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Shifting from semi-domestic to indoor rearing *Antheraea proylei* Jolly, 1970 of oak gives good results in terms of all parameters of its life cycle (Lepidoptera: Saturniidae)

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Abstract

The present study aims to evaluate the influence of controlled conditions of temperature and humidity on rearing and economic parameters of the *Antheraea proylei* Jolly, 1970. The experiments were carried out at Regional Tasar Research Station, Bhimtal (29º21'18"N 79º33'3"E) during the spring season of three years i. e. 2015-16, 2016-17 and 2017-18. In case of the control/indoor conditions the temperature and humidity were maintained at 25 ± 2ºC and 70-75% respectively, with a photoperiod of 12:12 (L:D) hrs., while the outdoor rearing was completely under natural conditions. It was found that the fecundity of a single female moth was 174.80 ± 7.22 under controlled conditions, whereas it was 148.33 ± 9.05 under natural conditions. The larvae showed significantly better growth and development under the controlled conditions resulting in improved economic traits as compared to outdoor/natural conditions. The larval weight showed significant positive correlation with most of the economic parameters, except total larval duration, peduncle length and silk conversion index. The contribution rates of the first 2 principal components were 65.45% and 18.22%. The study suggests that the rearing of *Antheraea proylei* if carried out in indoor/controlled conditions gives better results and reduces the cost of cocoon production.

KEY WORDS: Lepidoptera, Saturniidae, *Antheraea proylei*, life cycle, rearing condition, *Quercus serrata,* PCA, India.

Cambiando la cría interna de roble de la semidoméstica *Antheraea proylei* Jolly, 1970 da buenos resultados en relación con todos los parámetros de su ciclo vital (Lepidoptera: Saturniidae)

Resumen

El ánimo del presente estudio es evaluar la influencia del control de las condiciones de temperatura y humedad sobre la cría y los parámetros económicos de *Antheraea proylei* Jolly, 1970. Los experimentos fueron realizados en la Estación de Investigación Regional de Tasar, Bhimtal (29º21'18"N 79º33'3"E) durante la temporada de primavera de los tres años 2015-16, 2016-17 y 2017-18. En el caso del control/las condiciones internas, de la temperatura y la humedad, fueron mantenidas en 25 ± 2ºC and 70-75% respectivamente, con un fotoperíodo de 12:12 horas (L:D), mientras se criaba al aire libre, estaba totalmente bajo las condiciones naturales. Fue descubierto que la fecundidad de una sola hembra fue de174.80 ± 7.22 bajo las condiciones controladas, mientras que fue de 148.33 ± 9.05 bajo las condiciones naturales. Las larvas mostraron significativamente un mejor crecimiento y desarrollo, comparando las condiciones al aire libre/naturales bajo las condiciones controladas, que resultaba en los rasgos económicos mejorados. El peso de la larva indicaba una segura e importante correlación con la mayoría de los parámetros económicos, excepto en la total duración larval, la duración del pedúnculo y el índice de conversión de seda. Los ratios de contribución del primero de los dos componentes principales eran del 65.45% y18.22%. El estudio indica

que la cría de *Antheraea proylei* en las condiciones internas/controladas, da los mejores resultados y reduce el coste de la producción de capullo.
PALABRAS CLAVE: Lepidoptera, Saturniidae, *Antheraea proylei*, ciclo de vida, condición de cría, *Quercus serrata,* PCA, India.

Introduction

The members of the genus *Antheraea* Hübner, [1819] (Lepidoptera: Saturniidae) inhabit different ecological niches, widely ranging from the tropical to temperate with transitional zones. Among all the species of *Antheraea proylei* Jolly, 1970 is considered as the most prominent, viable and commercially exploited species in the temperate regions of the Indian sub-continent. *Antheraea proylei* being semi-domestic in nature, shows weak bivoltine, thus depending upon the geographical and agro-climatic conditions and one or more crops can be obtained per year. It is reared throughout the sub-Himalayan belt extending from Jammu and Kashmir in the north to Manipur in the Far East between 26º-34º latitude and 2000-8500' ASL altitude. In Uttarakhand, as many as 12 districts, 34 blocks 34,521 villages and 72 Departmental farms are reported to be actively engaged in silk cultivation and production yielding to 25,000 metric tonnes of silk with 14 tonnes of raw mulberry silk alone ("The Tribune, Chandigarh, India - Dehradun Plus," 2009).

Though the *Antheraea proylei* reared in north-eastern region and north-western region, however the biology and life table parameters are greatly affected by the topology and climatic conditions of the area, thus showing great variations both in biology and economic yield in both the Taser rearing regions. In the north-western region, there is a great deal of climatic variability with respect to altitude. GOEL & KRISHNA RAO, (2004) were successful in raising three crops of this species on different food plants and at different altitudes. The *A. proylei* is oligophagous in nature, as it feeds on a variety of oaks belonging to the family Fagaceae, order Fagales, and genus *Quercus*. There are more than 35 well-known species of the naturally occurring oaks in the north-western sub-Himalayan region of India, with varying diversity along the altitudes, ranging from 1200-3500 m, AMSL (GOEL & KRISHNA RAO, 2004; PANDEY & TAMTA, 2012; BARGALI *et al.*, 2014). It is also expected that even if 10% of the existing oak flora is used for Taser culture, this industry can generate significant and lucrative employment to several thousands of the people residing in those areas and will also help in the upliftment of the oak Taser industry in terms of production. As per YOKOYAMA, (1963) and KAKATI & KAKATI, (2011) the nutritional value of the leaves of the different host plants and their seasonal variations are directly correlated with the life tables of the silkworm.

Temperature is considered as the key regulator of insect development as it influences the rate of insect metabolism (PERVEZ, 2002). The climatological factors not only affect the biology of the silkworm but also play a significant role in maintaining the quality of the economic traits of the silkworm. There has been a direct correlation between the environmental factors and the fecundity and hatching percentage of the eggs, longevity, growth and development (HONEK *et al.*, 2003; NAKAGE *et al.*, 2003; PIESIK, 2006; AKSIT *et al.*, 2007). Fluctuations in the climatological parameters result in incidences of diseases in the silkworm which accounts for 10% loss to the total crop loss in the developing countries (DAVID, 1975; PAYNE & MERTENS, 1983; BABU *et al.*, 2009).

