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[Review]

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Food Ingestion, Assimilation and Conversion Efficiency of Mulberry Silkworm, *Bombyx mori* L.

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Feed conversion efficiency contributes directly or indirectly on the cost benefit ratio of silkworm rearing and is considered to be an important physiological criterion for evaluating the superiority of silkworm breeds/ hybrids. Food intake, assimilation and conversion of indigenous as well as exotic silkworm races are well studied by many researchers. In this review, an attempt has been made to consolidate works on feed conversion aspects of indigenous and exotic silkworm races. The paper also deals with the effect of various factors *viz.*, nutritional, environmental and feeding on food assimilation and conversion parameters of mulberry silkworm.

Key words: Food ingestion, Assimilation, Conversion efficiency, Mulberry silkworm

Introduction

In silkworm rearing, food is a factor of paramount importance, which regulates its growth, development and silk yield in commercial sericulture. Food intake and silk production in silkworm are very closely related to nutritional factors. Dietary efficiency of silkworm plays a major role in converting the mulberry leaves consumed by them to silk. Efficiency of Conversion of Ingested (ECI) mulberry leaves into silk or leaf silk conversion rate is a better economic index in cocoon production. The various studies connected with food consumption and utilization of *Bombyx mori* L. are summarized by Legay (1958). Measurement of intake and utilization has played little part in the classical studies of insect nutrition although their usefulness in this connection is obvious. Food utilization in silkworm has been well studied and the pioneering work of Hiratsuka (1920) is still valid, even though some changes have been made by Nakano and Monsi (1968) and Horie *et al.* (1976). Feed conversion efficiency contributes directly or indirectly to the major chunk of the cost benefit ratio of silkworm rearing and is considered to be an important physiological criterion for evaluating the superiority of silkworm breeds/hybrids (Junliang and Xiaofeng, 1992; Trivedi and Nair, 1998). In silkworm, different breeds vary in their growth, development, food consumption, utilization and conversion efficiency (Benchamin and Jolly, 1984; Remadevi *et al.*, 1992). Food conversion efficiency in silkworm varies according to the environmental conditions (Ueda and Suzuki, 1967; Ito, 1972; Muniraju *et al.*, 1999; Rahmathulla *et al.*, 2002), food quality (Takano and Arai, 1978; Sarkar and Fujita, 1994) and also quantity of food (Ueda, 1965; Sumioka *et al.*, 1982a; Singh and Ninagi, 1995; Mathur *et al.*, 2002). Feed utilization studies of Indian pure races and their hybrids have been extensively studied by various researchers (Benchamin and Jolly, 1984; Remadevi *et al.*, 1992; Anantharaman *et al.*, 1994a; Magdum *et al.*, 1996a; Aftab Ahamed *et al.*, 1998; Trivedy and Nair, 1999; Rahmathulla *et al.*, 2003). Retarded growth in insects may not be only due to the nutritional inadequacy of the diet, but also may be due to the effect of various environmental conditions and it also depends on the digestion and utilization of food, which varies from species to species, and even between different sexes of the same species. In China and Japan the sericulture scientist have realized the importance of dietary efficiency, and they are engaged in finding effective ways to enhance leaf silk conversion rate. This can be improved by breeding desirable silkworm strains and mulberry genotypes and by providing good rearing environment, nutrition level and also by

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applying some insect growth regulators.

The review paper deals on ingestion, digestion, assimilation and feed conversion efficiency of exotic as well as Indian silkworm races and also on nutritional efficiency of silkworm under different environmental, feeding and nutritional conditions.

