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Evaluation of commercial traits in bivoltine pure breeds of silkworm *Bombyx mori L.* for a breeding programme

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Abstract
The study evaluates the commercial characteristics of the bivoltine pure breeds APS12, J2, CSR53, A3, H281, RB18 and the control breeds KA and NB4D2 to assess the potential of these pure breeds in expressing differential quantitative traits for breeding programs. The pure breeds reared evaluated in all the three season of the year exhibited superiority and consistent mean values for hatching percentage, effective rate of rearing, cocoon weight, shell weight, shell ratio, pupation rate, pupation percentage, denier and raw silk recovery, revealed the superiority of the pure breeds over the control breeds in all the three seasons of the year. Hatching percentage exceeded 90% in all pure breeds, with H281n showing the highest rate at 95.21%. The highest cocoon weight was observed in the pure breed H281 (1.71 g), while J2 recorded the highest shell weight (0.35 g) and shell ratio (21.25%). Pupation rates surpassed 90% in all pure breeds and filament length was recorded above 1,000 meters in the control breeds. The study results demonstrate that the pure breeds exhibit superior performance in most economic traits, likely due to inherent genetic advancements. However, the control breeds were superior in certain traits, such as fecundity, larval weight, filament length and denier. Seasonal performance also varied, with the monsoon season (June to October) being the most favorable for all pure breeds, followed by post-monsoon (November to February) and pre-monsoon (March to May).

Keywords: Silkworm, *Bombyx mori* L, pure breed/race, control breeds, breeding, seasons, economic traits, quantitative traits

Introduction
The silkworm *Bombyx mori* L is a key insect in the production of silk, with its commercial traits having significant economic importance success of the sericulture industry is influenced by numerous factors, among which environmental factors, both biotic and abiotic, play a critical role in the growth and productivity of silkworms. Among the abiotic factors, temperature has a significant impact due to the poikilothermic (cold-blooded) nature of silkworms (Bench Amin and Jolly, 1986) [2]. As a result, sericulture is one of the important commercial crops in our country and hence India occupies second prominent position in the global silk production next to China (Datta, 1999) [5]. Realizing the importance of tropical environment for the production of quality silk, several studies were undertaken to understand the impact of different seasons on mulberry crop and cocoon production (Narayanan *et al.*, 1964) [10]. It is important to note that the introduction of promising bivoltine races during 1970-2000 has resulted in the increase of silk production by folds (Datta, 2000) [4]. Bivoltine silkworms in particular, have been the focus of various breeding programs aimed to improving silk yield, quality and robustness to environmental conditions. The studies have clearly demonstrated the influence of environmental factors on the expression of economic traits irrespective of the silkworm races and breeds (Umashankar and Subramanya, 2002) [23]. This study aims to assess the commercial characteristics of selected bivoltine pure breeds, viz., APS12, J2, CSR53, A3, H281 and RB18 alongside control breeds KA and NB4D2. The genotype of silkworm races which are selected for experiment related hybridization or for any basic experiment needs to be systemically reared and evaluated in known environmental conditions to understand the expression of economic traits (Tazima, 1998) [24]. Such an analysis of variable performance of both multivoltine and bivoltine races/breeds in different environments of our country have been demonstrated by many silkworm breeders.

(Narasimhanna, 1976; Subramanya, 1985; Maribashetty, 1991: Nirmal Kumar, 1995; Kalpana *et al*., 1998; Datta, 2000; Basavaraja *et al*., 2004; Rohith L Shankar *et al*., 2008) [8, 19, 11, 9, 7, 4, 1, 16].

Materials and Methods

The study was conducted over a year in three seasons: pre-monsoon (March-May), monsoon (June-October) and post-monsoon (November-February). Three replications were maintained for each season. For both selected pure breeds and controlled breeds.

