International Journal of Environment, Agriculture and Biotechnology
Vol-11, Issue-5; Sep-Oct, 2026
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Food Consumption, Digestibility and Conversion Efficiency in Bivoltine Silkworm (*Bombyx mori* L.) Hybrids under Temperate Conditions of Kashmir

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Received: 10 Sep 2026; Received in revised form: 19 Oct 2026; Accepted: 28 Oct 2026; Available online: 31 Oct 2026
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Abstract**—** *Feed conversion efficiency is a key physiological criterion for judging silkworm hybrids, yet little is known about how newly introduced CSR hybrids and regional hybrids utilise mulberry leaf under temperate conditions. This study compared food consumption, faecal egestion, growth rate, approximate digestibility (A.D.) and the efficiencies of conversion of ingested (E.C.I.) and digested (E.C.D.) food into body matter in four bivoltine Bombyx mori L. hybrids, NB4D2 × SH6, SKAU-R-1 × SKAU-R-6, CSR2 × CSR4 and CSR2 × CSR5. The hybrids were reared in a randomised complete block design with five replications during spring 2002 at Mirgund, Kashmir, on a single mulberry variety, Ichinose, and utilisation indices for the 4th and 5th instars were computed by the method of Waldbauer (1968). CSR2 × CSR5 recorded the lowest ingesta (18.70 g per larva, against 20.21 g in NB4D2 × SH6; C.D. = 0.984) and faecal egestion (6.87 g against 8.39 g; C.D. = 0.475) and the highest A.D. (63.177% against 58.466%; C.D. = 3.671). Growth rate was highest in CSR2 × CSR4 (0.1682) and CSR2 × CSR5 (0.1680), both significantly above the two conventional hybrids (0.1640–0.1645; C.D. = 0.0009). E.C.I. was numerically highest in CSR2 × CSR5 (24.736%) and E.C.D. in NB4D2 × SH6 (40.668%), but neither differed significantly among hybrids. The CSR hybrids thus achieved comparable conversion efficiency with lower leaf intake, lower egestion and higher digestibility, suggesting a lower leaf requirement per larva in commercial rearing. These indices can complement cocoon yield in breed evaluation for temperate regions.*

Keywords**— Bombyx mori, bivoltine hybrids, food consumption, approximate digestibility, efficiency of conversion of ingested food, efficiency of conversion of digested food, Kashmir**

I. INTRODUCTION

Sericulture is an agro-based industry that suits the socio-economic setting of India well. Silk has symbolised luxury for centuries, and it is the product of the combined efforts of seed producers, silkworm rearers and reelers. India continues to be the world's second-largest silk producer, with total raw silk production reaching 42,033 metric tonnes in 2025–26, Mulberry silk remains the principal component of national production, while India also produces tasar, eri and muga silks . Jammu and Kashmir has a distinctive place in this sector because its temperate agro-climatic conditions are particularly suitable for bivoltine sericulture. The Union Territory produces approximately 800 metric tonnes of bivoltine cocoons annually and the sector supports nearly 27,000 families, making it an important source of rural livelihood (Anonymous.,2026). The production of high-