Food utilization studies of exotic races

Nutritional ecology of insects is the prerequisite for a better knowledge on their ethobiology and physiology, which has been often neglected (Scriber and Slansky, 1981). Silkworm growth is a composite result of various physiological activities of an organism, by which matter accumulates in the body as a result of balance between assimilation and dissimilation in which complicated phenomena are involved (Ueda, 1982). It is also reported that digestibility of silkworm is influenced by accumulative amount of food ingested at each instar and digestibility decreases at an advanced instar, which shows greater accumulative amount of ingested food. The ECI to cocoon and cocoon shell are popularly known as leaf cocoon conversion rate (LSCR). These two traits are very important economic index in cocoon production.

Food utilization of temperate breeds was studied by many workers (Matsumara *et al.*, 1955; Takeuchi *et al.*, 1964; Ueda and Suzuki, 1967). The rate of food consumption of silkworm depends upon the nutritional quality of leaf and that the rate of consumption varied in each instar in a cyclic way (Ito, 1960, 1972). The consumption rate was lower in younger stages and the average rate of digestion depends upon the rearing temperature. Increase in ingesta, digesta and excreta per larva with advancement in age of silkworm of temperate breeds were studied (Horie *et al.*, 1978; Jeksheva and Genova, 1991). Nutritional background of the larval stages significantly influences the status of the resulting pupae, adult and production of silk in *B. mori* (Fakuda *et al.*, 1963; Takano and Arai, 1978). Horie and Watanabe (1983) have shown that male larva utilize more dry weight food for the production of silk compared to female. The lower consumption and higher conversion of food into cocoon shell in male also attracted attention of breeders. Mukiyama and Ito (1962) studied the variation of ingesta and digesta among breeds during different season by feeding with artificial diet and leaves.

There are many contributing factors which determine the digestibility and conversion efficiency of a breed among them eco physiological condition and morphological deviation are among major factors, which determine the efficiency and the variation among the breeds which cannot be attributed to a single factor. Kafian (1982) and Sumioka *et al.* (1982a) made clear that the evaluation of a silkworm strain must be made on the basis of food utilization efficiency under favourable conditions. It is important that it will not be beneficial for the animal to increase approximate digestibility (AD) beyond the optimal value till more food is available. Although the amount of food eaten by fifth instar larvae increase to each successive day of feeding period. It doesn't increase in proportion to the size of the gut as it must increase. The increase in retention would lead to an increase in AD % if the ability of the gut to absorb nutrients from the lumen remained same.

A correlation between the qualities of food digested in each stage of silkworm with percentage of moulting or pupation was reported (Takeuchi, 1961; Takeuchi and Kosaka, 1962). Waldbauer (1964) in his classic studies described the consumption and utilization of food by insects and also described the calculations of the various consumption, nutritional indices and nutritional efficiency parameters connected with insect nutrition. He concluded his study and declared that the efficiency is the amount of food required to reach its full potential will be manifest in various ways and degrees. Waldbauer (1968) and Ueda (1965) studied the changes in some quantitative factors and mutual relationship concerning the growth and development in 5th instar larvae of silkworm. Similarly, Horie (1978) showed that higher food consumption in fifth instar larvae increases body weight and cocoon characters. Many workers pointed out positive relationship between foods ingested, food digested and approximate digestibility (Sumioka *et al.*, 1982b; Horie *et al.*, 1985) According to Yamamoto and Gamo (1976), the relation between the quantities of food ingested and digested is negligible. However, Biren *et al.* (1987) detected a negative correlation between two indices (Ingesta and digesta). Fakuda (1960) found a positive correlation between mulberry leaves intake and silk protein in the silkgland and the silk filament.

Consumption of food influences insect growth, survival, biomass accumulation and reproductive performance (Slansky and Scriber, 1985). Hiratsuka (1920) reported that in case of silkworm *B. mori* L. 97% of the total food intake takes place during the last two instars. The statements were supported by Waldbauer (1968) and Horie *et al.* (1976). Kuribayashi *et al.* (1990) reported that the amount of food ingested and digested by the larvae of new productive silkworm races are about 40% higher than the traditional old races. Food utilization in sex limited strains for egg and larval traits of the silkworm *B. mori* L. at moderate, reduced and excess feeding amounts were observed (Tzenov, 1993) and reported that most important

indices characterizing food ingestion, digestion and utilization depends to a great extent on the feeding amount. He also observed that female silkworm ingested and digested a high quantity of food than the male.