The state of Uttarakhand has been observing the severe consequences of climate change. The average temperature at higher latitudes (Almora) which was 17.55ºC has significantly increased up to 0.46ºC during the past fifty-three years with a considerable decrease in the annual rainfall. This change in the climate has greatly affected the lifestyle and livelihood of the people residing in the Himalayan belt (SHARMA & DOBRIYAL, 2014; RAUTELA & KARKI, 2015). There is a considerable decline in the oak flora as a result of rising temperature, which prosses a tough challenge for the regeneration of the oaks. The rise in the temperature causes early maturation of the leaves of the host plant and thus becomes unsuitable for the feeding of the larvae. The relative increase in the incidence of the disease in the silkworm has resulted in the failure of the crop in many parts of the state and directly affects the income of the farmers. This is ultimately shifting the farmers to other occupations for sustaining their livelihood.

To overcome these problems, the rearing practices under the natural conditions may be shifted to the controlled conditions inside the polyhouse as is being done in case of *Bombyx mori* (Linnaeus, 1758).

After going through the available literature, it seems that the present experiment is the first study to compare the rearing performances of *A. proylei* including the larval development, larval period, fecundity and economic parameters on host plant, *Quercus serrata* Murray, under two different conditions. The findings of the present study will be useful in formulating an integrated strategy for rearing of *A. proylei*.

Material and methods

The study on variations in the biology and economic parameters of *A. proylei* under two different conditions i. e. indoor (controlled) and outdoor (natural conditions) was carried out at the Regional Tasar Research Station, Bhimtal (29º21'18"N 79º33'3"E) during the spring seasons of 2015-16, 2016-17 and 2017-18. The eggs were procured from the same centre and were incubated under the controlled climatological factors viz. temperature (22 ± 2ºC) and humidity (70-80%) as prescribed by JOLLY (1972). The life cycle of the insect was completed under the controlled conditions. However, the F2 generation thus obtained was used for further experimental studies. The host plant used was *Quercus serrata* Murray. All the plant materials used in this experiment were collected from the plants growing under field conditions.

Experimental setup for the rearing of silkworms: The rearing was carried out according to the rearing methods described by JOLLY *et al*. (1974). Prior to the experimental studies, the branches of the host plant were pruned during the month of December to ensure early sprouting of good quality foliage by the early March. The indoor rearing was carried out inside the rearing room where the climatological factors viz. temperature and humidity were maintained at 25 ± 2ºC and 70-75% respectively with a photoperiod of 12:12 (L:D) hr. (JOLLY, 1974). Two branches of the host plant were partially dipped in the bottles filled with water and a paper cork was used to seal the gap to make it airtight. The branches were immediately replaced by fresh ones as they become dry. Regular bed cleaning was done by removing the leftover leaves and litter. The outdoor rearing of Tasar silkworm was carried out under natural climatic conditions using nylon net in order to prevent attack by predators. Temperature and relative humidity were recorded using Digital Thermohydrometer (Mextech IT-202) (Fig. 1). Equal number of eggs were taken for the experimental studies under both the conditions. The complete life cycle of the insect was studied following the procedure explained by DANKS, (2000) for reporting the exact duration of each life stage in insects.

Egg parameters estimation: The variations in the egg characteristics of the Tasar silkworm such as length (mm), breadth (mm) and weight (g) were recorded. The egg was then washed in the soap solution and further disinfected with 2% formalin solution in order to remove the dried appendages from the egg masses. The eggs were dried under shade before incubation. The eggs were incubated at a temperature of 22 ± 2ºC and 70-80% R. H (GOEL & KRISHNA RAO, 2004). The incubation period was accounted for the period from the day of egg deposition until the day of hatching. The hatching percentage is defined as the total number of the eggs hatched per disease free laying and its values were expressed in percentage.

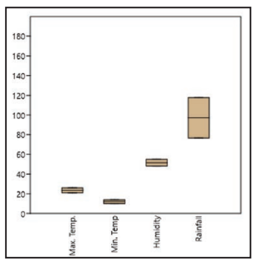

Fig. 1.– Average meteorological parameter recorded under the natural conditions.

Record of different rearing parameters: The morphological characters of the larvae, pupa, and cocoon of Tasar silkworm viz. length (mm), breadth (mm), weight (g) and duration (days) were also recorded for different conditions with n= 15. The larval duration was calculated as the number of days from the time of egg hatching to the sixth day of spinning.

Economic parameters estimation: Cocoon weight (g): The value of the single cocoon weight was expressed in gram (g) and was calculated by taking the weight of the 15 cocoons at random on an overly sensitive electronic balance (Essae).

$$\text{Weight of cocoon (g)} = \frac{\text{Weight of 15 cocoons}}{15}$$

Pupa weight (g): The cocoon was cut open to take out pupa. The value of pupa weight was also expressed in gram (g) and was calculated by taking the weight of the 15 pupae at random.

$$\text{Pupa weight (g)} = \frac{\text{Weight of 15 pupae}}{15}$$

Shell weight (g): The shell weight helps in evaluating the quality of cocoon. The value of shell weight was also expressed in gram (g) and was calculated by taking the weight of the 15 shells at random.

$$\text{Shell weight (g)} = \frac{\text{Weight of shells}}{15}$$

Shell ratio (%): It is the most reliable economic character expressing the cocoon quality. It is measured as the average ratio of 15 cocoon shell weight to the cocoon weight and values were expressed in percentage.

$$\text{Shell Ratio (\%)} = \frac{\text{Shells weight}}{\text{Cocoon weight}} \times 100$$

Cocoon/DFL: It was calculated as the total number of the live cocoons collected from a single disease-free laying's (DFLs).

Effective rate of rearing (ERR%): It was calculated as the total number of the cocoon harvested from the number of the worms reared. The values obtained were expressed in percentage.

$$\text{ERR (\%)} = \frac{\text{Number of cocoons harvested}}{\text{Number of worms reared}} \times 100$$

Silk gland properties: The length (cm) and weight (g) of the silk gland of the fully grown V^{th} instar larvae of oak Tasar silkworm was studied by dissecting it out.

