and its attributes in *Bombyx mori* L.

		Mean squares							
Source of variation	df	Silk gland weight (g)	Single cocoon weight (g)	Single shell weight (g)	Cocoon shell percentage (%)	Filament length (m)	Filament size (denier)	Silkgland somatic index (%)	Silk conversion index (%)
Environment (E)	1	72.82**	0.273**	0.105**	171.400**	357132**	0.454**	11.62**	20.324**
Genotype (G)	9	7.58**	0.166**	0.043*	42.075*	118929**	0.966*	35.95*	43.146**
G x E	9	0.45*	0.002*	0.001*	2.453*	5732**	0.176*	3.27**	3.806*
Error	40	0.98	0.017	0.003	1.240	212	0.108	1.17	3.500

weight (9.03) and silkgland somatic index (9.09), while rest of the characters exhibited moderate genotypic coefficient of variation (GCV). The estimates of phenotypic coefficient of variation (PCV) followed almost similar trend. The magnitude of PCV ranged from 11.68 for silkgland weight to 30.26 for single shell weight (Table 2). The characters with high PVC indicated more influence of environmental factors. Therefore, caution has to be exercised during the selection program because the environmental variations are unpredictable in nature and may mislead the results. The present findings are in close agreement with Jaiswal and Goel (2006), Moorthy *et al*. (2006), Moorthy *et al*. (2009), Mandal *et al*. (2009) and Pal and Moorthy (2011).

The coefficient of variability does not give any idea regarding heritable portion of variability. It can be ascertained by working out the heritability estimates. In present study, encouraging results were obtained with respect to the heritability of the characters studied; except for single cocoon weight. The heritability estimates ranged from 54.1 to 98.1 (Table 2). Estimates of heritability (bs) were high (>60%) for all the traits, except single cocoon weight and silkgland weight which suggested that the characters are least influenced by the environmental factors and also indicates the dependence of phenotypic expression which reflects the genotypic ability of cultivars to transmit the genes to their off-springs. The lowest value of heritability recorded for single cocoon weight (54.1) and silkgland weight (59.8) indicated that these characters are highly influenced by environmental effects and genetic improvement through selection will be difficult. The above findings are in agreement with Moorthy *et al*. (2010) and Kumar and Basavaraja (2011). Though the heritability estimates indicate the efficiency of selection system, yet their scope is restricted as they are prone to change with environment and breeds. The values of genetic advance as percent mean ranged from as low as13.24 for single cocoon weight to as high as 44.01 for single shell weight (Table 2). In general, the expected genetic advance as per cent mean for majority of traits was high, which indicates that traits are governed by additive genes and selection will be rewarding for improvement of each trait. High heritability coupled with high genetic advance were recorded for filament length, cocoon shell percentage and single shell weight, which suggested that these traits are governed by additive genes (Panse, 1957) and thus could be improved upon by adapting selection without progeny testing. High heritability with low genetic advance was observed for silk-gland somatic index and silk conversion index which indicated the presence of non-additive type of gene action. The above results are in conformity with the findings of Moorthy *et al*. (2010) and Pal and Moorthy (2011).

Table 2: Estimate of mean, components of variance, heritability (broad sense) and expected genetic advance in respect of 8 characters in *Bombyx mori* L. (Pooled data)

Characters	Mean	Coefficient of variation		Heritability (bs)	Genetic advance (GA)	Expected genetic gain (% of mean)
		GCV	PCV			
Silk gland weight (g)	11.36	9.03	11.68	59.8	1.66	14.39
Single cocoon weight (g)	1.67	8.74	11.88	54.1	0.22	13.24
Single shell weight (g)	0.32	25.43	30.26	70.6	0.14	44.01
Cocoon shell percentage(%)	18.88	14.31	15.21	88.6	5.24	27.75
Filament length (m)	893.70	14.06	14.19	98.1	256.36	28.69
Filament size (denier)	2.40	17.66	22.16	63.5	0.69	28.98
Silkgland somatic index (%)	27.90	9.09	9.93	83.9	4.79	17.16
Silk conversion index (%)	28.15	11.21	13.13	73.0	5.56	19.73

Table 3: Correlation between silkgland and some economic traits of silkworm (*Bombyx mori* L.) in spring season