Inheritance of food ingestion and digestion between univoltine and multivoltine silkworm, *B. mori* races was studied by Tzenov *et al.* (1999) and results manifested that the quantities of food supplied, ingested, digested and leaf digestibility was higher with the multivoltine races. However, the food digestibility was significantly higher in the polyvoltine.

Assal *et al.* (1994) studied the nutritional behaviour of three different strains of mulberry silkworm in relation to insegar (Fenoxycarb) and reported that the most important effect was on the consumption index, growth rate and approximate digestibility, while efficiency of conversion of ingested or digested food were not significantly affected.

Food utilization studies in Indian races

Numerous exotic silkworm breeds and hybrids have been brought to India to improve productivity and feed utilization have been conducted on some of these breeds and hybrids. Dietary efficiency of silkworms plays a major role in converting the mulberry leaves consumed by them to silk. Any improvement in the leaf silk conversion ability of a given mulberry genotype or silkworm race will add to its economics (Trivedy and Nair, 1998). Quantitative requirements of feed varied in different bivoltine breeds (Benchamin and Jolly, 1984; Magadum *et al.*, 1996a). Periaswamy *et al.* (1984) studied the pattern of food utilization in exotic, semi exotic and indigenous races of final instar larvae of *B. mori* and reported that semi exotic race is better food converter than the indigenous races. Allocation of converted energy for cocoon shell was highest in semi exotic cross breeds. Periaswamy and Radhakrishnan (1985) reported that the bivoltine races ingest a higher quantity of food than the multivoltine. Food consumption in Indian bivoltine pure races (KA and NB_4D_2) is two times more than Pure Mysore and they also shown that the semi exotic races are better converters than the Pure Mysore. Variation in food and dietary water intake and utilization between different life stages are observed to be due to difference in biomass of insects at chosen stages. As the larva gets older the approximate digestibility, efficiency of ingested and digested food into larval matter gradually reduces and the mean daily food ingested and digested increases as the age of larvae advances (Naik and Delvi, 1987). The lowest food consumption and assimilation in Pure Mysore race is composed by highest feeding and assimilation rates. It was surprising to note that lower consumption and assimilation in Japanese strains of *B. mori* did not increase the rate of feeding and assimilation. Lower food consumption in new race naturally leads to food assimilation and assimilation efficiency and this is in conformity of higher approximate digestibility reported in the larvae of Pure Mysore (Benchamin and Jolly, 1984). However, assimilation efficiency averages 51.8% in indigenous Pure Mysore race and about 39.3% in semi exotic race. Total ingestion, ingestion to body gains ratio and ingestion to cocoon ratio varied significantly in different polyvoltine breeds (Remadevi *et al.*, 1992).

Anantharaman *et al.* (1992) studied the nutritional efficiency of cross breed (PM × NB_4D_2) and reported that the amount of dry matter ingested and digested in different instars was significantly different. The ingesta, digesta, excreta, reference ratio, mean daily food ingested and digested varies for each instars. These parameters differ from one larval instar to another, as there always exists a correlation between the food consumption and the age of the larvae (Naik and Delvi, 1987). The approximate digestibility and efficiency of conversion of ingested food were inversely correlated with the larval age (Anantharaman *et al.*, 1994 a, b). They reported that the patterns of correlation are different in bivoltine hybrids and multivoltine × bivoltine hybrids, which clearly indicated that the contributory factors for the productivity are very different. There is significant mutual relationship between total ingesta, total digesta, mature larval weight, larval duration and fecundity (Magadum *et al.*, 1996b).