quality bivoltine silk therefore depends not only on cocoon yield but also on the nutritional performance and efficient utilisation of mulberry leaves by silkworm hybrids. The feasibility of bivoltine hybrids that give better productivity therefore needs to be recognised. Jammu and Kashmir is ideally suited to rearing bivoltine hybrids and is a major bivoltine silk-producing state in India, with silk comparable in quality to the best imported raw silk. Identifying hybrids suited to specific agro-climatic regions and seasons, with emphasis on hardy strains that give good commercial cocoon yields, is therefore one of the central research problems in sericulture. The performance of a hybrid reflects both heredity and environment. Heredity transmits characters that nature has pre-fixed, but nurture is equally important, and *Bombyx mori* L. maintains a fine balance between the two. The expression of a race's useful characteristics depends on its genetic make-up and on prevailing conditions such as climate and soil, with food being the most important contributor; uniform conditions and careful handling of rearing material are therefore essential. Tazima (1957) noted that climatic conditions are the most important factor in improving sericulture. Although silkworms are reared indoors, their food source, mulberry, grows in the open and cannot escape the influence of climate and soil.The alimentation and physiology of the silkworm are closely correlated, and the nutritional demands of the larva have received growing attention in recent years. Supplying quality leaf is the most direct and efficient way to obtain good-quality raw silk, and the aim of rearing is to reduce the leaf–cocoon ratio, which depends on silkworm variety, leaf quality and management. Growth will not be uniform if leaf quality is poor, and leaf quantity directly influences silk production (Ramachandra *et al.*, 1992). The characteristics of a mulberry variety affect the amount ingested, so qualitative under-feeding is always linked with quantitative under-feeding (Legay, 1958). The importance of leaf quality for growth, development and silk production is well documented (Dasgupta, 1961; Yokoyama, 1963; Das and Sikdar, 1970; Krishnaswami, 1971; Radha *et al.*, 1978; Venugopala Pillai *et al.*, 1980; Tayade and Jawale, 1984; Dar *et al.*, 1988, ; Kulbir, 2001). Many mulberry varieties are available in Kashmir, but only a few are popular commercially because significant varietal differences exist and affect rearing performance and cocoon characters in *B. mori* L.

How efficiently a larva turns leaf into body matter is quantified by food utilisation indices: approximate digestibility, the efficiency of conversion of ingested food (E.C.I.) and the efficiency of conversion of digested food (E.C.D.) (Waldbauer, 1968). These indices contribute directly to the cost–benefit ratio of rearing and are regarded as important physiological criteria for judging the superiority of hybrids (Trivedy and Nair, 1998). A larva that uses food to the maximum extent for its own gain is considered more efficient (Remadevi *et al.*, 1992), and the leaf-to-silk conversion rate is treated as an important economic index in breeding programmes (Xu and Wu, 1992). Consumption, utilisation and conversion efficiency differ among breeds (Benchamin and Jolly, 1986; Slansky and Scriber, 1985).Despite extensive evaluation of quantitative cocoon parameters, the nutritional physiology of newly introduced high-yielding CSR combinations and traditional regional hybrids has received little attention under temperate conditions. Conventional breeding trials prioritise final cocoon yield, yet ingesta, approximate digestibility and conversion efficiencies are central to optimising leaf-to-silk conversion. The present study addresses this gap. Its objectives were (i) to quantify ingesta, faecal egestion, growth rate and approximate digestibility, and (ii) to estimate E.C.I. and E.C.D., in four bivoltine hybrids (NB4D2 × SH6, SKAU-R-1 × SKAU-R-6, CSR2 × CSR4 and CSR2 × CSR5) fed on a single exotic mulberry variety, Ichinose, in the spring season. Using one variety isolates hybrid differences from variation in leaf quality, so that the results indicate how far the genotype itself determines how efficiently food is used.

II. MATERIALS AND METHODS

The four hybrids, NB4D2 × SH6, SKAU-R-1 × SKAU-R-6, CSR2 × CSR4 and CSR2 × CSR5, are standard hybrids reared commercially in Jammu and Kashmir. They were procured from the Division of Sericulture, SKUAST-K, Mirgund, and the Central Sericultural Research and Training Institute, Pampore. The experiment was laid out in a randomised complete block design with five replications per treatment and was conducted in spring 2002 (April–May) at the Division of Sericulture, Mirgund, SKUAST-K. Two hundred larvae taken after the third moult formed one replication.

The first three instars were reared following Krishnaswami (1978) and Dar and Singh (1998). A weighed quantity of leaf was given soon after resumption of feeding in the 4th and 5th instars. After each feed, the unconsumed leaf and the faecal matter were weighed, and a control without larvae was kept to estimate moisture loss from the leaf between feeds. Any mortality was compensated from reserve larvae of the same treatment. Larval weight was recorded at the beginning of the 4th instar and at the end of the 5th instar, one day before spinning, to calculate the average weight gain and the maximum weight attained during the feeding period. At the end of the 5th instar, growth rate and the efficiencies of conversion of ingested and digested food into

body matter were computed by the methods of Waldbauer (1968).