Characters	Silk gland weight	Single cocoon weight	Single shell weight	Cocoon Shell (%)	Filament length	Filament size	Silkgland somatic index	Silk conversion index
Silk gland weight	1.000	0.230	0.078	0.228	0.160	0.183	-0.263	0.129
Single cocoon weight		1.000	0.518**	0.577**	0.543**	0.309	0.350	-0.091
Single shell weight			1.000	0.738**	0.668**	0.423*	0.485**	-0.213
Cocoon shell percentage				1.000	0.793**	0.384*	0.488**	-0.140
Filament length					1.000	0.491**	0.509**	-0.284
Filament size						1.000	-0.013	0.381*
Silkgland somatic index							1.000	-0.587**
Silk conversion index								1.000

The study of inter-relationship of various characters in the form of correlation is in fact, one of very important aspect in selection programme .Knowledge of nature and magnitude of associations among different characters are important on three accounts that indirect selection is important when desirable characters have low heritability measure in one sex only. Knowledge of correlation is required when selection is to be made on the several characters at a time though some simultaneous selection model (Singh, 1972). Even if, the objective is to make selection on a single trait, the knowledge of correlation is essentials to avoid the undesirable related changes in other characters. In the present findings during spring season, silkgland weight showed positive and significant correlation with shell ratio, while it showed significantly negative association with silkgland somatic index (Table 3). Among the significant *inter se* association, the strong positive association were observed between single cocoon weight with single shell weight, cocoon shell percentage and filament length, single shell weight with cocoon shell percentage, filament length, filament size and silkgland somatic index, cocoon shell percentage with filament length, filament size and silkgland somatic index and filament length with filament size and silkgland somatic index. Silk conversion index exhibited negative association with almost all the characters; however, there was one exception to this that it showed significant positive association with filament length. Rest of the characters exhibited positive but non-significant association with silkgland weight. During the summer season silk gland weight showed significant positive association with all the traits except silk conversion index where it exhibited negative association (Table 4). The *inter se* associations followed the same trend of association as observed during spring season. When two characters are correlated due to common genetic or common environmental factors, the parameters estimating the co-variance between two characters are termed as genetic correlation. Hence,

Table 4: Correlation between silkgland and some economic traits of silkworm (*Bombyx mori* L.) in summer season

Characters	Silk gland weight	Single cocoon weight	Single shell weight	Cocoon Shell (%)	Filament length	Filament size	Silkgland somatic index	Silk conversion index
Silk gland weight	1.000	0.543**	0.651**	0.617**	0.708**	0.402*	0.593**	-0.355
Single cocoon weight		1.000	0.598**	0.624**	0.677**	0.496**	0.284	-0.260
Single shell weight			1.000	0.670**	0.709**	0.521**	0.727**	-0.358
Cocoon shell percentage				1.000	0.789**	0.607**	0.493**	0.009
Filament length					1.000	0.661**	0.627**	-.0423*
Filament size						1.000	0.294	-0.022
Silkgland somatic index							1.000	-0.415*
Silk conversion index								1.000

*, ** Correlation is significant at 0.05 and 0.01 level, respectively

Table 5: Direct effects (bold values) and indirect contribution of different traits towards silkgland weight in 10 genotypes of silkworm during summer season

Characters	Single cocoon weight	Single shell weight	Cocoon Shell (%)	Filament length	Filament size	Silkgland somatic index	Silk conversion index	Correlation with silkgland weight
Single cocoon weight	0.277	0.261	0.268	0.267	0.287	0.155	-0.142	0.543**
Single shell weight	0.941	0.998	0.869	0.855	0.700	0.939	-0.465	0.651**
Cocoon shell percentage	-0.323	-0.291	-0.334	-0.282	-0.301	-0.191	0.053	0.617**
Filament length	0.814	0.721	0.711	0.842	0.719	0.561	-0.443	0.708**
Filament size	-0.571	-0.387	-0.496	-0.472	-0.552	-0.227	-0.011	0.402*
Silkgland somatic index	-0.122	-0.205	-0.125	-0.145	-0.089	-0.218	0.113	0.593**
Silk conversion index	-0.050	-0.046	0.015	-0.052	0.002	-0.051	0.098	-0.355

Residual effect - 1.165

knowledge of correlation between such characters is essential while aiming at rational improvement in silk yield through selection, so that the antagonistic correlations may not nullify the expected regress under selection programme. Many workers have analyzed correlation between different traits in silkworm on the basis of quantitative traits (Kumar *et al*., 2006, Kumaresan *et al*., 2007, Rama Mohana Rao *et al*., 2008, Mohan *et al*., 2009, Shabdini *et al*., 2011).

