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Standardization of rearing protocol for sustainable Eri Silk production in India: A focus on *Ricinus communis* and *Ailanthus grandis* through age-stage, two-sex life table approach

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Abstract

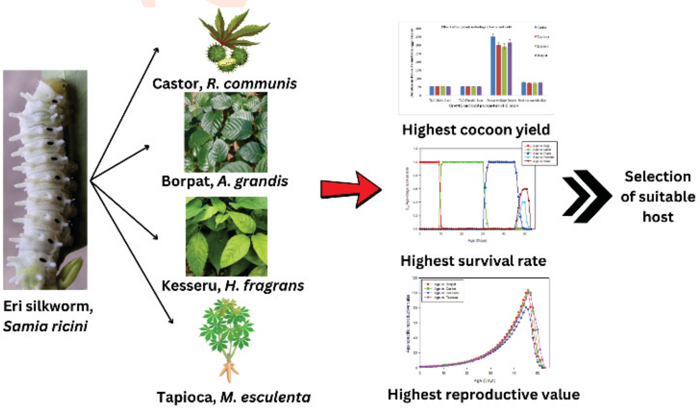
Aim: To standardize the rearing protocol for the Eri silk worm, *Samia ricini* (Donovan) (Lepidoptera: Saturniidae) by studying its life history traits.

Methodology: Fifty newly hatched larvae of *S. ricini* from disease-free layings were reared on leaves from four different host plants under controlled laboratory conditions. Observations were made on their developmental and reproductive traits. The life table parameters were constructed using the age-stage, two-sex life table method, and the analysis was conducted using the TWOSEX-MS Chart software.

Results: Highest fecundity was recorded on castor (350.16 eggs/ female), followed by borpat, *Ailanthus grandis* Baiu (Simaroubaceae) (315.16eggs/ female). The intrinsic rate of increase was higher on castor (0.10 female/females/day), followed by borpat (0.098/ female/females/day). Similarly, the net reproductive rate is highest on castor (128.34 female/females/generation), followed by borpat (125.14/ female/females/day). The population doubles for every 6.92 days on castor and 7.26 days on kesseru, *H. fragrans* Roxb (Araliaceae). The fresh cocoon yield of 100 disease free laying's larvae was highest on the castor, *i.e.,* 78 kg, while it was 74.75 kg on the borpat.

Interpretation: This study suggests that using castor and borpat host plants, either alone or in combination, benefits Eri culture. For combination feeding, castor can be used up to the chawki stage, with borpat for later stages. This method could lower production costs compared to solely using castor, which needs annual replanting, especially in North-east India, where farmers grow host plants only for ericulture.

Key words: *Ailanthus grandis*, Castor, Demographic parameters, Eri silkworm, Kesseru, *Ricinus communis*, Tapioca



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Introduction

Eri silk, commonly known as 'Endi silk' or 'Erandi silk,' is produced by *Samia ricini* (Donovan) (Lepidoptera: Saturniidae). It is economically considered the third most important silk in the world after Mulberry and Chinese Tasar silk (Suryanarayana, 2005). In India, Eri silk is the second most produced silk after mulberry silk, with a total output of 7359 metric tons in 2022-23. In North-eastern India, agriculture is uniquely intertwined with Ericulture, where Agroforestry-based farming prevails. Besides yielding spun silk, Eri silk also serves as a food source for farmers in the form of pre-pupa and pupa. These pupae are a food source and rich in proteins and lipids, making them a valuable nutritional supplement. The domesticated eri silkworm is multivoltine and exclusively reared indoors, distinguishing it from other wild silks. Eri silkworms produce open-ended cocoons, facilitating the extraction of live pupae, a practice known as Ahimsa silk, where pupae undergo complete metamorphosis into moths (Mahesh and Arunkumar, 2020). Eri cultivation aligns well with integrated farming ecosystems in North-east India due to its polyphagous nature, thriving on both annual and perennial host plants. Notably, the Eri silkworm tolerates various biotic and abiotic stresses, rendering it suitable for rearing in diverse agroclimatic conditions throughout the year (Mahesh and Arunkumar, 2020).

Moreover, larvae of the Eri-silkworm will eventually eat any plant leaves unless the leaves are too hard or hairy. The larvae are polyphagous and feed on the leaves of various plants, mainly belonging to the family Euphorbiaceae, Araliaceae, Apocynaceae and Simarubiaceae (Chowdhury, 1982). Though castor, *Ricinus communis* (Euphorbiaceae) is the primary host plant of the Eri silkworm, the availability of its leaves decline by the end of the year after sowing, as castor is an annual crop that requires sowing or establishment each year, consequently raising the production costs. Several other host plants, including Kesseru (*Heteropanax fragrans* Roxb.), tapioca (*Manihot esculenta*), Borpat (*Ailanthus grandis* Baiu.), Borkesseru (Ailanthus excelsa Roxb), Payam (*Evodia flaxinifolia* Hook.), *etc.,* are exploited for rearing Eri silkworms during the scarcity of castor. The nutritional status of leaves is considered a prime factor for the survival of silkworms (Kumara, 2023). Castor is rich in biochemical composition, foliar constituents and rearing parameters compared to other host plants (Mahesh *et al.,* 2023).