2.1 Food utilisation parameters

- **Leaf fed per larva (g):** from the feeding chart prepared separately for each treatment.
- **Ingesta (g):** F = leaf fed − [(leaf fed ÷ leaf in control at the end of feeding) × leftover leaf].
- **Faeces voided per larva (g):** collected separately and weighed at the end of every feed.
- **Moisture loss in leaves per feed (g):** calculated from a single control tray holding the same quantity of weighed leaf without larvae.
- **Growth rate (G.R.):** G ÷ (T × A), where G is the fresh weight gained per larva (g), T the duration of the feeding period (days) and A the mean fresh weight of the larvae (g).
- **Approximate digestibility (A.D., %):** [(weight of food ingested − weight of faeces voided) ÷ weight of food ingested] × 100.
- **Efficiency of conversion of ingested food (E.C.I., %):** (weight gained ÷ weight of food ingested) × 100.
- **Efficiency of conversion of digested food (E.C.D., %):** [weight gained ÷ (weight of food ingested − weight of faeces voided)] × 100.

Data were analysed by analysis of variance for a randomised block design, and means were compared at the 5% level of significance (Gomez and Gomez, 1976). Percentage data were square-root transformed before analysis; transformed values are given in parentheses in Table 2. Results are presented in Tables 1 and 2 and Figures 1–6.

III. RESULTS

The commercial hybrids NB4D2 × SH6 and SKAU-R-1 × SKAU-R-6 and the newly evolved CSR hybrids CSR2 × CSR4 and CSR2 × CSR5 differed in their dietary and nutritional efficiency, as detailed in Tables 1 and 2 and Figures 1–6.

3.1 Food consumption and faecal egestion

Leaf fed per larva was 41.92 g in NB4D2 × SH6 and SKAU-R-1 × SKAU-R-6 and 41.62 g in CSR2 × CSR4 and CSR2 × CSR5; the two CSR hybrids differed significantly ($p < 0.05$) from the other two (Table 1). Ingesta per larva ranged from 18.70 g in CSR2 × CSR5 to 20.21 g in NB4D2 × SH6, with 19.07 g in CSR2 × CSR4 and 20.01 g in SKAU-R-1 × SKAU-R-6. Faeces voided per larva was lowest in CSR2 × CSR5 (6.87 g), followed by CSR2 × CSR4 (7.24 g), SKAU-R-1 × SKAU-R-6 (8.18 g) and NB4D2 × SH6 (8.39 g) (Table 1; Figure 1). Moisture loss in leaves per feed was 31.88 g for NB4D2 × SH6 and SKAU-R-1 × SKAU-R-6 and 32.06 g for the CSR hybrids, a non-significant difference (Table 1).

Table 1. Mean leaf fed, ingesta, faeces voided and moisture loss in leaves per feed during the 4th and 5th instars of Bombyx mori L. larvae fed on the Ichinose variety.

S. No.	Hybrid	Leaf fed / larva (g)	Ingesta / larva (g)	Faeces voided / larva (g)	Moisture loss in leaves / feed (g)
1	NB4D2 × SH6	41.92^{b}	20.21^{c}	8.39^{b}	31.88
2	SKAU-R-1 × SKAU-R-6	41.92^{b}	20.01^{bc}	8.18^{b}	31.88
3	CSR2 × CSR4	41.62^{a}	19.07^{ab}	7.24^{a}	32.06
4	CSR2 × CSR5	41.62^{a}	18.70^{a}	6.87^{a}	32.06
	S.E. diff.	0.109	0.451	0.218	–
	C.D. (p = 0.05)	0.238	0.984	0.475	N.S.

Note: Means followed by the same letter(s) within a column are statistically at par. N.S., non-significant.