The study of correlation alone is often misleading as the correlation observed may not be always true. Two characters may show correlation just because they are correlated with a common third trait. In such cases, it becomes necessary to study a method, which takes into account the casual relationship between the variables in addition to the degree of relationship. The partitioning of total correlation into direct and indirect effects provides actual information on contribution of characters and thus forms the basis for selection for improvement in yield. The direct and indirect effects of various characters on silkgland weight followed almost similar trend, hence the results have been discussed only at phenotypic level. In general different silkgland attributes exhibited varied magnitude of direct effects on silkgland weight during both spring and summer season. It was observed that during summer season (Table 5, Fig. 1) single shell weight had the highest direct positive effect on silkgland weight (0.998). This was followed by the filament length (0.842) and single cocoon weight (0.277) while filament size exhibited highest negative direct effect (-0.552) on silkgland weight. The positive direct effect means a slight increase in any one of above traits may directly contribute towards silkgland weight. During spring season (Table 6, Fig. 2) most of the traits showed negative direct effect on silkgland weight. Among them the highest value was shown by

Table 6: Direct effects (diagonal) and indirect contribution of different traits towards silkgland weight in 10 genotypes of silkworm (*Bombyx mori* L.) during spring season

Characters	Single cocoon weight	Single shell weight	Cocoon Shell (%)	Filament length	Filament size	Silkgland somatic index	Silk conversion index	Correlation with silkgland weight
Single cocoon weight	-4.671	-4.144	-4.809	-3.684	-2.899	-1.941	0.790	0.230
Single shell weight	2.968	3.345	3.548	2.819	1.990	2.830	-1.289	0.078
Cocoon shell percentage	3.680	3.791	3.574	3.137	2.131	2.157	-1.391	0.228
Filament length	-0.564	-0.603	-0.628	-0.715	-0.504	-0.404	0.268	0.160
Filament size	0.354	0.339	0.340	0.402	0.570	-0.022	0.349	0.183
Silkgland somatic index	-1.084	-2.206	-1.574	-1.472	0.102	-2.607	1.908	-0.263
Silk conversion index	0.234	0.532	0.537	0.519	-0.846	1.011	-1.380	0.129

Residual effect - 0.518

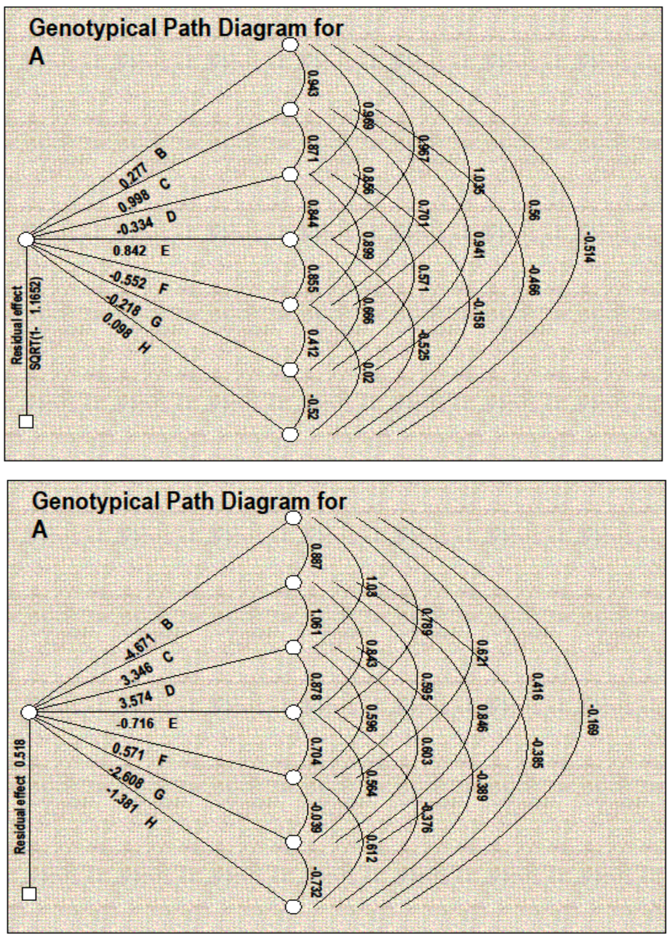

Fig. 1: Path diagram representing cause and effect relationships between silk gland weight and its associated traits during summer season (above) spring season (below); A - silk gland weight (g); B - single cocoon weight (g); C - single shell weight (g); D - cocoon shell (%); E - filament length (m); F - filament size (denier); G - silkgland somatic index (%); and H - silk conversion index (%)