Different host plants may often exert variable effects on the relative survival of an herbivore insect (Anjumoni and Yadav, 2015). The growth, development and cocoon yield are influenced by the castor genotype and quality of leaves on which worms are reared (Pandey, 1995). Further, the larval and cocoon characters are greatly influenced by different hosts, which results in difference in cocoon yield and silk quantity (Subramanianan *et al.,* 2013; Anjumoni and Yadav, 2015). Life tables are valuable tools for assessing the consequences of external factors such as host plants, on the growth and development of insects (Ramalho *et al.,* 2015; Qayyum *et al.,* 2018). It provides an integrated and extensive description of a population's survival, development, and reproduction, thus giving an accurate estimate of the growth rate of an insect population (Tuan *et al.,* 2016; Chang *et al.,* 2016). An insect's life table parameters on a particular host plant offer essential clues regarding its fitness for that host plant (Liu *et al.,* 2004). They also make it easier to comprehend the dynamics of pest populations by giving a detailed account of the demographic characteristics of an insect population on a particular host plant (Qayyum *et al.,* 2018). It is generally known that the host plant's quality can influence the growth, death and fecundity of herbivorous insects (Price *et al.,* 1980; Chandrakumara *et al.,* 2024). The number of produced offspring on a host plant can be affected through more indirect route of reduced fecundity arising from feeding on nutritionally inadequate plants (Verkerk and Wright, 1996). These properties of host plants can play a vital role in insect population dynamics by enhancing immature and adult performance (Morgan *et al.,* 2001; Liu *et al.,* 2004). Shorter developmental time, greater total fecundity, and relatively higher survival rate of insects on a host plant indicate a greater preference for that host plant. The population dynamics of silkworms on different host plants give information on the preference for various alternative hosts.

Further, establishing the larval population on a particular host determines the final cocoon harvest and silk yield. Keeping all these points in view, the current investigation aimed to comprehend the preference and population dynamics of Eri silkworms on diverse host plants including Castor, Borpat, Kesseru and Tapioca. This is the first attempt from India to understand the life table and demographic parameters of Eri silkworm on diverse host plants, which ultimately helps in exploiting alternative host plants in the event of uncertainty in rainfall and adverse climatic conditions to achieve sustainability in Eri culture.

Materials and Methods

Plant material: Different host plants of the Eri silkworm, including Castor, Borpat, Kesseru and Tapioca, were grown in experimental plots of the Germplasm Conservation Centre (GCC) of CMER&TI, Chenijan, Jorhat, Assam (26°46'56"N. 94°17'13"E.). The study centre is located 94.12 m (308.79 feet) above sea level. The experimental area has a humid subtropical, dry winter climate, with annual temperature of 25.67ºC. All these climatic attributes are well suited for raising host plants as well as silkworm rearing. Additionally, all the recommended agronomic practices were followed to raise the host plants. Randomly selected plants of each test host plant were tagged for biological studies.

Developmental biology of *Samia ricini* on test host plants: The biological studies of *S. ricini* on leaves of test host plants were carried out at 25±1°C temperature and 70-80% relative humidity under controlled conditions in the laboratory. Disease-free laying of Eri silkworms from own source (Grainage, CMERTI, Lahdoigarh) were collected, and 50 newly hatched larvae after black boxing were brushed on the respective host plants kept in a plastic tray measuring 2 × 3 feet. The experiment was laid out for each test host plants *viz., R. communis, H. fragrans, M. esculenta* and *A. grandis* in a completely randomized design. The observations were recorded on incubation period, total larval period (from first instar to end of fifth instar), pre-reproductive period (emergence of adult to first day of oviposition), reproductive period (first day of oviposition to last day of oviposition), post-reproductive period (last day of oviposition to death of adult), total developmental period (birth of the first instar larvae to death of the resulting female) and daily fecundity (number of eggs produced per day by each female). Finally, the fresh cocoon yield of *S. ricini* from 100 Disease Free Layings (DFL) larvae was recorded to assess the impact of different host plants on the quantitative output of silkworm cocoons.

Construction of life table of *Samia ricini*: The biological and reproductive data were analyzed by One-way ANOVA, followed by a comparison of the means with least significant difference (LSD) test at α=0.05 using the online statistical software WASP-Web Agri Stat Package 2.0. The life tables of both the pests were constructed with 'TWOSEX-MS Chart' software. According to the age-stage, two-sex life table principle (Chi, 1988; Huang and Chi, 2012) and method (Tuan *et al.,* 2014), the following parameters viz.,

Age-stage-specific survival rates, age-specific survival rate, age-stage-specific fecundity, age-specific fecundity (m_x): age-specific maternity, age-stage-specific life expectancy (e_{xj}): age-stage-specific reproductive value (V_{xj}): intrinsic rate of increase ®: finite rate of increase (λ): net reproductive rate (R_0): mean generation time(T): were calculated.