Table 1. List of authors contributed for feed conversion of exotic and Indian races

Race	References
Temperate breeds	Fakuda, 1960; Takeuchi *et al.*, 1964: Ueada and Suzuki, 1967; Horie *et al.*, 1978; Horie and Watanabe, 1983; Junliang and Xiaofeng, 1992
Indian traditional bivoltine race	Benchamin and Jolly, 1984; Periaswamy and Radhakrihnan.1985; Naik and Delvi, 1987; Magadum *et al.*, 1996; Maribashetty *et al.*, 1999
Multivoltine	Benchamin and Jolly, 1984; Remadevi *et al.*, 1992 Maribashetty *et al.*, 1999b
Cross breeds hybrids	Anantha raman *et al.*, 1993; Trivedi and Nair, 1998; Maribashetty., 1999
New bivoltine races	Rahmathulla *et al.*, 2002; Trivedi *et al.*, 2003; Maribashetty *et al.*, 1999b

Datta *et al.* (1996) reported that the breeds and season had no effect so far as food digestibility was concerned. The breeds Nistari was better converter of ingested as well as digested food to body biomass though its food intake was less and growth rate was slightly less compared to Sarupat breed. The lower food consumption in new races during fifth instar must be due to shorter larval duration when compared to that of Pure Mysore. The lower food consumption in new races naturally leads to lower food assimilation and accumulation efficiency. Benchamin and Jolly (1984) and Remadevi *et al.* (1992) reported that some polyvoltine breeds exhibit higher conversion efficiencies than Pure Mysore.

Trivedi and Nair (1999) studied the feed conversion efficiency of improved multivoltine × bivoltine hybrids of silkworm *B. mori* and reported that the new cross breed (BL44 × NB_4D_2) was the best converter of food to the ultimate produce, cocoon shell followed by BL45 × NB_4D_2, which established its clear edge over traditional cross breed (PM × NB_4D_2). Trivedi *et al.* (2003) studied efficiency of feed conversion in fifth instar larvae of eleven bivoltine silkworm hybrids (A × CSR5, A × CSR6, A × B61, A × 935 A, A3935E, A3916B, G × CSR2, G × CSR13, G × CSR12, F × A1 and F × A3) and the data was compared with that of popular hybrid KA × NB_4D_2. They showed that newly developed bivoltine hybrids are superior to the existing hybrids in relation to their efficiency in converting food.

Metabolic rate of silkworm was significantly higher in males but assimilation efficiency was similar in both male and female (Chandrakala *et al.,* 1999). The dietary water intake by both male and female silkworm was similar, though the male exhibited higher water absorption efficiency than females, while females showed higher water retention efficiency. Maribashetty *et al.* (1999a) studied the consumption and conversion efficiency of food and water in new multivoltine breeds of silkworm (MH1 and MH2), *B. mori* and concluded that the various nutritional parameters like food consumed, feeding rate, amount of fecal matter, food assimilated, water taken in, water intake rate, water loss through faeces, water absorbed and water loss through transpiration were higher during 4th instar and lower during 5th instar in the new silkworm breeds when compared to Pure Mysore.

Maribashetty *et al.* (1999b) in another experiment studied the food and water utilization patterns in new bivoltine races of silkworm *B. mori*. The increment was observed in new races (NP2) and (SP2) for food intake, conversion rate, metabolic rate, gross conversion efficiency and net conversion efficiency when compared with NB_4D_2. Whereas decrement was noticed in parameters like feces defecated, feeding rate and assimilation rate.

Prabhakar *et al.* (2000) studied the consumption and utilization of mulberry leaves by the silkworm and reported that the indices *viz.,* consumption index, and co-efficient of metabolism were negatively correlated with the characters like fecundity, larval duration, silk gland weight and length, cocoon weight, shell weight, cocoon shell ratio, cocoon filament length and denier, but positively related with floss content and no of breaks per cocoon, while the reverse was established with growth rate, assimilation effect, ECI and ECD with the above characters.