single cocoon weight (-4.67) which was followed by silk-gland somatic index (-2.61), silk conversion index (-1.38) and filament length (-0.716) which suggested that selection directly towards these traits may not be rewarding since these traits had negative direct effect. Earlier, similar results were also reported by Kumaresan *et al*. (2007) and Pal and Moorthy, (2011). The highest positive direct effect on silkgland weight was exhibited by cocoon shell percentage (3.574), single shell weight (3.346) and filament size (0.571). The residual effect to silkgland weight was 1.1652 and 0.518 during summer and spring seasons, respectively, (Fig. 1 and 2). The overall results of path analysis are in conformity with the earlier reports of Mohan *et al*. (2009).

Conclusion: The correlation between different traits and degree of its manifestation should be taken into account while performing selection. High heritability compiled with high genetic advance were recorded for filament length, cocoon shell percentage and single shell weight which suggested that these traits were governed by additive genes and could be improved by proper selection procedure.

REFERENCES

Ahsan, M.K., and Rahman, S.M. 2008. Genetic variability and correlation analysis in hybrids of mulberry silkworm, *Bombyx mori* L. for egg characters. *University Journal of Zoology Rajshahi University,* **27**: 13-16.

Akanda, M.A.L., Alam, M.S. and Uddin, M.M. 1998. Genetic variability, correlation and path analysis in composite maize. *Bangladesh Journal of Agricultural Research,* **23**: 107-113.

Al-Jibouri, H.A., Miller, R.A. and Robinson, H.F. 1958. Genetic environmental variances and covariances in an upland cotton cross interspecific origin. *Agronomy Journal,* **50**: 633-636.

Burton, G.W. 1952. Quantitative inheritance in grasses. *Proceeding of Sixth International Grassland Congress,* **1**: 277-288.

Darmand, S., Lavvaf, A., Seidavi, A. R., Eila, N., Nematollahian S. and Farahvash, T. 2011. Estimation of genetic parameters in three commercial silk-worm lines of Iran. *African Journal of Biotechnology,* **10**(61): 13324-13330.

Dewey, D.R. and Lu, H.R. 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agronomy Journal,* **51**: 515-518.

Hanson, C.H., Robinson, H.F. and Comstock, R.E. 1956. The biometrical studies on yield in segregating population of korian lespedeza. *Agronomy Journal,* **48**: 268-272.

Jaiswal, K. and Goel, R. 2006. Studies on cocoon shapes in most popular mulberry silkworm race of Uttaranchal different seasons of Uttar Pradesh. pp. 57. **In**: *National Conference on New Strategies in Research and Development of Sericulture – Indian Perspective.* 9-10th March, 2006. Department of Sericulture, Jnanabharathi, Bangalore University, Bangalore, Karnataka India.

Johnson, H.W., Robinson, H.F. and Comstock, R.E. 1955. Estimation of genetic and environmental variability in soybean. *Agronomy Journal,* **47**: 314-318.

Krishnaswami, S. 1978. New technology of silkworm rearing. *Bulletin of Central Sericultural Research and Training Institute, Mysore*. **2**: 1-23.

Kumar, K.C.M. and Basavaraja, H.K. 2011. Synthesis of bivoltine silkworm breeds of *Bombyx mori* L. with longer and thin cocoon filament. pp. 66-67. **In**: *Indian Abstracts of Golden Jubilee National Conference on Sericulture Innovations - Before and Beyond*. 28-29th January 2011, CSRTI, Mysore, Karnataka, India.

Kumar, S. N., Basavaraja, H.K., Joge, P.G., Mal Reddy, N., Kalpana G.V. and Dandin, S.B. 2006. Development of a new robust bivoltine hybrid (CSR46 x CSR47) of *Bombyx mori* L. for the tropics. *Indian Journal of Sericulture*, **45**: 21-29.

Kumar, T., Bhattacharya, S., Morthy, M.S. and Kunda, K. 2012. Breeding and isozyme variability of a superior multivoltine strain of *Bombyx mori* L. *Iranain Journal of Entomology,* **2**: 1-6.

Kumaresan, P., Koundinya, P.R., Hiremath, S.A. and Sinha, R.K. 2007. An analysis of genetic variation and divergence on silk fibre characteristics of multivoltine silkworm (*Bombyx mori* L.) genotypes. *International Journal of Industrial Entomology*, **14**: 23-32.