Silk gland somatic index (SSI%): The silk gland somatic index (SSI) represents the biomass of the silk gland in relation to the total body weight and was calculated as:

$$\text{SSI (\%)} = \frac{\text{Silk gland weight}}{\text{Mature larvae weight}} \times 100$$

Silk conversion index (SCI%): The silk conversion index (SCI) is the measure of the ratio of shell weight to silk gland weight and was calculated as:

$$\text{SSI (\%)} = \frac{\text{Sell weight}}{\text{Silk gland weight}} \times 100$$

Data analysis: Variations in the developmental time of the egg, larvae, and economic parameters of *A. proylei* reared on *Q. serrata* under two different condition were analysed with the analysis of variance (ANOVA) using IBM®-SPSS® statistics version 20.0. The correlation between the larval weight and the economic parameters was also analysed using the same software. The Principal Component Analysis (PCA) and the Figures were processed using OriginPro 2020.

Results

Egg Parameters: The results of the present study clearly indicate that the egg parameters of the inbred silkworm were affected by controlled conditions (Table 1 and Fig. 2). Under both the conditions of rearing (i. e. indoor and outdoor) the rate of fecundity was higher for initial 72 hrs after decoupling. During the spring season of 2015-16, 2016-17 and 2017-18, significantly more eggs (172.93 ± 8.34, 174.80 ± 7.22 and 171.80 ± 10.66) were deposited by female moths reared under controlled conditions of temperature and relative humidity as compared to the outdoor experiments (143.33 ± 8.54, F= 92.17, P= 0.001, 148.33 ± 9.05, F= 78.34, P= 0.001 and 141.67 ± 10.78, F= 59.26, P= 0.001). Similar trend of better results for egg development were also observed for the controlled conditions as compared with outdoor experiments. The egg length (mm), breadth (mm) and weight (g) showed slightly higher values (2.46-2.48, 1.96-2.01 and 0.007-0.008) for indoor experiments as compared to outdoor studies (2.10-2.39, 1.90-1.94 and 0.006-0.007) throughout the study period. The incubation period (days) was found to be significantly lower in case of eggs incubated in the indoor conditions ((8.96 ± 0.81, 8.98 ± 0.80 and 9.06 ± 0.77) as compared to the outdoor conditions (10.12 ± 0.73, F= 17.03, P= 0.001, 10.21 ± 0.74, F= 19.48, P= 0.001 and 10.16 ± 0.81, F= 14.61, P= 0.001) during the study period. Hatching percentage was higher (73.54 ± 4.09%) in the indoor conditions as compared to the outdoor (62.11 ± 5.21%).

Table 1.– Characteristics of egg of *Antheraea proylei* fed with *Quercus serrata* during spring season of 2015-16, 2016-17 and 2017-18. (n=15).

Year	Condition	Length (mm)	Breadth (mm)	Weight (g)	Incubation (Days)	Fecundity (Nos.)
2015-16	**Indoor**	2.47 ± 0.28	2.01 ± 0.70	0.008 ± 0.002	8.96 ± 0.81	172.93 ± 8.34
	Outdoor	2.35 NS ± 0.26	1.93 NS ± 0.70	0.007 NS ± 0.002	10.12*** ± 0.73	143.33*** ± 8.54
		F value = 1.46	**F value = 0.09**	**F value = 0.12**	**F value = 17.03**	**F value = 92.17**
2016-17	**Indoor**	2.48 ± 0.27	1.98 ± 0.69	0.008 ± 0.003	8.98 ± 0.80	174.80 ± 7.22
	Outdoor	2.10*** ± 0.23	1.90 NS ± 0.70	0.006* ± 0.002	10.21*** ± 0.74	148.33*** ± 9.05
		F value = 16.74	**F value = 0.12**	**F value = 3.11**	**F value = 19.48**	**F value = 78.34**
2017-18	**Indoor**	2.46 ± 0.27	1.96 ± 0.66	0.007 ± 0.003	9.06 ± 0.77	171.80 ± 10.66
	Outdoor	2.39 NS ± 0.28	1.94 NS ± 0.70	0.007 NS ± 0.002	10.16*** ± 0.81	141.67*** ± 10.78
		F value = 0.54	**F value = 0.01**	**F value = 0.00**	**F value = 14.61**	**F value = 59.26**

*, **, *** Significant P<0.05, P<0.01, P<0.001, NS = Non significant

Larval characteristics: The larval instars showed significant variations in the body length, breadth, weight, and duration under different rearing conditions. The body length, breadth and weight were found to be significantly higher in the indoor reared larvae with shortest larval duration throughout the study period as compared to the larvae reared under natural conditions. In case of Its instar larvae, maximum body length (mm), breadth (mm) and weight (g) were recorded as 7.38 ± 0.29, 0.84 ± 0.15 and 0.005 respectively, with minimum larval period (4.18 ± 0.39 days) under controlled conditions, while the body length, breadth and weight (7.19 ± 0.30 mm, 0.73 ± 0.16 mm and 0.003 ± 0.001 g) of the larvae with maximum larval duration of 4.75 ± 0.60 days was recorded under natural conditions for three consecutive years (Table 2 and Fig. 3). Similar, results were also recorded for the IInd instar larvae in which maximum growth i. e. body length, breadth and weight were recorded as 15.93 ± 0.55 mm, 2.46 ± 0.49 mm and 0.54 ± 0.17 g with shortest larval duration (3.65 ± 0.27 days) under control conditions, while the body length, breadth and weight (15.78 ± 0.49 mm, 2.35 ± 0.31 mm and 0.48 ± 0.10 g) of the larvae with maximum larval period (3.92 ± 0.30 days) was observed for outdoor experiments during the study period (Table 2 and Fig. 4). In III[rd] instar larvae significantly better growth and development i. e. 58.03 ± 0.42 mm, 4.63 ± 0.37 mm and 2.61 ± 0.13 g, with reduced larval duration (5.27 ± 0.41 days) was observed for the larvae reared under indoor conditions, while retarded in case of outdoor conditions throughout the study period (Table 3 and Fig. 5). Similar results were also observed for IV[th] and V[th] instar larval (Table 3-4 and Fig. 6-7). The fully grown caterpillar showed maximum body length, breadth, and weight (83.96 ± 0.93 mm, 18.21 ± 0.43 mm and 16.67 ± 0.32 g) with shortest larval duration (12.07 ± 0.08 days) under control conditions, while the body length, breadth and weight (82.22 ± 0.74 mm, 17.81 ± 0.66 mm and 15.74 ± 0.40 g) of the larvae with maximum larval duration (12.97 ± 0.23 days) was recorded for outdoor experiments throughout the study period (Table 4 and Fig. 7). The total larval duration (days) was found to be significantly prolonged in the outdoor reared worms (44.38 ± 1.80, F= 31.68, P= 0.001, 44.63 ± 0.47, F= 411.40, P= 0.001 and 43.96 ± 0.88, F= 211.27, P= 0.001), while shortest (39.96 ± 2.45, 38.95 ± 0.98 and 39.84 ± 0.66) was recorded for indoor conditions (Table 4 and Fig. 7).