The raw life-history data for *S. ricini* obtained for each of the hosts were entered separately into the notepad (text document). TWOSEX-MS Chart 2024 software (available from the web page http://140.120.197.173/Ecology/prod02.htm) was used to calculate each population parameter. The means, standard errors and variances of the population parameters by bootstrapping technique (100,000 repetitions) (Efron and Tibshirani, 1993). The software greatly simplifies the normally laborious and time-consuming process of calculating all the relevant population parameters. Sigma plot 14.5 was used to create graphs.

Results and Discussion

The results on the total life cycle of *S. ricini* on different host plants shows the males lived longer than the females (Fig. 1), further the fecundity of *S. ricini* on castor (350.16 eggs/ female) was significantly more than the other crops, followed by borpat (315.16 eggs/ female) and least number of eggs were recorded on kesseru (291.18 eggs/ female). In line with our findings, Sarkar *et al.* (2015) showed that the grainage performance of *S. ricini* can also be influenced by different cultivars of a host plant. Besides biological parameters, population or demographic parameters are essential in predicting the population dynamics of any insect. In sericulture, these tools provide detailed information on the influence of host plants on the silkworm population growth rate.

This information facilitates for maximum rearing performance of silkworms on the most suitable host plants. The population buildup, which can be assessed using several crucial growth parameters like Gross Reproduction Rate (*GRR*), Net Reproduction Rate (R_0), Intrinsic Rate of Increase *(r)*, Finite Rate of Increase *(λ)*, Generation Time *(T)* and Doubling Time *(DT)*, evaluates the insect's preference for its host and eventual acceptance. Ecologists frequently employ the intrinsic rate of increase *(r)* as an essential measure in their demographic analyses of insect populations to compare population fitness under various conditions (Chandrakumara *et al.,* 2024; Keerthi and Suroshe 2024a; Keerthi *et al.,* 2024). The intrinsic rate of

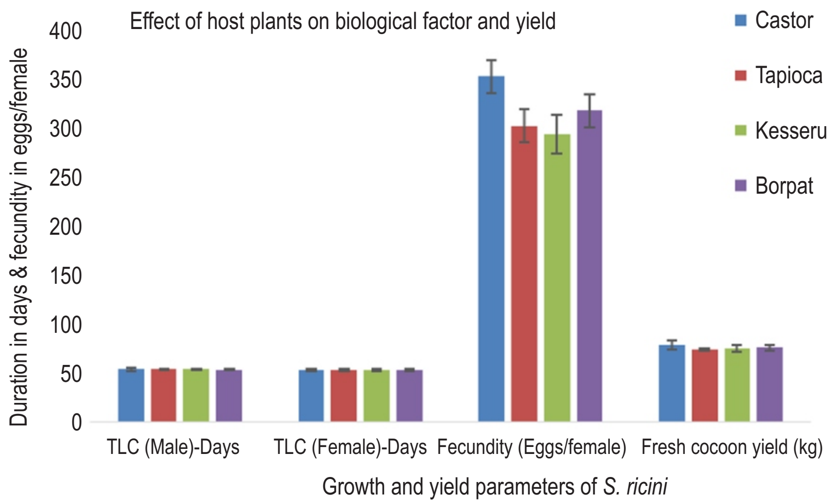

Fig. 1: Variations in the biological parameters of *Samia ricini* on different host plants under laboratory conditions

increase *(r)* is the number of females produced per female/day. Gotelli (2008) stated that *r* reveals whether a population is declining (r< 0), growing exponentially (r > 0), or remaining constant (r= 0). In the present study, the value of the *r* for all test cultivars was more than zero *i.e.,* the population showed an increasing trend. However, the analysis of the bootstrapping values showed that *r* varied considerably among the tested host plants. The results showed that the *r* value of *S. ricini* on different hosts was maximum on castor (0.100) followed by Borpat (0.098), Tapioca (0.098) and Kesseru (0.095) (Table 1).

The finite rate of increase *(λ)* also followed the same trend, where castor (1.11) was recorded with the highest *λ* followed by Borpat (1.10), Tapioca (1.10) and Kesseru (1.10) (Table 1). The *r* value covers numerous factors, including fecundity, survival and generation time, providing a comprehensive measure of the physiological attributes of an insect in terms of its capability to multiply. It serves as a highly suitable metric for assessing the performance of an insect on various host plants and gauging the suitability of host plants (Huang and Chi, 2012; Tuan *et al.,* 2014; Ning *et al.,* 2017). Earlier studies also recorded the highest intrinsic rate of increase of an insect on the most preferable host plants as compared to less preferred ones (Chandrakumara *et al.,* 2024; Keerthi and Suroshe, 2024). Furthermore, the number of produced offspring on a host plant can be affected through the more indirect route of reduced fecundity arising from feeding on nutritionally poor plants (Verkerk and Wright 1996). These properties of host plants can play a role in insect population dynamics by affecting immature and adult performance (Morgan *et al.,* 2001; Liu *et al.,* 2004).