Rahmathulla *et al.* (2003) evaluated the consumption and nutritional efficiency in three new bivoltine hybrids silkworm *B. mori* and concluded that various nutritional indices like ingesta, digesta, AD% and Reference ratio were recorded higher in CSR2 × CSR4 compared to other two races (CSR2 × CSR5, CSR18 × CSR19). However, the nutritional efficiency parameters were recorded significantly higher in the robust bivoltine hybrid CSR18 × CSR19. This indicates more food conversion efficiency of the robust bivoltine hybrid.

Feed conversion efficiencies of silkworm under various feeding, nutritional and environmental conditions

Silkworm larva obtains all nutrients from mulberry leaves to build its body, sustain and spin cocoons. Under different environmental, feeding and nutritional condition, though the silkworm ingests same amount of mulberry leaves it shows significant difference in its ability to digest, absorb and convert to body matter. Sumioka *et al.* (1982a, b) studied the relationship among food ingestion, food digestion and body weight gain in the silkworm larvae, *B. mori* under the restricted feeding and reported that the approximate digestibility remained more or less at constant levels from the first to middle day of the instar, declined gradually during the latter days and then fell sharply just before the spinning. The efficiency with which digested food was converted to body substances was decreased with larval growth in every feed index.

He further reported that a severe restricted feeding decreased the total amount of food consumed by the larvae during the 5th instar to about a half amount in an ordinary feeding. Also severe restricted feeding resulted in a remarkable decrease in characters such as food amount ingested, digested, cocoon layer weight, pupal weight, number of eggs produced, number of eggs laid etc. Hidashi *et al.* (1982) also supported this statement. Where as approximate digestibility (AD%) and consumption index (C.I.) was not affected. But the conversion efficiency of digested food to cocoon (ECD) and the effi-

Table 2. Nutritional parameters of silkworm worked out by different authors

Silkworm race	Ingesta (g)	Digesta (g)	AD (%)	ECI cocoon (%)	ECD cocoon (%)	ECI shell (%)	ECD shell (%)	References
C-nichi	1.48	0.552	36.64	18.20	54.58	-	-	Remadevi *et al.*, 1992
RD1	2.29	1.094	45.79	14.54	38.11	-	-	
MY1	2.85	1.346	47.84	15.64	32.61	-	-	
A × CSR5	3.55	1.0960	30.85	18.17	-	9.18	-	Trivedy *et al.*, 2003
G × CSR2	3.88	1.188	30.41	17.95	-	8.80	-	
BL24 × NB_4D_2	3.90	1.057	27.15	15.16	55.91	7.43	27.417	Trivedy *et al.*, 1999
BL45 × NB_4D_2	3.89	1.332	34.28	16.56	48.36	8.30	24.254	
KA	-	-	30.34	23.74	74.33	-	39.95	Magdum *et al.*, 1996a
NB_4D_2	-	-	32.37	17.70	57.68	-	32.832	
NB18	-	-	32.21	21.19	68.41	-	32.02	
Pure Mysore	3.08	1.597	51.81	18.80	-	-	-	Naik and Delvi, 1987
NB_4D_2	5.85	2.263	38.7	20.30	-	-	-	
KA	6.47	2.582	39.9	20.7	-	-	-	
NB_4D_2	5.15	2.785	54.0	14.1	-	7.60	-	Maribashetty *et al.*, 1999b
NP2	5.64	2.493	55.7	15.5	-	8.70	-	
Sp2	5.79	2.234	61.4	17.7	-	10.8	-	
MH1	2.61	1.347	51.7	14.60	-	2.30	-	Maribashetty *et al.*, 1999a
MH2	2.34	1.194	51.1	16.60	-	2.80	-	
Pure Mysore	3.57	2.301	66.00	11.70	-	1.70	-	

ciency of food ingested to cocoon (ECI) was unchanged because of counter balance among the three components of the feed efficiency like approximate digestibility, consumption index and efficiency of ingested and digested substance into body matter.