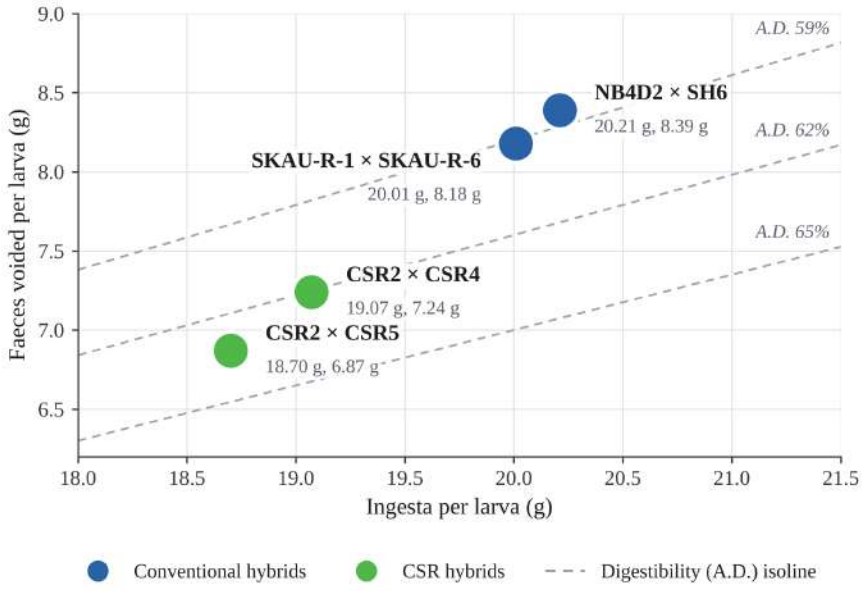


Fig.1. Relationship between ingesta and faeces voided per larva (g) in four bivoltine silkworm hybrids (data from Table 1). Dashed lines are isolines of approximate digestibility: a hybrid lies lower for a given ingesta when more of its food is digested.

3.2 Growth rate, digestibility and conversion efficiency

Growth rate ranged from 0.1640 to 0.1682, in the order CSR2 × CSR4 > CSR2 × CSR5 > NB4D2 × SH6 > SKAU-R-1 × SKAU-R-6 (Table 2; Figu\re 2). Approximate digestibility was highest in CSR2 × CSR5 (63.177%), followed by CSR2 × CSR4 (61.932%), SKAU-R-1 × SKAU-R-6 (59.018%) and NB4D2 × SH6 (58.466%) (Figure 3). E.C.I. was 24.736% in CSR2 × CSR5, 24.684% in CSR2 × CSR4, 23.724% in NB4D2 × SH6 and 23.690% in SKAU-R-1 × SKAU-R-6, whereas E.C.D. was 40.668% in NB4D2 × SH6, 40.358% in SKAU-R-1 × SKAU-R-6, 39.958% in CSR2 × CSR4 and 39.198% in CSR2 × CSR5. Differences in E.C.I. and E.C.D. were not statistically significant (Table 2; Figure 4). Partitioning the Table 2 means (Figure 5), 23.7–24.7% of ingested food was converted to body matter, 34.7–38.4% was digested but metabolised, and 36.8–41.5% was egested; the egested share was smallest in CSR2 × CSR5. Figure 6 summarises all six traits in one view: ingesta and faeces voided are highest in the conventional hybrids, whereas approximate digestibility and growth rate are highest in the CSR hybrids.

Table 2. Mean growth rate, approximate digestibility and efficiency of conversion of ingested (E.C.I.) and digested (E.C.D.) food into body matter in four Bombyx mori L. hybrids during the spring season.

S. No.	Hybrid	Growth rate	Approximate digestibility, A.D. (%)	E.C.I. (%)	E.C.D. (%)
1	NB4D2 × SH6	0.1645^{b}	58.466^{b}	23.724 (4.87)	40.668
2	SKAU-R-1 × SKAU-R-6	0.1640^{b}	59.018^{b}	23.690 (4.86)	40.358
3	CSR2 × CSR4	0.1682^{a}	61.932^{ab}	24.684 (4.96)	39.958
4	CSR2 × CSR5	0.1680^{a}	63.177^{a}	24.736 (4.97)	39.198
	S.E. diff.	0.0004	1.685	–	–
	C.D. (p = 0.05)	0.0009	3.671	N.S.	N.S.