Table 4.– Characteristics of Vth instar larvae of *Antheraea proylei* reared on *Quercus serrata* during spring season of 2015-16, 2016-17 and 2017-18. (n=15).

Year	Condition	Vth Instar				Total Larval
		Length (mm)	Breadth (mm)	Weight (g)	Duration (Days)	Duration (Days)
2015-16	**Indoor**	83.88 ± 0.92	18.12 ± 0.40	16.65 ± 0.33	12.12 ± 0.09	39.96 ± 2.45
	Outdoor	82.31*** ± 0.86	17.89 NS ± 0.44	15.79*** ± 0.41	12.96*** ± 0.08	44.38*** ± 1.80
		F value = 23.23	**F value = 2.22**	**F value = 40.60**	**F value = 747.00**	**F value = 31.68**
2016-17	**Indoor**	83.94 ± 0.91	18.21 ± 0.43	16.67 ± 0.32	12.07 ± 0.08	38.95 ± 0.98
	Outdoor	82.22*** ± 0.74	17.81* ± 0.66	15.74*** ± 0.40	12.97*** ± 0.23	44.63*** ± 0.47
		F value = 32.10	**F value = 4.03**	**F value = 48.13**	**F value = 203.31**	**F value = 411.40**
2017-18	**Indoor**	83.96 ± 0.93	18.17 ± 0.39	16.62 ± 0.31	12.09 ± 0.09	39.84 ± 0.66
	Outdoor	83.43* ± 0.62	18.03 NS ± 0.54	16.11*** ± 0.38	12.34*** ± 0.14	43.96*** ± 0.88
		F value = 3.48	**F value = 0.69**	**F value = 15.97**	**F value = 32.25**	**F value = 211.27**

*, **, *** Significant P<0.05, P<0.01, P<0.001, NS = Non significant

Economic Parameters: The results on the economic parameters reared under two different conditions on the same host plant, *Q. serrata* for three consecutive years are presented in Table 6 and Fig. 8. The economic parameters viz. peduncle length, cocoon parameters, pupa weight, shell weight, silk ratio, cocoon/DFL, ERR% and silk gland parameters also showed significant variations under two different rearing conditions. The peduncle length was found to be 7.35 ± 0.17 cm, 7.31 ± 0.18 cm and 7.36 ± 0.17 cm respectively in case of the indoor reared larvae, which is significantly higher than the peduncle length of the larvae reared under natural conditions (6.78 ± 0.18 cm, F= 18.25, P= 0.001, 7.54 ± 0.33 cm, F= 5.47 P= 0.05 and 6.97 ± 0.33 cm, F= 15.98, P= 0.001). The length, breadth and weight of the cocoon was found to be significantly higher in the indoor reared worms (3.89-3.97 cm, 2.34-2.35 cm, and 5.18-5.35 g) as compared to outdoor reared worms (3.61-3.87 cm, 2.27-2.32 cm and 4.75-4.94 g) during the study period.

Similarly, the pupa weight was found to be higher (4.79 ± 0.16 g, 4.72 ± 0.14 g and 4.65 ± 0.14 g), in case of the larvae reared indoor under controlled conditions, while it was significantly lower (4.30 ± 0.07 g, F= 119.49, P= 0.001, 4.48 ± 0.05 g, F= 41.60, P= 0.001 and 4.43 ± 0.26 g, F= 8.40, P= 0.01) for outdoor reared larva throughout the study period. The shell weight was also found to be higher (0.55 ± 0.05 g, 0.44 ± 0.08 g and 0.53 ± 0.06 g) in case of the indoor reared larvae, which was significantly lower (0.44 ± 0.08 g, F= 19.66, P= 0.001, 0.46 ± 0.18 g, F= 4.47, P = 0.05 and 0.44 ± 0.09 g, F= 9.39, P= 0.01) for the outdoor reared larvae during the study period. Significantly higher value of silk ratio (10.72 ± 1.04%) was observed for the indoor reared larvae as compared to outdoor conditions (9.06 ± 1.70%) throughout the study period.

Table 2.– Characteristics of Ist and IInd Instar larvae of *Antheraea proylei* reared on *Quercus serrata* during spring season of 2015-16, 2016-17 and 2017-18. (n=15).

Year	Condition	Ist Instar				IInd Instar			
		Length (mm)	**Breadth (mm)**	**Weight (g)**	**Duration (Days)**	**Length (mm)**	**Breadth (mm)**	**Weight (g)**	**Duration (Days)**
2015-16	**Indoor**	7.33 ± 0.30	0.84 ± 0.15	0.005 ± 0.002	4.21 ± 0.40	15.83 ± 0.55	2.41 ± 0.51	0.52 ± 0.17	3.68 ± 0.29
	Outdoor	7.19 ^{NS} ± 0.30	0.81 ^{NS} ± 0.14	0.004 ^{NS} ± 0.001	4.72** ± 0.50	15.78 ^{NS} ± 0.49	2.41 ^{NS} ± 0.45	0.50 ± 0.13	3.89** ± 0.27
		F value = 1.67	**F value = 0.25**	**F value = 0.48**	**F value = 9.49**	**F value = 0.07**	**F value = 0.00**	**F value = 0.08**	**F value = 4.24**
2016-17	**Indoor**	7.36 ± 0.31	0.82 ± 0.15	0.005 ± 0.002	4.18 ± 0.39	15.93 ± 0.55	2.46 ± 0.49	0.54 ± 0.17	3.65 ± 0.27
	Outdoor	6.81*** ± 0.32	0.73 ^{NS} ± 0.16	0.003*** ± 0.001	4.68** ± 0.53	15.91 ^{NS} ± 0.58	2.39 ^{NS} ± 0.42	0.52 ± 0.17	3.92** ± 0.30
		F value = 22.80	**F value = 2.84**	**F value = 13.35**	**F value = 8.53**	**F value = 0.01**	**F value = 0.14**	**F value = 0.14**	**F value = 0.13**
2017-18	**Indoor**	7.38 ± 0.29	0.81 ± 0.16	0.004 ± 0.002	4.23 ± 0.39	15.91 ± 0.55	2.45 ± 0.40	0.51 ± 0.14	3.71 ± 0.28
	Outdoor	7.20* ± 0.24	0.83 ^{NS} ± 0.15	0.004 ^{NS} ± 0.001	4.75** ± 0.60	15.83 ^{NS} ± 0.90	2.35 ^{NS} ± 0.31	0.48 ± 0.10	3.84 ^{NS} ± 0.29
		F value = 3.47	**F value = 0.24**	**F value = 1.69**	**F value = 7.99**	**F value = 0.09**	**F value = 0.58**	**F value = 0.52**	**F value =1.60**