The reduced quantity of mulberry leaves produced a number of negative effects on *B. mori* such as high mortality, extension of larval period and reduction in the food consumption and utilization. The amount of dietary water intake and water expenditure decreased with the reduced food level (Radhakrishna and Delvi, 1987). Meenal and Ninagi (1995) reported that food ingested was significantly less in polyvoltine breeds and ingestion was less at less feeding level in both polyvoltine and bivoltine races. Accordingly the body weight of larvae and cocoon characters are declined and percentage of leaf driage affected the ingestion pattern of bivoltine silkworm. Similarly, Singh and Ninagi (1995) reported that less fed batches registered maximum ingestibility with minimum digestibility and better efficiency of conversion of ingested and digested food into body matter, cocoon shell and pupa. Nutritional efficiency parameters *i.e.*, ECI and ECD to cocoon and shell were significantly higher in restricted feeding level batches. This increase is attributed due to the physiological adaptation of silkworm under nutritional stress condition (Nath *et al.*, 1990; Mathur *et al.*, 2002). Such type of trend indicates towards some sort of physiological adjustment under the stress condition to divert the available resources towards body mass built up rather than using maintenance (Muthukrishnan *et al.*, 1978). Meenal *et al.* (2001) estimated the quantum of food required for new bivoltine hybrid CSR2 × CSR5 at different feeding levels and reported that the amount of food ingested and digested were significantly high when the larvae were fed with 20% more mulberry leaves than the present standard recommendation of 1200 kg/40,000 larvae. Significant improvement in larvae and cocoon characters was observed in 20% excess feeding level. The production efficiency of cocoon shell (PECS) was also higher with 20% more feeding.

Tzenov (1993) studied the food utilization in genetic sex limited breeds for egg and larval traits of silkworm, *B. mori* at moderate, reduced and excess feeding amounts and it was observed that the most important indices characterizing the food ingestion, digestion and utilization depend to great extent on the feeding amounts. The female larvae in the T1514 strain utilized the food better for body matter at moderate and excess feeding amount. The male larvae in the same strain utilized the food better than the female ones in respect of body matter at the reduced feeding amount and in respect of cocoon shell at all levels of feeding amount.

Nakmura *et al.* (1982) studied the ingestion, digestion and utilization of phosphorus by the silkworm. Efficiency of conversion of ingested (ECI) and digested (ECD) food admitted a positive relation with the concentration of the biosalt mixture (Suburathnam *et al.*, 1991). Larvae fed with diet containing more minerals divert minimum energy for maintenance by which the larvae can channel maximum energy for seed and silk production. Hamano (1989) studied effect of dietary pyridoxine content on silkworm diet efficiency and it was shown that the dietary level of both protein and pyridoxine affected not only the silk production but the utilization of diet. The efficiency of the diet for cocoon shell productuion increased with an increase in dietary protein. Where as, the efficiency of conversion of ingested nitrogen was the highest on the 10 percent protein diet. Aftab Ahamed *et al.* (1999a) studied influence of sodium fluoride on nutritional efficiency of multivoltine silkworm race and reported less feed conversion in treated batches.

Baldev Sharma *et al.* (1986) evaluated five mulberry varieties existing in Jammu and Kashmir region by feeding them to silkworm and it was observed that growth index was maximum in case of Chakmajra followed by KNG, Berhampuri. ECI and ECD values were highest in case of the larvae fed on Berhampuri mulberry variety followed by Chakmajra. Sarkar *et al.* (1998) studied the nutritional efficiency of silkworm fed with different mulberry varieties raised under different cultivation system and result showed that silkworm fed with bush leaves showed highest value of AD, ECI and ECD to silkworm body while tree leaves fed batches shows least. However larvae fed on the leaves of tree mulberry showed highest value of ECD to cocoon shell. Dar *et al.* (1988) evaluated three improved Japanese varieties of mulberry, namely Ichinose, Goshoerami, and Kokuso-27 for nutritional potential by feeding to silkworm and it was observed that ingestion and faeces excluded were significantly low in larvae fed with Ichinose variety leaves, thus decreasing the consumption index and increasing the efficiency of conversion of ingested and digested food into body matter. The feeding on Ichinose leaves resulted in higher weight of mature larvae and improvement in economic traits of cocoons such as cocoon and shell weights and silk percentage as compared to other two varieties.