Note: Values in parentheses are transformed data (Gomez and Gomez, 1976). Means followed by the same letter(s) within a column are statistically at par. N.S., non-significant.

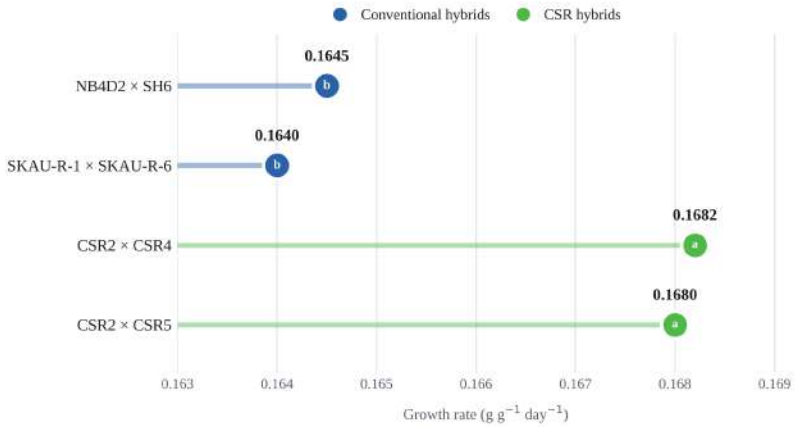


Fig.2. Growth rate of four bivoltine silkworm hybrids. Data from Table 2. Letters inside the markers indicate significance groupings: hybrids sharing a letter are statistically at par (C.D. = 0.0009 at p = 0.05).

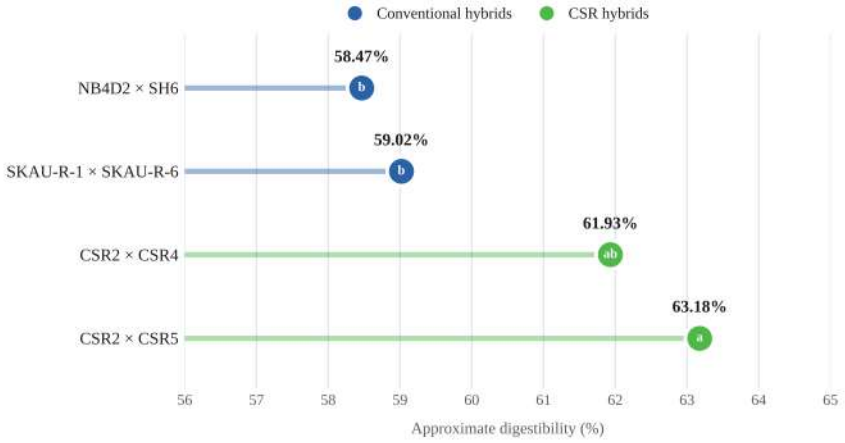


Fig.3. Approximate digestibility (%) of four bivoltine silkworm hybrids (data from Table 2). Letters inside the markers: hybrids sharing a letter are statistically at par (C.D. = 3.671 at p = 0.05).