*, **, *** Significant P<0.05, P<0.01, P<0.001, NS = Non significant

Table 3.– Characteristics of IIIrd and IVth Instar larvae of *Antheraea proylei* reared on *Quercus serrata* during spring season of 2015-16, 2016-17 and 2017-18. (n=15).

Year	Condition	IIIrd Instar				IV^{thd} Instar			
		Length (mm)	**Breadth (mm)**	**Weight (g)**	**Duration (Days)**	**Length (mm)**	**Breadth (mm)**	**Weight (g)**	**Duration (Days)**
2015-16	**Indoor**	57.98 ± 0.42	4.61 ± 0.36	2.57 ± 0.11	5.29 ± 0.39	69.54 ± 0.74	10.08 ± 0.45	8.11 ± 0.44	6.22 ± 0.39
	Outdoor	57.70* ± 0.44	4.38* ± 0.27	2.14*** ± 0.05	5.94*** ± 0.49	68.98* ± 0.96	9.81* ± 0.40	6.68*** ± 0.49	7.01*** ± 0.72
		F value = 3.25	**F value = 4.02**	**F value = 209.25**	**F value = 16.26**	**F value = 3.17**	**F value = 3.00**	**F value = 70.68**	**F value = 13.95**
2016-17	**Indoor**	57.94 ± 0.43	4.58 ± 0.28	2.38 ± 0.06	5.33 ± 0.39	69.61 ± 0.73	10.11 ± 0.38	8.16 ± 0.36	6.15 ± 0.38
	Outdoor	57.73 ^{NS} ± 0.51	4.41 ^{NS} ± 0.38	2.18*** ± 0.18	5.74** ± 0.39	69.25 ^{NS} ± 0.72	9.98 ^{NS} ± 0.55	7.14*** ± 0.35	6.81*** ± 0.56
		F value = 1.60	**F value = 1.90**	**F value = 19.29**	**F value = 8.33**	**F value = 1.80**	**F value = 0.50**	**F value = 61.82**	**F value =14.26**
2017-18	**Indoor**	58.03 ± 0.42	4.63 ± 0.37	2.61 ± 0.13	5.27 ± 0.41	69.58 ± 0.73	10.05 ± 0.44	8.12 ± 0.43	6.17 ± 0.39
	Outdoor	57.86 ^{NS} ± 0.72	4.48 ^{NS} ± 0.33	2.23*** ± 0.22	5.87*** ± 0.34	69.41 ^{NS} ± 0.74	9.92 ^{NS} ± 0.41	7.51*** ± 0.25	6.62** ± 0.49
		F value = 0.63	**F value = 1.32**	**F value = 35.15**	**F value = 18.80**	**F value = 0.42**	**F value = 0.64**	**F value = 22.86**	**F value = 7.85**

*, **, *** Significant P<0.05, P<0.01, P<0.001, NS = Non significant

As the temperature and humidity were optimum for the growth and development of the larvae under the controlled conditions, maximum number of cocoons were obtained from each disease-free laying (74.67 ± 7.37, 69.67 ± 5.63 and 72.67 ± 5.84) from the larvae reared under controlled conditions, which was significantly higher than the outdoor experiment (41.13 ± 7.46, F= 153.23, P= 0.001, 38.27 ± 5.68, F= 231.53, P= 0.001 and 44.33 ± 4.78, F= 211.61 P= 0.001) during the study period. The effective rate of rearing (%) also showed better results (59.03 ± 7.68%, 56.95 ± 7.40% and 59.61 ± 6.25%) for those larvae which were reared under controlled conditions of temperature and humidity, as compared to the outdoor reared worms (46.27 ± 9.22%, F= 16.96 P= 0.001, 40.65 ± 8.18%, F= 32.78, P= 0.001 and 51.00 ± 8.08%, F= 10.65, P= 0.001) during the study period.

The silk gland parameters viz. length, weight, silk gland somatic index and silk conversion index showed significant variations under both rearing conditions (Table 5 and Fig. 8). Maximum length (81.30 ± 4.35 cm, 81.72 ± 4.09 cm and 81.41 ± 4.34 cm) of the silk gland was recorded for the indoor reared larvae, as compared to those of the outdoor reared larvae (73.86 ± 0.93 cm, F= 42.00, P= 0.001, 73.21 ± 5.26 cm, F= 24.50, P= 0.001 and 74.34 ± 7.28 cm, F= 10.45, P= 0.01). The weight of the silk gland showed better results (0.42 ± 0.06 g, 0.43 ± 0.06 g and 0.42 ± 0.06 g) for those larvae which were reared under controlled conditions of temperature and humidity as compared to those reared under natural conditions (0.32 ± 0.03 g, F= 33.40, P= 0.001, 0.31 ± 0.08 g, F= 22.16, P= 0.001 and 0.34 ± 0.06 g, F= 15.36, P= 0.001) during the study period. Similar results were also observed for the silk gland somatic index. Maximum value (2.59 ± 0.34%) of silk gland somatic index was recorded for the indoor reared larvae, while minimum (1.96 ± 0.44%) for the outdoor reared larvae. However, higher value of silk conversion index (155.74 ± 62.33%) was recorded for the outdoor reared larvae as compared to indoor reared larvae (126.98 ± 11.39%) during the study period.

Table 5.– Properties of silk gland of *Antheraea proylei* reared on *Quercus serrata* during spring season of 2015-16, 2016-17 and 2017-18. (n=15).