The *GRR* was highest on Tapioca (180.26), followed by Borpat (147.80), castor (132.06) and Kesseru (109.44) (Table 1). However, the net reproductive rate of *S. ricini* was highest on castor (128.34) followed by Borpat (125.14), Tapioca (124.96) and Kesseru (99.00), implying the significant influence of constitute and induced physico-chemistry of host plants on silkworm bionomics. Similarly, the lowest net reproductive rate of insects was prominently observed on the least preferred host plant as compared to the more preferred one in earlier studies (Chandrakumara *et al.,* 2024; Keerthi and Suroshe, 2024). Likewise, the faster developmental rate on a particular host cultivar may allow a short life cycle and rapid population growth, which would be subsequently reflected in the final population size. Mean generation time (T) is one of the important parameters indicating an average interval between an individual's birth and its offspring. The mean generation time was longer on Tapioca (49.14) followed by Borpat (49.10), castor (48.24) and Kesseru (48.11), while the doubling time was longer on Kesseru (7.26), followed by Tapioca (7.06), Borpat (7.01) and Castor (6.92) (Table 1). Several findings also suggest that shorter developmental times and higher reproduction of herbivore insects on a host plant indicate higher susceptibility of a host plant and vice-versa (van Lenteren and Noldus 1990; Liu *et al.,* 2004; Golizadeh and Razmjou 2010; Chandrakumara *et al.,* 2024; Keerthi and Suroshe, 2024). Various parameters, including the physico-morphic characteristics, biochemical content and nutritional value of the host plant, may influence these discrepancies in the performance of Eri silkworm on different host plants. Further, cultivars of a single host plant also influence the bionomics of silkworms (Swathiga *et al.,* 2019).

It is well documented that the host plant quality can impact the life history traits of their herbivore insects by impairing growth, increasing mortality, and reducing fecundity (Price *et al.,* 1980). Chemical properties such as secondary metabolites and nutrient balance, photosynthetic pigments and various regulating enzymes such as AO, APX, catalase, PAL, TAL and myrosinase vary from one host plant to another and consequently influence population levels of the herbivore insects differently (Bhoi *et al.,* 2020; Sau *et al.,* 2022; Samal *et al.,* 2022; Chandrakumara *et al.,* 2023a, 2023b; Chandrakumara *et al.,* 2024). The biochemical contents/parameter levels in different host plants considered in this study may differ, and our results may reflect this variability. These variability among several parameters may finally exhibit the disparity in the final output, *i.e.,* raw silk production by silkworm. Similarly, the fresh cocoon yield of 100 DFL larvae was highest on the castor, *i.e.,* 78 kg, while it was 74.75 kg on the Borpat host and lowest on tapioca (73.25 kg), signifying the superiority of castor, followed by Borpat. Similarly, Kakati and Merenjungla (2018) also showed significant variation in the yield parameters of eri silk reared on different alternate host.

The values of S_{xj} of *S. ricini* varied across developmental stages, and the survival curves overlapped, which can be

Table 1: Disparities in the demographic parameters of Eri silkworm, *Samia ricini* mass reared on different annual and perennial host plants

Host	Intrinsic rate of increase (females/ female/day)	Finite rate of increase (females/ female/day)	Net reproductive rate (females/ female/generation)	Gross reproduction rate (females/ female/generation)	Mean generation time (Days)	Doubling time (Days)
Borpat	0.09±0.018	1.10±0.077	125.14±1.86^{a}	147.80±1.74^{b}	49.10±0.33	7.01±0.34
Castor	0.10±0.022	1.11±0.111	128.34±2.80^{a}	132.06±1.06^{c}	48.24±0.91	6.92±0.44
Kesseru	0.09±0.012	1.10±0.074	99±1.07b	109.44±1.17^{d}	48.11±0.93	7.26±0.35
Tapioca	0.09±0.016	1.10±0.070	124.96±1.64^{a}	180.26±0.73^{a}	49.14±0.90	7.06±0.20
F Cal	0.003	0.001	55.49	575.35	0.515	0.180
P value	1.000	1.000	<0.0001	<0.0001	0.678	0.909

Means (± SE) within one row followed by different letters are significantly different at 0.01level based on One-way ANOVA and DMRT