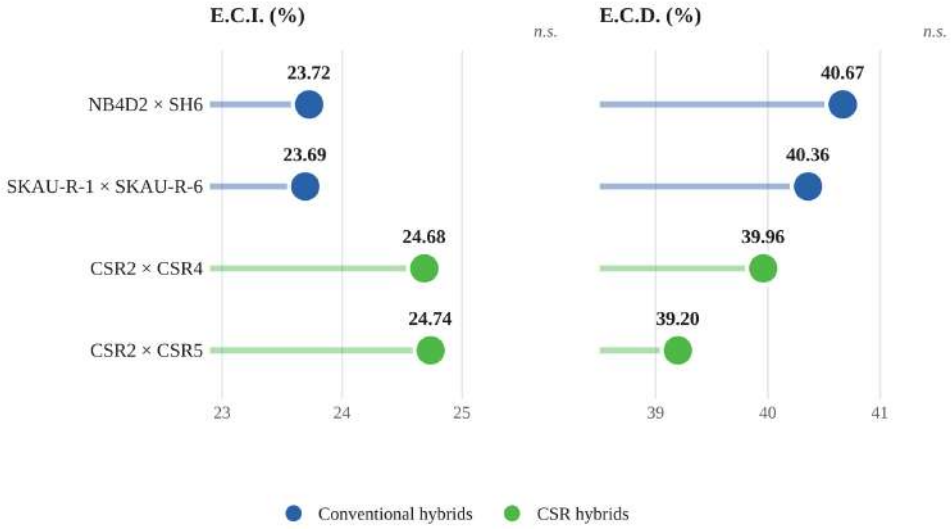


Fig.4. Efficiency of conversion of ingested food (E.C.I., left) and digested food (E.C.D., right) into body matter (data from Table 2). Differences among hybrids were not significant. Note the different x-axis ranges of the two panels.

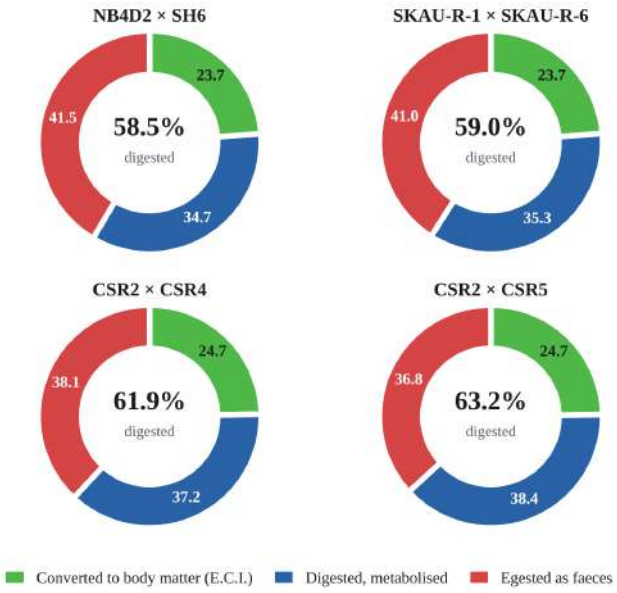


Fig.5. Partitioning of ingested food (%) in each hybrid, with approximate digestibility shown at the centre of each ring; derived from the mean values in Table 2: converted to body matter (E.C.I.), digested but metabolised (A.D. − E.C.I.) and egested (100 − A.D.). Hybrid means were used, so the segments are indicative of the overall budget rather than separately analysed variables.

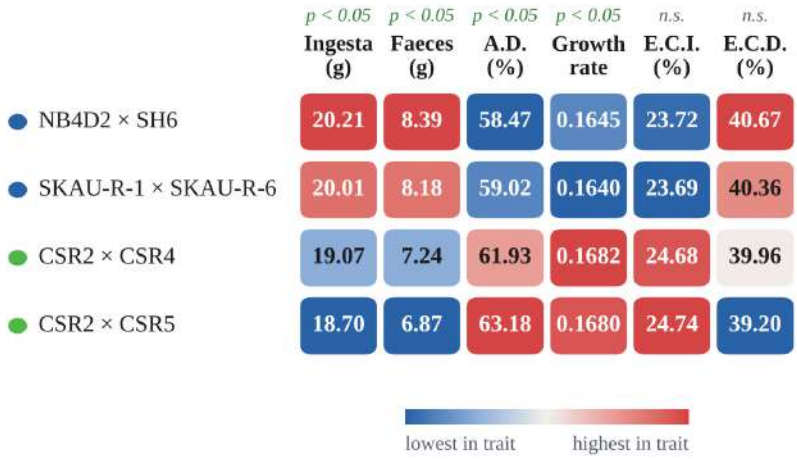


Fig.6. Heat map of the six measured traits in the four hybrids (values from Tables 1 and 2). Colour shows each value relative to the lowest (blue) and highest (red) hybrid within the same trait; red does not necessarily mean worse. Traits marked p < 0.05 differed significantly among hybrids; n.s., non-significant.