Year	**Condition**	**Length (cm)**	**Weight (g)**	**Silk gland Somatic Index %**	**Silk Conversion Index %**
2015-16	**Indoor**	**81.30 ± 4.35**	**0.42 ± 0.06**	**2.53 ± 0.29**	**132.31 ± 10.54**
	Outdoor	73.86*** ± 0.93	0.32*** ± 0.03	2.05*** ± 0.18	138.82 ^{NS} ± 30.58
		F value = 42.00	**F value = 33.40**	**F value = 29.64**	**F value = 0.61**
2016-17	**Indoor**	81.72 ± 4.09	0.43 ± 0.06	2.59 ± 0.34	132.84 ± 16.43
	Outdoor	73.21*** ± 5.26	0.31*** ± 0.08	1.96*** ± 0.44	155.74 ^{NS} ± 62.33
		F value = 24.50	**F value = 22.16**	**F value = 18.77**	**F value = 1.89**
2017-18	**Indoor**	81.41 ± 4.34	0.42 ± 0.06	2.53 ± 0.29	126.98 ± 11.39
	Outdoor	74.34** ± 7.28	0.34*** ± 0.06	2.09*** ± 0.33	132.22 ^{NS} ± 22.79
		F value = 10.45	**F value = 15.36**	**F value = 15.15**	**F value = 0.64**

*, **, *** Significant P<0.05, P<0.01, P<0.001, NS = Non significant

The Principal Component Analysis of larval weight effect on the associated economic parameters viz. peduncle length, cocoon weight, pupa weight, shell weight, silk ratio, cocoon/DFL, ERR% and silk gland parameters generated four axis accounting for the complete variance observed. The contribution rates of the first 2 principal components were 65.45% and 18.22%, respectively (Fig. 9). The peduncle length, total larval duration and silk conversion index showed significant negative correlation with the larval weight, while a significant positive correlation of the larval weight with rest of the economic parameters was recorded (Table 7).

Table 6.– Economic characteristics of *Antheraea proylei* fed with *Quercus serrata* during spring season of 2015-16, 2016-17 and 2017-18. (n=15).

Year	Condition	Peduncle	Cocoon characteristics			Pupa	Shell	Silk Ratio	Cocoon /DFL	ERR %	Hatching %
		Length (cm)	Length (cm)	Breadth (cm)	Weight (g)	Weight (g)	Weight (g)				
2015-16	**Indoor**	7.35 ± 0.17	3.92 ± 0.20	2.34 ± 0.22	5.35 ± 0.20	4.79 ± 0.16	0.55 ± 0.05	10.33 ± 0.63	74.67 ± 7.37	59.03 ± 7.68	73.54 ± 4.09
	Outdoor	6.78*** ± 0.18	3.61*** ± 0.21	2.27 ^{NS} ± 0.24	4.75*** ± 0.12	4.30*** ± 0.07	0.44*** ± 0.08	9.32* ± 1.53	41.13*** ± 7.46	46.27*** ± 9.22	62.50*** ± 4.43
		F value = 80.25	**F value = 16.85**	**F value = 0.71**	**F value = 101.22**	**F value = 119.49**	**F value = 19.66**	**F value = 5.54**	**F value = 153.23**	**F value = 16.96**	**F value = 50.23**
2016-17	**Indoor**	7.31 ± 0.18	3.97 ± 0.21	2.35 ± 0.22	5.29 ± 0.18	4.72 ± 0.14	0.44 ± 0.08	10.72 ± 1.04	69.67 ± 5.63	56.95 ± 7.40	70.52 ± 4.91
	Outdoor	7.54* ± 0.33	3.87 ^{NS} ± 0.23	2.31 ^{NS} ± 0.19	4.94*** ± 0.19	4.48*** ± 0.05	0.46* ± 0.18	9.30 ^{NS} ± 3.17	38.27*** ± 5.68	40.65*** ± 8.18	64.42*** ± 5.51
		F value = 5.47	**F value = 1.50**	**F value = 0.29**	**F value = 26.31**	**F value = 41.60**	**F value = 4.47**	**F value = 2.73**	**F value = 231.53**	**F value = 32.78**	**F value = 10.21**
2017-18	**Indoor**	7.36 ± 0.17	3.89 ± 0.21	2.34 ± 0.22	5.18 ± 0.18	4.65 ± 0.14	0.53 ± 0.06	10.25 ± 0.94	72.67 ± 5.84	59.61 ± 6.25	71.37 ± 4.23
	Outdoor	6.97*** ± 0.33	3.83 ^{NS} ± 0.21	2.32 ^{NS} ± 0.48	4.87*** ± 0.30	4.43** ± 0.26	0.44** ± 0.09	9.06*** ± 1.70	44.33*** ± 4.78	51.00*** ± 8.08	62.11*** ± 5.21
		F value = 15.98	**F value = 0.59**	**F value = 0.04**	**F value = 11.78**	**F value = 8.40**	**F value = 9.39**	**F value = 5.58**	**F value = 211.61**	**F value = 10.65**	**F value = 28.59**

*, **, *** Significant P<0.05, P<0.01, P<0.001, NS = Non significant

Table 7.– Correlation between the larval weight and economic parameters of *Antheraea proylei* (n=15).

Parameters		Larval Weight	Total Larval Duration	Peduncle Length	Cocoon Weight	Pupa Weight	Shell Weight	Silk Ratio	Cocoon /DFL	ERR %	SG Weight	SG Length	SSI %	SCI %
Larval Weight	Pearson correlation	1	-.490	-.607*	.929**	.904**	.822**	.640*	.453	.143	.940**	.823**	.920**	-.663**
	Sig. (2-tailed)		.064	.016	.000	.000	.000	.010	.090	.612	.000	.000	.000	.007
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
Total Larval Duration	Pearson correlation	-.490	1	.125	-.394	-.378	-.365	-.292	.004	-.085	-.402	-.211	-.375	.247
	Sig. (2-tailed)	.064		.657	.147	.165	.180	.292	.990	.764	.137	.451	.168	.374
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
Peduncle Length	Pearson correlation	-.607*	.125	1	-.569*	-.464	-.791**	-.805**	-.608*	-.156	-.654**	-.676**	-.643**	.164
	Sig. (2-tailed)	.016	.657		.027	.082	.000	.000	.016	.579	.008	.006	.010	.560
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
Cocoon Weight	Pearson correlation	.929**	-.394	-.569*	1	.986**	.844**	.631*	.547*	.181	.892**	.757**	.879**	-.558*
	Sig. (2-tailed)	.000	.147	.027		.000	.000	.012	.035	.519	.000	.001	.000	.031
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**