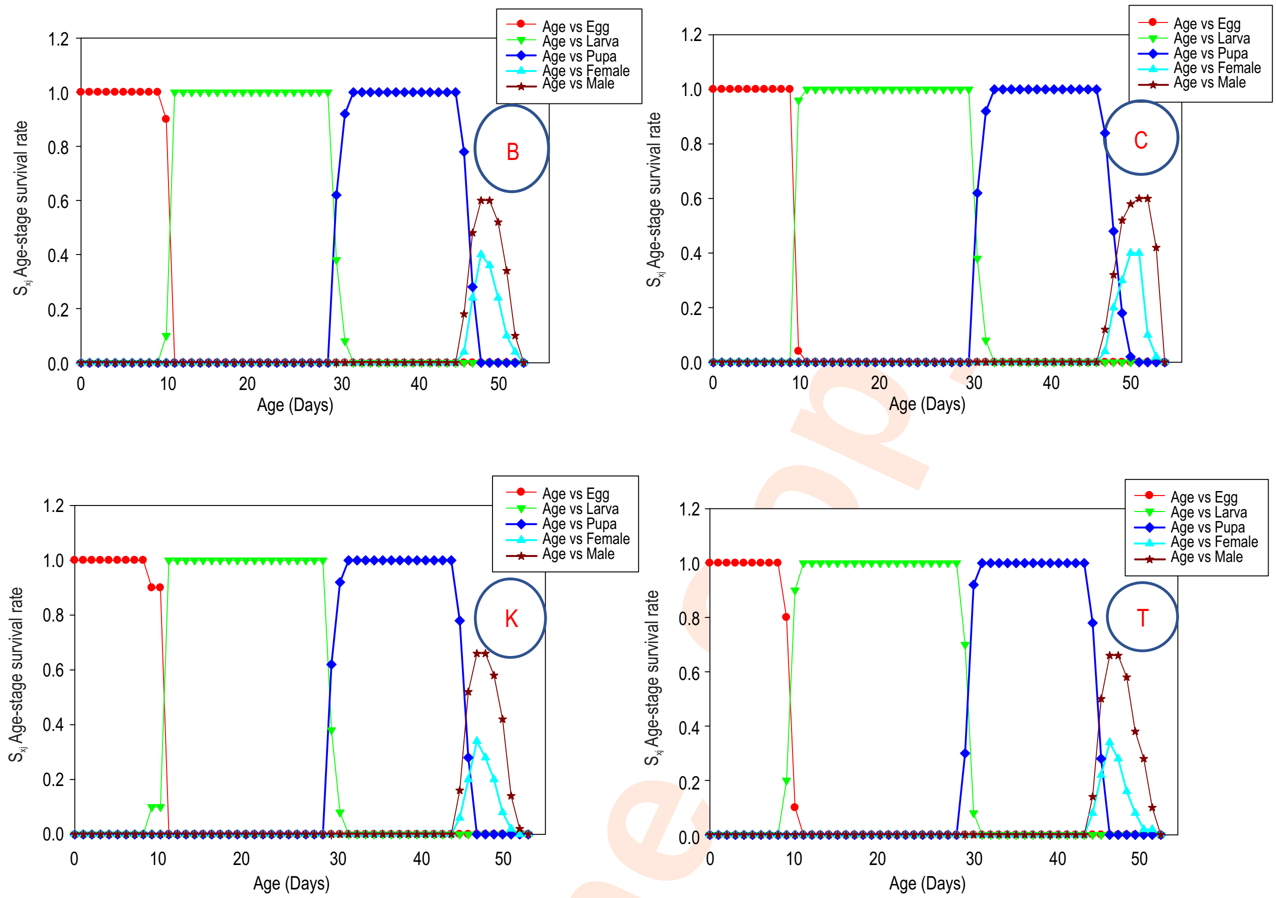

Fig. 2: Variations in the Age stage survival rate (S_{xj}) of *Samia ricini* on B (Borpat), C (Castor), K (Kesseru) and T (Tapioca).

attributed to the fact that different individuals grow at different rates (Fig. 2). The lowest S_{xj} of stage larva was observed on Tapioca (0.90). Further, it was 0.99 on the castor, while on other hosts, it was 1. During the adult stage, the highest S_{xj} of females was observed on castor (0.45) and Borpat (0.45), while the lowest was on Tapioca (0.38) and Kesseru (0.38). However, the value of S_{xj} for male was observed on Tapioca (0.70) and Kesseru (0.70), while the lowest on castor (0.60) and Borpat (0.60) (Fig. 2). Age-specific total fecundity of *S. ricini* was highest on 49th day in all the host plants *viz.,* Borpat (1800), followed by Castor (1600), Tapioca (1600) and Kesseru (1500) (Fig. 3). These findings provide valuable insights into the bionomics and population growth parameters of Eri silkworm, enhancing our understanding of its behavior and preferences.