Mandal, K., Moorthy, S.M., Das, N.K., Das, S.K., Bajpai, A.K. and Sahu C. 2009. An analysis of genetic diversity in bivoltine silkworm, *Bombyx mori* L. pp.150. **In**: *Indian National Conference on Vanya Silk.* 2-3rd Feb., 2009, CMERTI, Jorhat, Assam, India.

Mohan, B., Balachandran, N., Muthulakshmi, M., Hiremath, S.A., Srinivasa Babu, G.K.S. and Kamble, C.K. 2009. Cocoon size variables vis-a-vis reeling traits of silkworm (*Bombyx mori* L.) germplasm. *Madras Agricultural Journal,* **96**: 411-415.

Moorthy, S.M., Das, S.K., Rao, P.R.T., Debnath, S and Raje Urs, S. 2006. Genetic variability and selection index of some quantitative traits of bivoltine Silkworm, *Bombyx mori* L. *Indian Journal of Genetics and Plant Breeding,* **66**: 82-84.

Moorthy, S.M., Mandal, K., Das, N.K., Kar, N.B. and, Das, S.K., 2010. Genotypic variability and genotype × environment interactions in bivoltine silkworm genotypes of *Bombyx mori*. pp.10. **In**: *National Symposium on Deccan Biodiversity Co-existance of Funal Species in Changing Landscapes*. 2-3rd Dec., 2010, Osmania University, Hyderabad, Andhra Pradesh, India.

Nagalakshmamma, K. and Naga Jyothi, P. 2010. Studies on commercial exploitation of selected multivoltine races of the silkworm *Bombyx mori* L. in different seasons of Rayalaseema region (a. p.) in india. *The Bioscan*, **5**: 31-34.

Naseema, B.A., Basavaraja, H.K., Palit, A.K. and Ramaswmy, G.N. 2007. Seasonal variation in cocoon filament size deviation in the bivoltine silkworm, *Bombyx mori* L. *Indian Journal of Sericulture,* **46**: 153-162.

Pal, N.B., Moorthy, S.M., Khan, M.Z, Das, N.K, Mandal, K. 2011. Analysis of genetic diversity in some multivoltine silkworm genotypes of *Bombyx mori* L. pp.68. **In**: *Indian Golden Jubilee National Conference on Sericulture Innovations: Before and Beyond*. 28-29th January, 2011. CSRTI, Mysore, Karnataka, India.

Panse, V.G. 1957. Genetics of quantitative characters in relation to plant breeding. *Indian Journal of Genetics and Plant Breeding,* **17**: 318-328.

Rajesh, K. and Elangovan, K. 2010. Rearing performance of Eri silkworm, Philosamia ricini in monsoon season of Uttar Pradesh. *Asian Journal of Experimental Biological Sciences*, **1**: 303-310.

Rama Mohana Rao, P., Premalatha, V., Joge, P.G., Nirmal Kumar, S. and Kamble, C.K. 2008. Impact of productive female parent in improving silk productivity in cross-breeds of the silkworm *Bombyx mori* L. pp. 91. **In**: *National Seminar on Scenario of Seri-biotechnological Research in India*. 28-30th August 2008. Department of Sericulture, Sri Padmavati Mahila Visvavidyalayam, Tirupati, Andhra Pradesh, India.

Reza, N.H., Alireza, S. and Shahabodin, G. 2014. A review on correlation, heritability and selection in silkworm breeding. *Journal of Applied Animal Research,***2**: 1-10.

Shao, Z. and Vollrath, F. 2002. Surprising strength of silkworm silk. *Nature,* **418**: 741-742.

Shabdini, A., Seidavi, A.R., Gharahveysi, S. and Mirhosseni, S.Z. 2011. Genetic trend, phenotype trend, correlation, heritability and breeding values of three oval cocoon silkworm pure lines under selection pressure using Wombat software. *Journal of Food, Agriculture and Environment*, **9**: 609-617.

Singh, R.K. 1972. Selection index - yes or no? *Vistas Plant Sciences*, **2**: 111-140.

Singh, T. and Madan, M. 2011.Critical analysis of correlation and heritability phenomenon in silkworm, *Bombyx mori* L. *Advances in Bioscience and Biotechnology,* **2**: 347-353.

Wright, S. 1921. Correlation and causation. *Agricultural Research,* **20**: 557-558.