Pupa Weight	Pearson correlation	.904**	-.378	-.464	.986**	1	.742**	.491	.476	.153	.853**	.699**	.841**	-.615*
	Sig. (2-tailed)	.000	.165	.082	.000		.002	.063	.073	.585	.000	.004	.000	.015
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
Shell Weight	Pearson correlation	.822**	-.365	-.791**	.844**	.742**	1	.948**	.663**	.232	.837**	.790**	.825**	-.266
	Sig. (2-tailed)	.000	.180	.000	.000	.002		.000	.007	.406	.000	.000	.000	.338
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
Silk Ratio	Pearson correlation	.640*	-.292	.805**	.631*	.491	.948**	1	.639*	.236	.681*	.694**	.672**	-.052
	Sig. (2-tailed)	.010	.292	.000	.012	.063	.000		.010	.398	.005	.004	.006	.854
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
Cocoon/DFL	Pearson correlation	.453	.004	-.608*	.547*	.476	.663**	.639*	1	.474**	.504	.457	.503	-.097
	Sig. (2-tailed)	.090	.990	.016	.035	.073	.007	.010		.001	.056	.087	.056	.730
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
ERR %	Pearson correlation	.143	-.085	-.156	.181	.153	.232	.236	.774**	1	.090	.007	.081	.093
	Sig. (2-tailed)	.612	.764	.579	.519	.585	.406	.398	.001		.748	.981	.775	.743
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
SG Weight	Pson correlation	.940**	-.402	-.654**	.892**	.853**	.837**	.681**	.504	.090	1	.906**	.998**	-.748**
	Sig. (2-tailed)	.000	.137	.008	.000	.000	.000	.005	.056	.748		.000	.000	.001
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
SG Length	Pearson correlation	.823**	-.211	-.676**	.757**	.699**	.79**	.694**	.457	.007	.906**	1	.908**	-.631*
	Sig. (2-tailed)	.000	.451	.006	.001	.004	.000	.004	.087	.981	.000		.000	.012
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
SSI %	Pearson correlation	.920**	-.375	-.643**	.879**	.841**	.825**	.672**	.503	.081	.998**	.908**	1	-.761**
	Sig. (2-tailed)	.000	.168	.010	.000	.000	.000	.006	.056	.775	.000	.000		.001
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
SCI %	Pearson correlation	-.663**	.247	.164	-.558*	-.615*	-.266	-.052	-.097	.093	-.748**	-.631*	-.761**	1
	Sig. (2-tailed)	.007	.374	.560	.031	.015	.338	.854	.730	.743	.001	.012	.001	
	N	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**

Discussion

The *A. proylei*, respond idiosyncratically to myriad of the abiotic and biotic factors leading to variations in life cycle. In this study, the biology and economic parameters varied under different rearing conditions mainly due to the variations in the climatological variables. Occurrence of shortest developmental duration and better growth of the insects with reference to rearing conditions and host plant indicate greater suitability to those conditions (VAN LENTEREN & NOLDUS, 1990). The results on fecundity and hatching (%) showed significant variations with respect to the rearing conditions. Maximum fecundity and hatching% was observed for the larvae reared under indoor conditions with controlled temperature and humidity (22 ± 1ºC and 75-80%) as compared to natural conditions. HUSSAIN *et al*. (2011) recorded that variations in rearing temperature and humidity causes adverse effects on the egg production and fertility of the silkworm. The results of this study are also supported by findings of the earlier workers (HUGAR & RAO, 2012; ZHANG *et al*., 2015; MA *et al*., 2017; ZHANG, 2018). GOEL & KRISHNA RAO (2004) reported that the most suitable temperature and relative humidity for the incubation and development of the eggs is 22 ± 1ºC and 75-80%, respectively. Any rise or fall in these values may result in retarded development and prolonged incubation duration. The fluctuations in the temperature and humidity resulted in prolonged incubation duration of the egg under outdoor conditions in the present study.

JOLLY (1987) reported that the temperature and humidity play a significant role in the growth and development and suggested that the temperature and relative humidity of 23-28ºC and 70-75% is best suitable for its growth. The better growth and development of the larvae was achieved under the indoor conditions as a result of the optimum temperature and humidity which were maintained as per suggested by JOLLY *et al*. (1987) and GOEL & KRISHNA RAO (2004). BHATIA & YOUSUF (2014) studied the role of host plants, temperature, humidity, rainfall, photoperiod and climatic variables on the growth and development of the silkworm and found that the larvae of *A. mylitta* feed on many forest tree species, but always show a great degree of fussiness as a function of its behavioural responses to physical structure and chemical features of the host plants. Several earlier researchers have also reported the effect of temperature, humidity, photoperiod, season and host plants on the biology of the silkworms and their findings supports our results (LIU & TSAI, 2000; BALE, 2002; RODRIGUES & MOREIRA, 2004; NAVA *et al*., 2007; REDDY, 2010; KOI & DANIELS, 2017). The findings of RAJU & KRISHNAMURTHY (1987) suggested that the shooter larval duration is much beneficial as there are fewer chances of occurrence of disease, reduced feeding duration as well as a reduction in the cost of cocoon production. The spinning duration was shortest for the indoor conditions. Pupal weight can be usually considered as indirect but easily dignified indicator of the Lepidopteran insect fitness (LEUCK & PERKINS, 1972). The pupae produced by the larvae reared under indoor conditions were comparatively higher than that of pupae produced by the larvae reared under outdoor conditions. This re-in forces the suggestion that the indoor conditions are more suitable for rearing of Tasar silkworm. In addition to variations in the developmental rate and duration, there were marked differences in the survival of the larvae under the different conditions. Least mortality was observed in the indoor reared worms, which was much higher under natural conditions. This may be due to the reason that under natural conditions worms are easily accessible to its predators and also become more susceptible to diseases, leading to increased mortality rates. The observations pertaining to the economic parameters viz. cocoon characteristics, shell weight, silk ratio, cocoon per DFL and effective rate of rearing (ERR%) showed better results for the worms reared under indoor conditions. The results of the present study are in conformation with the study of SAIKIA *et al*. (2011) who performed the rearing of a population of a wild Tasar silk moth, *Antheraea frithi* Moore, 1858 in outdoor and indoor conditions, and found that the reproductive viability and productivity parameters were greatly influenced by the seasonal variations and the rearing conditions. The parameters like larval weight, cocoon weight, shell weight, shell ratio percent, etc., were found to be highest in the autumn season, followed by spring and summer. A significant variance (two-way ANOVA, at 5% & 1% level) of rearing parameters was found among the rearing seasons under the two rearing conditions. The silkworm breeding and rearing performance improves economically valuable traits to increase the profit of the sericulture industry. Calculation of breeding values, quantitative and qualitative traits, consanguinity, and heritability under the influence of the climatological parameters are the most important tool for improvement of silkworm productivity. The correlations among the traits have an important role in silkworm breeding. During the present study, the correlation of the growth parameters and economic traits were also analysed and a significant positive correlation was found between the larval weight and most of the economic traits except total larval duration, peduncle length and silk conversion index, where significant negative correlation exists. MAHESHA (2013) analysed the correlation between the commercial characters of the silkworm, *Bombyx mori* L. and found that out of the 36 selected traits, 20 traits showed a highly significant positive correlation, while the rest showed either moderate positive, negative or neutral correlation. The silk gland is an important organ that plays a major role in silk production and directly affects the yield (TAZIMA, 1978). Variations in the development of the silk gland may be due to the growing conditions.