The influence of brassicaceous hosts on the survival rate and fecundity of *S. ricini viz., l_x, f_x* and $l_x \cdot m_x$ showed a downward trend with increasing age. The estimated values indicated that the death of the last adult (female) occurred early on Borpat and Kesseru. In contrast, late on Castor and Tapioca (Fig. 4). The results showed that the maximum f_x value was recorded on Castor (1.0) and Tapioca (1.0) on the 46th day. In contrast, the lowest f_x value was recorded on the 45th day in Kesseru. Similarly, $l_x \cdot m_x$ reached its maximum value on Borpat (0.1), followed by Tapioca (0.09), Castor (0.08) and Kesseru (0.07) on the 46th, 47th, 46th and 48th day, respectively. The seed availability in sericulture ultimately depends on the emergence of gravid females from the pupae. The current experiment showed a higher population survival rate and fecundity on castor than other hosts, implying that castor is preferred by *S. ricini*, followed by Borpat and Tapioca. In sericulture, successful seed production depends largely on the emergence of vigorous, gravid females, making host-plant quality a critical factor. In the present study, Casror, *Ricinus communis* supported the highest survival and fecundity rates, confirming its role as the most effective host plant for *S. ricini*, closely followed by Borpat and Tapioca. These findings align with the previous studies that emphasize Castor's superior nutritional profile and its positive influence on cocoon yield, larval growth, and reproductive traits (Ahmed *et al.*, 2015; Anjumoni and Yadav, 2015; Kakati and Merenjungla, 2018). The enhanced performance observed on castor is likely due to its rich biochemical composition and optimal leaf quality, which are known to promote physiological development and reproductive efficiency in eri silkworms.

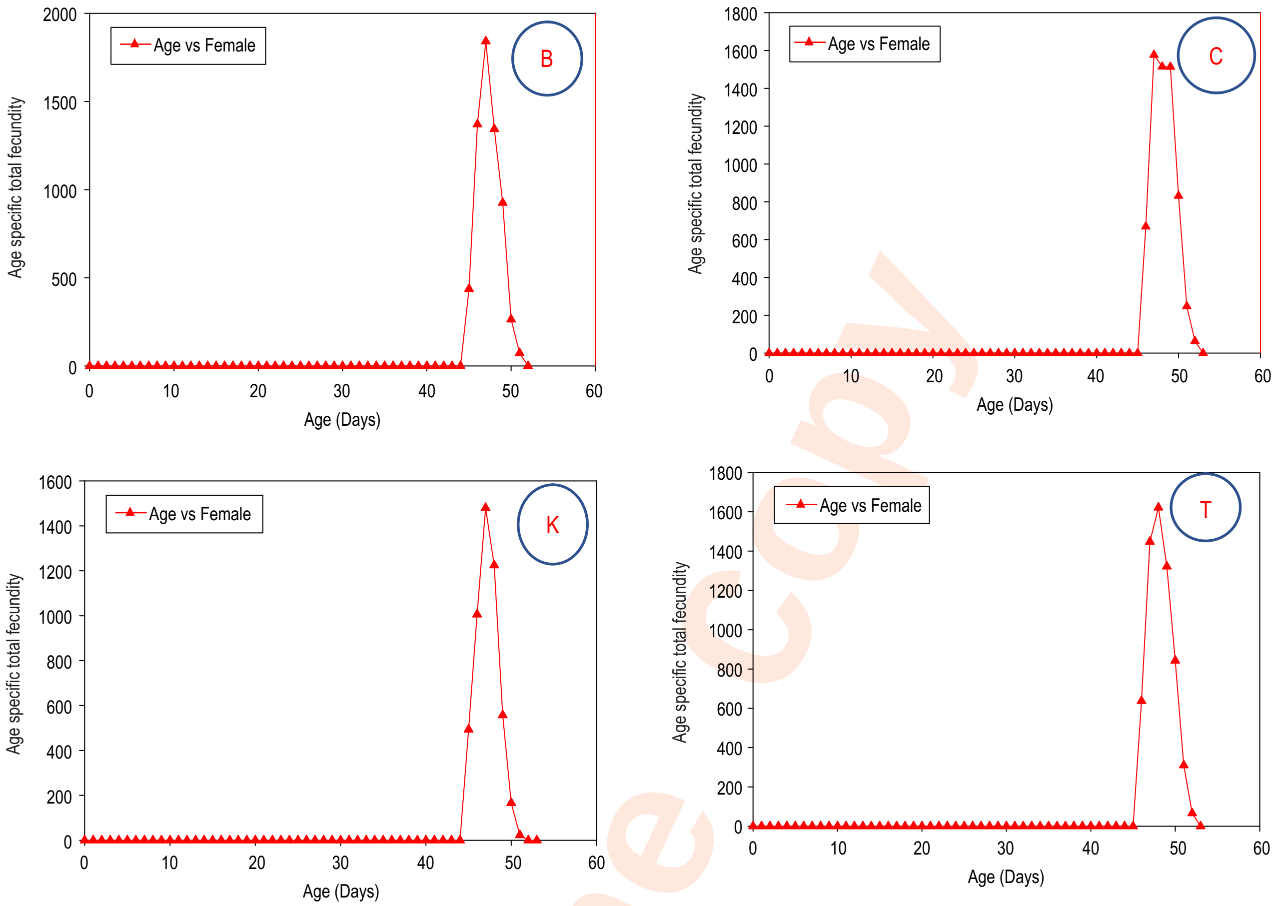

Fig. 3: Variations in the Age specific total fecundity of *Samia ricini* on B (Borpat), C (Castor), K (Kesseru) and T (Tapioca).