- **Silkworm breeds studied:** The following bivoltine pure breeds were selected for the study: breeds APS12, J2, CSR53 characterized by white dumbbell cocoons and A3, H281, RB18 characterized by white oval cocoons. KA is a white oval- shaped cocoon and NB4D2 is white dumbbell-shaped cocoon utilized as control breeds.
- **Economic characters studied:** There are twelve economic characters studied in this analysis. Viz., fecundity, effective rate of rearing (ERR), larval weight, larval duration, cocoon weight, shell weight, shell percentage, pupal weight, pupation rate, filament length, denier and raw silk percentage.
- **Statistical methods:** The analysis of variance (Anova) was estimated following the methodology described by Snedecor and Cochran (1976). The data obtained on the seasonal performance of the bivoltine pure and controlled breeds was analyzed by employing the statistics SPSS 2.0 packages.

Pure breeds-Figure 1 and Figure 2

Fig 1: Oval shaped cocoons

Fig 2: Dumbbell shaped cocoons

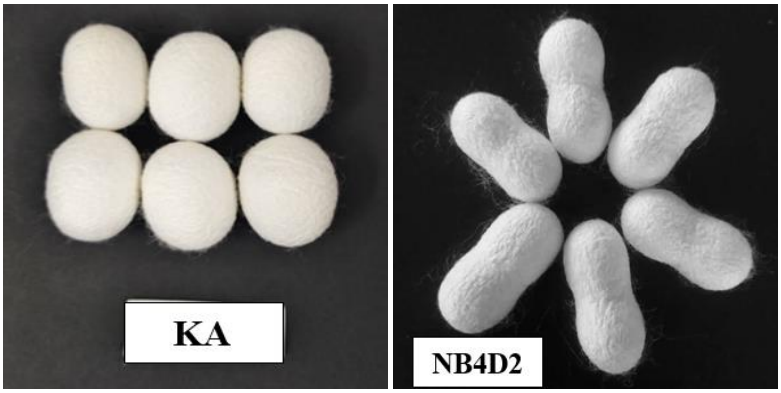

Fig 3: Control Breeds

Table 1: The morphological characteristic features of bivoltine pure and control breeds/races

Sl. No.	Race/breeds	Origin	Larval marking	Cocoon colour	Cocoon shape	Voltinism
1.	APS12	India	Marked	white	Dumbbell	Bivoltine
2.	J2	India	Marked	White	Dumbbell	Bivoltine
3.	CSR53	India	Marked	White	Slight dumbbell	Bivoltine
4.	A3	India	Plane	White	Oval	Bivoltine
5.	H281	India	Plane	White	Oval	Bivoltine
6.	RB18	India	Plane	White	Oval	Bivoltine
7.	KA	India	Plane	White	Oval	Bivoltine
8.	NB4D2	India	Plane	white	Dumbbell	Bivoltine

Table 2: Economic characters of the parental and control bivoltine breeds (averaged seasonal)

Breeds	Fecundity	Hatching (%)	ERR (%)	Larval. Weight (g)	Cocoon. Weight (g)	Shell. Weight (g)	Shell. Ratio (%)	Pupal. Weight (g)	Pupation (%)	Filament. Length (M)	Denier	Raw Silk (%)
APS-12	477.33	92.45	85.69	4.48	1.68	0.34	20.27	1.34	90.16	1058.00	3.14	18.39
J2	497.33	92.49	83.89	4.34	1.66	0.35	21.34	1.30	91.36	1040.33	2.79	18.29
CSR53	484.00	91.75	82.97	4.33	1.56	0.32	20.44	1.37	92.72	1034.33	2.84	19.81
A3	522.33	93.15	86.13	4.46	1.63	0.31	18.41	1.32	90.61	1065.00	3.36	20.43
H281	512.33	95.21	86.16	4.65	1.72	0.33	19.23	1.38	93.28	1068.67	3.01	21.14
RB18	512.00	93.90	85.80	4.67	1.55	0.31	18.81	1.24	91.21	1051.33	2.92	20.55
NB4D2	552.00	91.49	89.44	4.39	1.61	0.31	19.19	1.31	90.50	1085.33	2.52	19.05
KA	545.00	93.37	90.49	4.58	1.57	0.32	19.79	1.24	89.20	1085.67	2.75	18.89
F-TEST	NS	S	NS	NS	S	S	S	S	S	S	NS	S
SD	26.70	1.21	2.54	0.13	0.06	0.02	0.97	0.05	1.34	18.96	0.26	1.07
SE(M)	6.93	0.79	0.54	0.59	0.75	0.01	0.51	0.04	0.74	22.37	0.09	0.79
SE(D)	9.80	1.12	0.76	0.84	1.06	0.02	0.72	0.05	1.04	31.64	0.13	1.11
C.V.	2.34	1.47	3.09	3.37	4.08	6.36	4.50	4.84	1.40	3.65	5.23	6.98
F-VALE	10.93	2.11	11.62	4.68	1.95	2.06	2.25	1.58	3.64	0.79	6.70	1.90
SIGN.	.000	.102	.000	.005	.127	.109	.085	.211	.015	.606	.001	.137