There are many factors affecting the growth and development of the larvae including the climatological parameters, nutrient content in their diet and secondary substances of the host plant, digestibility, and assimilation by the insects. The overall results of the present study suggest that the rearing practices may be shifted indoor control conditions of temperature and humidity by means of polyhouses/rearing houses. This will result in achieving better growth and development and thus resulting in improved economic characteristics and better income of farmers. This technique shall be beneficial for the farmers in reducing the cost of cocoon production.

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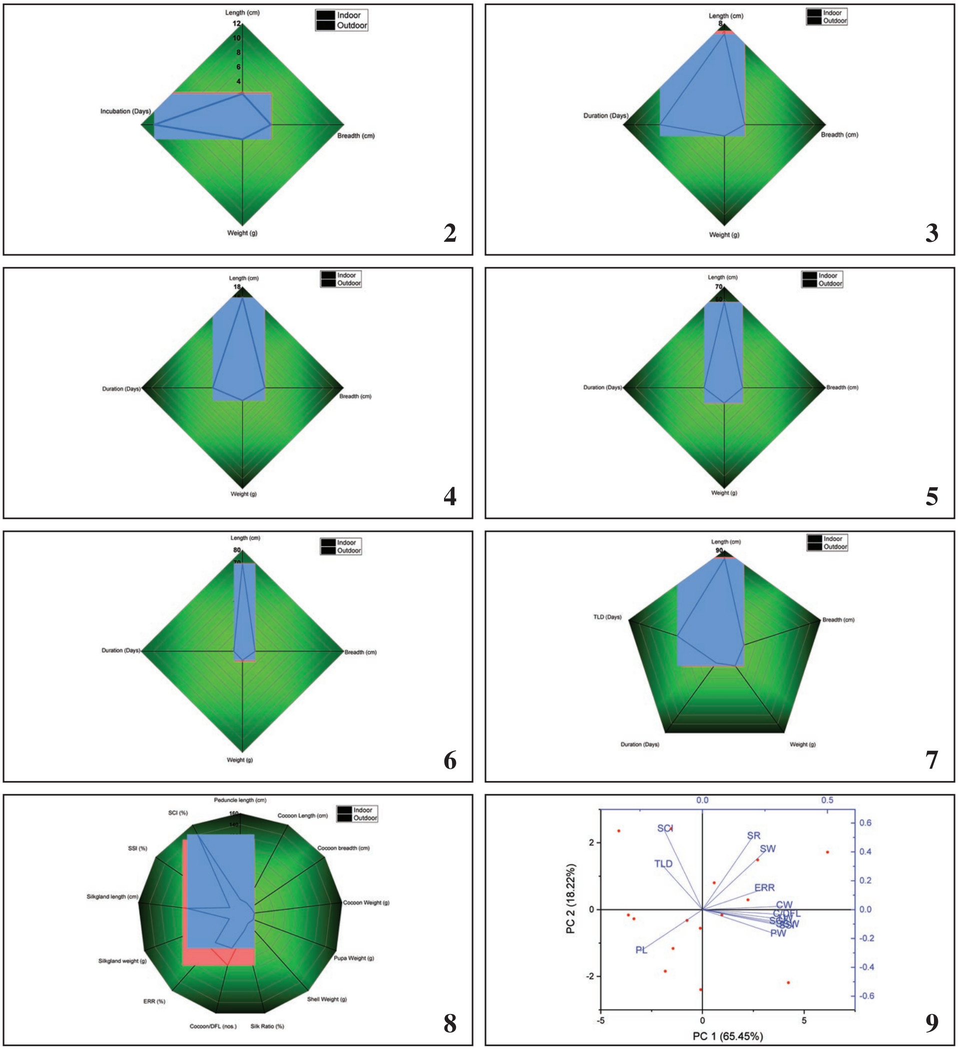

Figs 2-9.– 2. Egg Characteristics of oak Tasar silkworm, *Antheraea proylei* reared under two different conditions (on average basis). **3.** Characteristics of Ist instar larvae of oak Tasar silkworm, *Antheraea proylei* reared under two different conditions (on average basis). **4.** Characteristics of II^nd^ instar larvae of oak Tasar silkworm, *Antheraea proylei* J. reared under two different conditions (on average basis). **5.** Characteristics of III^rd^ instar larvae of oak Tasar silkworm, *Antheraea proylei* reared under two different conditions (on average basis). **6.** Characteristics of IV^th^ instar larvae of oak Tasar silkworm, *Antheraea proylei* reared under two different conditions (on average basis). **7.** Characteristics of V^th^ instar larvae of oak Tasar silkworm, *Antheraea proylei* reared under two different conditions (on average basis). **8.** Economic parameters of oak Tasar silkworm, *Antheraea proylei* recorded under two different conditions (on average basis). **9.** Ordination diagram of PCA of larval weight effect on associated economic parameters of the silkworm. The contribution rates of first 2 principal components were 65.45% and 18.22%, respectively. Variables with correlation are having vectors with opposing direction as well as orientation, while perpendicular ones indicates independent variables or no correlation.