The age-specific life expectancy (e_x) estimates the time individuals of age x are expected to live (Fig. 5). The expected longevity of *S. ricini* at age zero (e_0) was in the ascending order as follows: Kesseru < Tapioca < castor < Borpat. In all the tested crops, the results showed that as age advanced, the chances of survival decreased. The age-specific reproductive value (v_x) indicates the contribution of individuals from age *x* to the future population (Fig. 6). The results showed that as reproduction begins, the curve for the reproductive value increases rapidly. The peak of the vx curve was highest on Borpat, followed by Castor, Tapioca and Kesseru, implying that reproductive performance was good on Borpat and Castor as compared to other host plants. In the past, researchers have endeavored to examine the biological parameters of *S. ricini* on different host plants (Swathiga *et al.,* 2019; Bindroo *et al.*, 2007).

Nevertheless, upon review, it becomes evident that these studies have yet to provide a comprehensive account of the survival rates, life expectancy and reproductive values of *S. ricini* graphically at different age intervals, particularly in the context of significant host plants. The intrinsic and finite rate of increase and GRR were notably higher in the current investigation. At the same time, the mean generation and doubling time were lower on the castor than other cultivars, implying that the *S. ricini* multiplied faster on the castor than other host plants. Moreover, the survival rate of the larvae hatched is more important than the number of eggs produced by the adult (Keerthi and Suroshe, 2024b). In that case, castor, followed by Borpat was also recorded with the highest R_0 as compared to other cultivars, indicating more preference for *S. ricini.* However, castor is the annual host plant of Eri silkworm, and the availability of leaves throughout the year may hinder silkworm rearing. If it is cultivated across the year for rearing, it may also increase the cost of cultivation. However, Tapioca could be one of the promising alternatives in place of castor during its unavailability (Patil *et al.,* 2009). However, the current findings showed the lowest performance of Eri silkworm on Tapioca, as the R_0 was lowest compared to Castor and Borpat. This may also be attributed to the presence of anti-nutritional/ toxic such as hydrogen cyanide in Tapioca. Hence, looking for the best alternative perennial host plant is crucial for successful year-round Eri culture practices. Borpat is a perennial host and a highly preferred host plant of the Eri silkworm.