Results and Discussion

The evaluation of commercial characteristics across bivoltine pure breeds (APS12, J2, CSR53, A3, H281 and RB18) and control breeds (KA, NB4D2) revealed significant variations in key economic traits. The pure breeds showed superior performance across most of the traits studied, which is indicative of their genetic potential for future breeding programs.

- Fecundity (Number of Eggs) the fecundity values ranged from 477.33 (APS-12) to 552.00 (NB4D2), with NB4D2 recording the highest fecundity. Despite this range, the F-Test result for fecundity was non-significant (NS), indicating that the variations among breeds are not statistically significant. This suggests that fecundity is not a decisive factor for distinguishing between these silkworm breeds. Prior studies (Kumar *et al.*, 2022) have similarly noted that environmental factors, alongside genetic variation, can moderate fecundity across silkworm strains.
- Hatching Percentage hatching percentage ranged from 91.49% (NB4D2) to 95.21% (H281), with a statistically significant difference with a (p<0.05) found among the breeds. H281 shows superior hatching percentage that highlights its strong potential for producing a higher number of viable larvae, a critical factor in commercial rearing. According to Singh *et al.* (2021) [20], higher hatching rates are often linked to enhanced larval quality and better environmental adaptability.
- Effective Rate of Rearing (ERR%) the ERR% ranged from 82.97% (CSR53) to 90.49% (KA), with no statistically significant differences among the breeds (NS). This finding suggests that ERR%, while important, may not vary substantially across breeds in controlled conditions. Previous research Sharma & Pandey (2019) [18] highlights how rearing practices, more than breed-specific traits, can influence ERR, reinforcing the non-significant differences in this study.
- Larval Weight ranged from 4.33g (CSR53) to 4.67g (RB18), with minor differences observed among breeds. However, the F-test result was non-significant, indicating that the differences in larval weight do not represent a statistically meaningful distinction. The relatively small variation in larval weight aligns with findings by Rao *et al.* (2020) [15], who suggested that nutrition plays a more pivotal role than Genetics in determining larval weight.
- Cocoon Weight and Shell Weight - cocoon weight ranged from 1.55g (RB18) to 1.72g (H281), and shell weight varied from 0.31g (A3, RB18, NB4D2) to 0.35g (J2). Significant differences (p<0.05) were found in both cocoon and shell weight. H281 and J2 performed well, producing heavier cocoons and thicker shells, respectively. Cocoon weight and shell thickness are key indicators of economic value and breeds like H281 and J2 are favored by silk producers. These findings align with work by Reddy *et al.* (2020) [14], who emphasized the role of Genetic improvement in enhancing cocoon characteristics.
- Shell percentage is an important determinant of silk yield, ranged from 18.41% (A3) to 21.34% (J2), with a significant difference among the breeds (p<0.05). J2 exhibited the highest shell percentage, which correlates with its superior shell weight. According to Choudhary and Yadav (2018) [3], shell percentage is a critical selection criterion in breeding programs aimed at improving silk yield, making J2 an ideal candidate for such efforts.
- Pupal Weight ranged from 1.24g (RB18, KA) to 1.38g (CSR53, H281), with significant differences observed. Heavier pupae, such as those in CSR53 and H281, are

often associated with better silk yield, as confirmed by the study conducted by Verma *et al*. (2021) [22]. The correlation between pupal weight and silk production suggested that breeds like H281 holds substantial commercial potential.