IV. DISCUSSION

Rearing success and cocoon crop quality depend on the rearing technique, the quality, quantity and management of leaf, and the silkworm race. Leaf quality strongly influences how much leaf is ingested, and feed conversion efficiency contributes substantially to the cost–benefit ratio of rearing, which makes it an important physiological criterion for judging the superiority of hybrids (Trivedy and Nair, 1998). Larvae take up nutrients from mulberry leaf to build the body, sustain life and spin cocoons, and the capacity to ingest, digest, absorb, assimilate and convert leaf into silk differs among breeds. Because all four hybrids here received the same variety, Ichinose, under the same conditions, the differences described below can be attributed largely to the hybrids themselves.

4.1 Food consumption and faecal egestion

The hybrids differed in ingesta, faeces voided and leaf fed (Table 1; Figure 1). CSR2 × CSR5 had the lowest ingesta

(18.70 g per larva) and CSR2 × CSR4 the next lowest (19.07 g), against 20.01–20.21 g in the two conventional hybrids. A lower leaf requirement per larva is economically advantageous in commercial rearing because it reduces leaf demand and the labour involved in feeding. Overall food consumption influences growth, survival, biomass accumulation and reproductive performance in insects (Slansky and Scriber, 1985), so intake is an informative trait in its own right. Whether the lower intake of CSR2 × CSR5 reflects earlier maturity could not be assessed here, as larval duration was not compared among treatments.

Faecal egestion, an indicator of feed acceptance linked to the nutritive status of the feed and to cocoon productivity, followed the same order: lowest in CSR2 × CSR5 (6.87 g per larva), then CSR2 × CSR4 (7.24 g), then SKAU-R-1 × SKAU-R-6 (8.18 g) and NB4D2 × SH6 (8.39 g). Both CSR hybrids differed significantly from both conventional hybrids in faecal output. This agrees with Mathavan and Pandian (1974), who used faecal weight as an index of food consumption in lepidopterans, and with Benchamin and Jolly (1986), who did the same in *B. mori*.

4.2 Approximate digestibility

Approximate digestibility was highest in CSR2 × CSR5 (63.177%), followed by CSR2 × CSR4 (61.932%) (Table 2; Figure 3). Statistically, NB4D2 × SH6 and SKAU-R-1 × SKAU-R-6 were at par with CSR2 × CSR4 but differed significantly ($p < 0.05$) from CSR2 × CSR5. The pattern of higher digestibility with lower consumption suggests that digestibility varies inversely with consumption. In the two conventional hybrids, higher intake probably speeded the passage of food through the gut and left less time for digestion; in the CSR hybrids, the smaller quantity of food passing through the gut allowed more time for digestion (Figure 5). This agrees with Trivedy and Nair (1999).

4.3 Leaf moisture

Leaf moisture affects palatability, assimilation and food consumption in the silkworm (Parpiev, 1968; Maribashetty *et al.*, 1999). Because a single variety was used and a single control tray was kept, moisture loss per feed was essentially the same across hybrids (Table 1): 31.88 g for NB4D2 × SH6 and SKAU-R-1 × SKAU-R-6 and 32.06 g for the CSR hybrids. Moisture loss therefore cannot explain the differences in intake or digestibility. Kulbir (2001), working on indigenous mulberry varieties of the Kashmir valley, reported a moisture loss of 40.03 g per feed in Ichinose leaves. The difference between the two studies, conducted in different years, may be attributed to the environmental conditions prevailing in each year.

4.4 Growth rate

Growth rate indicates how efficiently nutrients are used for growth and development. It was significantly higher in CSR2 × CSR4 (0.1682) and CSR2 × CSR5 (0.1680) than in NB4D2 × SH6 (0.1645) and SKAU-R-1 × SKAU-R-6 (0.1640) (Table 2; Figure 2). Approximate digestibility and E.C.D. interact to determine growth (Slansky and Scriber, 1985), and Remadevi *et al.* (1991) reported that these components vary significantly among races, in line with the present findings. The CSR hybrids thus grew faster while ingesting less, a combination that points to more efficient use of the leaf they consumed. A larva that uses food to the maximum extent for its own gain is considered more efficient (Remadevi *et al.*, 1992).