The current study also highlighted the positive influence

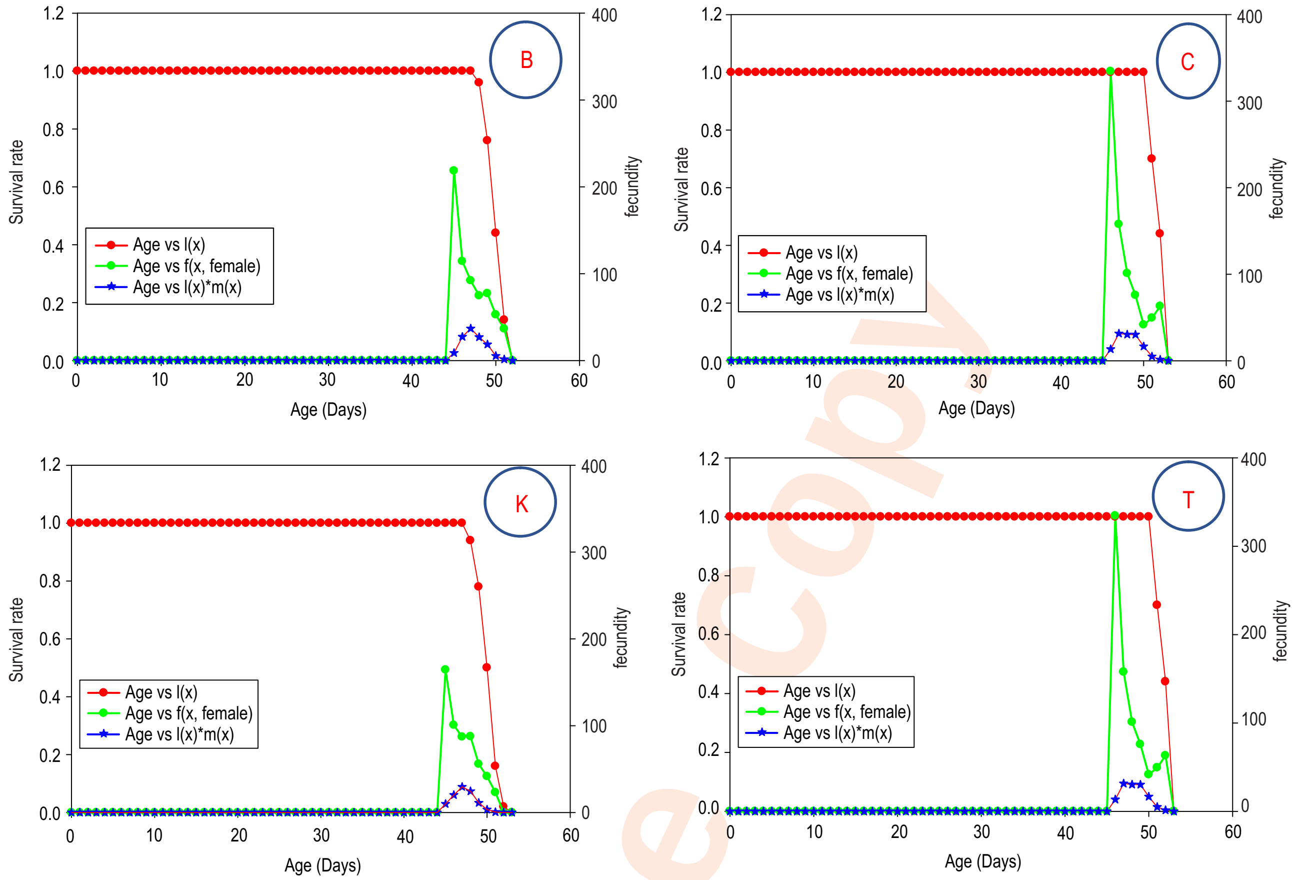

Fig. 4: Variations in the Age specific survival rate and fecundity of *Samia ricini* on B (Borpat), C (Castor), K (Kesseru) and T (Tapioca).

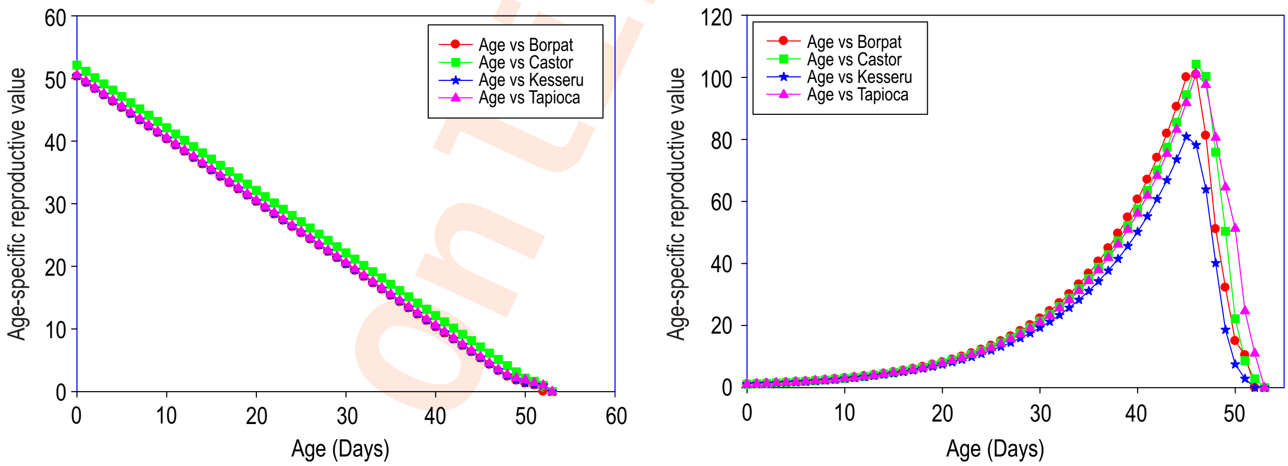

Fig. 6: Variations in the Age specific reproductive value of *Samia ricini* on different hosts.

of Borpat on the bionomics and population growth parameters of the Eri silkworm, suggesting that Borpat can be exploited in commercial Eri silkworm rearing either solo/or in combination with castor. It is always advisable to opt for combined rearing rather than solo rearing. This approach is supported by positive population growth parameters, such as the intrinsic rate of increase and net reproductive rate, observed with castor. Additionally, life expectancy and reproductive value were favorable with Borpat. Therefore, feeding both castor (during the chawki stages up to the 2nd instar) and Borpat (for late-age rearing from the 3rd to the 5th instar) in combination may address feed unavailability and help sustain year-round Eri culture. Similarly, a previous study also documented better results when feeding Castor and Borpat in combination (Ahmed *et al.,* 2015).

In conclusion, this study examined how four host plants- Castor, Borpat, Tapioca, and Kesseru, affect the population growth rate of *S. ricini* and the resulting cocoon yield. Among these plants, Castor and Borpat showed the best performance based on metrics like intrinsic and finite rates of increase, net reproductive rate, life expectancy and reproductive values. Although castor is an annual crop, increasing production costs, combining it with Borpat (used during later stages) can reduce costs and ensure a continuous leaf supply. This strategy can boost the income of the farmers, support the industrialization of Eri culture, and enhance sustainability.

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Authors' contribution: D.S. Mahesh, K.P. Arun Kumar: Conceptualized, planned and executed the research; **K. Chandrakumara:** Wrote and edited the original manuscript; **M.C. Keerthi:** Analysed the data and reviewed the manuscript; **K. Neog:** Supervision, revision and editing of the manuscript.

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Data availability: All the data analysed for this study are included.

Consent to publish: All authors agree to publish the paper in *Journal of Environmental Biology.*

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