- Pupation Rate, which indicates the percentage of larvae successfully transforming into pupae, ranged from 89.20% (KA) to 93.28% (H281). The F-test result showed a significant difference, H281 outperforming other breeds. High pupation rates are critical for silk production and breeds like H281, with their robust pupation capabilities, are considered ideal for rearing (Ghosh *et al*., 2021) [6].
- Filament Length and Denier filament length varied significantly among the breeds, ranging from 1034.33M (CSR53) to 1085.67M (KA), whereas denier (thickness) did not show significant differences. Filament length is an important factor in determining the quality and quantity of silk produced and KA superior filament length makes it a valuable breed for silk industries. Studies by Prasad and Rao (2019) [13] have corroborated the importance of filament length in maximizing raw silk output.
- Raw Silk Percentage ranged from 18.29% (J2) to 21.14% (H281), with significant breed differences observed. H281, with the highest raw silk percentage would favored for its silk producing efficiency. Raw silk percentage is a crucial economic factor and according to Rajpur and Kulkarni (2020) [17], higher raw silk output directly translates to greater profitability to silk producers.

Season-wise detailed summary

- **Pre-Monsoon:** The control breeds such as NB4D2 and KA demonstrate superior fecundity (561 for NB4D2), a high hatching percentage (96.75% for KA) and an effective rate of rearing (ERR) as high as 90.56% (KA). These traits make them particularly robust during this season, contributing to reliable rearing outcomes.
- Parental breeds like CSR53 shows a standout performance in raw silk production, with CSR53 yielding up to 21.43% raw silk in this season. This indicates that although control breeds perform well in survivability and fecundity, the parental lines are more efficient in producing high-quality silk.
- **Monsoon:** Parental breeds, notably H281 and A3, excel in several critical economic traits. H281 shows the highest larval weight at 4.75 g and the highest cocoon weight at 1.78 g during the monsoon, while A3 maintains a competitive performance in cocoon parameters and raw silk percentage (19.97%). These results suggest that parental breeds are optimal for maximizing the yield of silk and cocoon mass.
- Meanwhile, control breeds like NB4D2 maintains a steady performance with higher ERR (89.34%) and consistent results in other traits, highlighting their stability across different environmental conditions, making them dependable for large-scale rearing.
- **Post-Monsoon:** In this season, parental breeds, especially H281 and A3, outperform control breeds significantly in economic traits. H281 achieves the highest raw silk percentage at 23.43%, making it ideal for post-monsoon silk production. This period is also characterized by the highest larval weight (4.68 g) and cocoon weight (1.71 g) for H281.

Despite these advantages of parental breeds, control breeds continue to exhibit high ERR and fecundity. NB4D2 shows excellent ERR (90.23%) and fecundity, which indicates that while parental breeds excel in silk production, control breeds ensure high survival and reproduction rates, making them versatile for commercial purposes.

This seasonal variation shows that while control breeds are more resilient and consistent across the year, parental breeds shine in specific seasons, particularly in terms of raw silk production and cocoon characteristics, especially during the monsoon and post-monsoon periods.

Conclusions

Breeds such as H281, NB4D2 and KA emerged as top performers in multiple categories. H281, in particular, excelled in hatching percentage, cocoon weight, pupation rate and raw silk percentage, making it the most promising breed for large-scale silk production genetic variability of the breeds, these traits are pivotal for improving silk production. NB4D2, with its high fecundity and ERR%, also presents strong potential for commercial silk farming. KA's strong performance in fecundity and filament length makes it another valuable breed for silk producers. J2 and H281 were particularly noteworthy for their superior shell weight and shell percentage, traits critical for high silk yield. J2, with its high shell percentage, would be ideal for maximizing silk output. These findings align with current breeding goals, as emphasized by Sharma *et al.* (2019) [18], which prioritize cocoon and shell qualities for optimizing silk yield. Factors like fecundity and ERR%, while important, showed non-significant variation, suggesting the influence of environmental and management practices. Considering the above result the pure breeds could be utilized in the breeding programme to evolve a new bivoltine breeds that can suit the existing climatic conditions and can be exploited for commercial utilization, if fixed at the end of the breeding programme.

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