4.5 Efficiency of conversion of ingested and digested food

The CSR hybrids had numerically higher E.C.I. than the conventional hybrids (24.684–24.736% against 23.690–23.724%) but numerically lower E.C.D. (39.198–39.958% against 40.358–40.668%), a reverse trend between the two efficiencies (Table 2; Figure 4). Neither difference was statistically significant, so this trend should be interpreted cautiously. Waldbauer (1968) explained that E.C.I. varies both with digestibility and with the proportion of the digested food converted to body substance rather than metabolised for energy. E.C.I. therefore rises and falls with approximate digestibility and E.C.D., and E.C.D. decreases as the proportion of digested food metabolised for energy increases. The partitioning in Figure 5 illustrates this: the CSR hybrids digested a larger share of their intake, and a larger part of that digested share was metabolised, so their higher digestibility did not translate into a significantly higher conversion to body matter. E.C.D. is affected by factors that influence the energy devoted to maintenance, and it is not directly dependent on digestibility but varies with the level of nutrient intake.

4.6 Practical implications and limitations

Taken together, the CSR hybrids reached similar conversion efficiency with less leaf, less faecal output, higher digestibility and faster growth. For commercial rearers this means a lower leaf requirement per larva, which is relevant where leaf supply or labour is limiting, and conversion efficiency is regarded as an important economic index in breeding programmes (Xu and Wu, 1992). The findings are, however, based on one mulberry variety, one season and one rearing year, and E.C.I. and E.C.D. did not differ significantly. Confirmation across seasons and mulberry varieties, together with larval duration and cocoon and silk traits, would show whether the nutritional advantage of the CSR hybrids carries through to leaf-to-silk conversion.

V. CONCLUSION

The newly introduced CSR hybrids (CSR2 × CSR4 and CSR2 × CSR5) showed more favourable nutritional indices than the conventional hybrids (NB4D2 × SH6 and SKAU-R-1 × SKAU-R-6): lower leaf consumption (ingesta), lower faecal egestion, higher approximate digestibility and higher growth rates. Lower ingesta is advantageous to commercial rearers because it reduces leaf requirement and labour in the final larval instars. The inverse relationship between consumption and approximate digestibility suggests that slower gut passage in the CSR hybrids allows more time for nutrient extraction. E.C.I. and E.C.D. did not differ significantly among the hybrids, so the advantage of the CSR hybrids lies in lower intake and higher digestibility rather than in a demonstrably better conversion of food into body matter. Including feed-conversion measures in breed evaluation protocols can help sericulturists select superior genotypes and so improve raw silk productivity and economic returns.

AUTHOR CONTRIBUTIONS

Gh. **Nabi** Mir: Conceptualization, interpretation of findings, writing and reviewing the original draft, critical review and editing of the manuscript. Aabid Ahmad Bhat: Compilation and organization of experimental data, preparation of tables, development of graphical illustrations, literature review and initial drafting of the manuscript. Lubna Altaf: Data compilation, verification of tables, literature search and proofreading. Misara Jaan: Literature compilation, manuscript formatting, reference checking and proofreading. M. A. Malik and H. U. Dar: Formulation of research objectives, supervision, and guidance on experimental design and methodology. Ishfaq Ahmad Malla: Interpretation and verification of results, review of tables and figures, critical reading and proofreading of the manuscript. All authors reviewed the manuscript and approved the final version.

ACKNOWLEDGEMENTS

The authors acknowledge the institutional support provided by the Division of Sericulture, CoTS Mirgund, SKUAST-Kashmir.

FUNDING

The authors received no specific external funding for this study.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICS APPROVAL

Not applicable. The study involved routine rearing and assessment of silkworm larvae and did not involve human participants or vertebrate animals.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

CONSENT TO PUBLISH

Not applicable.

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