Sarkar and Fujita (1994) studied better technique for nutritive evaluation of mulberry leaves for silkworm and production efficiency of cocoon shell of silkworm was compared among several varieties. The production efficiency of cocoon shell was found to be highest in Ichinose mulberry variety. The nutritive superiority of Ichinose in silkworm rearing was confirmed by higher efficiencies for conversion (ECI and ECD), higher cocoon weight, higher shell weight and higher efficiency of cocoon production. The high correlation between production efficiency of cocoon shell (PECS) and other characters are indicators for the evaluation of the nutritive value of mulberry leaves.

Evripids and Dimitar (2000) studied nutritional efficiency of eight Bulgarian silkworm hybrids fed with locally cultivated Japanese variety Kinriu. The results showed that remarkably higher feed intake and feed utilization by the hybrids Hessa 2 × Vrataz-35, Vrataz-52 × Vrataz 53.The same hybrids showed an efficient food utilization by means of daily growth, cocoon shell ratio and raw silk output. In terms of food to silk conversion efficiency Hessa 2 × Super 1 showed better results.

Paul *et al.* (1992) studied the impact of dietary moisture on indices and growth of silkworm and concomitant larval duration. The quantity of dry matter consumed and digested, the values of ECI and ECD% and final larval weight increased significantly with increase of leaf water and showing a high positive correlation. Approximate digestibility increased progressively up to 70% leaf moisture but was reduced at the control dietary water level. Larval duration was prolonged under low water content without a corresponding increase in the quantity of leaf consumed. Deb *et al.* (2000) studied the role of foliar moisture on consumption and conversion efficiency of dry matter of food into cocoon and shell by 5th instar larvae of silkworm and reported that quantity of food ingested and digested increased with the rise of foliar water. Weight of

Table 3. List of authors contributed for feed conversion efficiency of silkworm under different condition

Condition	References
Restricted feeding	Muthukrishnan *et al.*, 1978; Sumioka *et al.*, 1982; Radhakrishnan and Delvi, 1987; Nath *et al.*, 1990; Tzenov, 1993; Meenal and Ninagi, 1995; Singh and Ninagi, 1995; Mathur *et al.*, 2002
Moisture effect	Paul *et al.*, 1992; Deb *et al.*, 2001; Rahmathulla *et al.* 2004.
Different mulberry variety feeding	Machi and Katagiri, 1991; Sarkar and Fujita, 1994; Dar *et al.*, 1988; Anatntharaman *et al.*, 1995
Different temperature	Takeuchi et al., 1964; Sigematsu and Takeshita, 1967; Ueada and Suzuki.1967; Mishra and Upadhaya, 1995; Muniraju *et al.*, 1999; Rahmathulla *et al.*, 2002

cocoon, shell and percentage of efficiency of conversion of digested food for cocoon also increased with the increasing percentage of moisture. The mulberry variety S54 and M5 contains less fibre and more moisture, protein, minerals and sugar content compared to Mysore local. Soo Hoo and Fraenkal (1985) reported similar findings.

Very recently Rahmathulla (2004) studied effect of feeding mulberry leaves with different moisture contents to the 5th instar bivoltine silkworm (CSR3 × CSR6). The results indicated that nutritional parameters like ingesta, digesta, approximate digestibility, reference ratio and consumption index were recorded significantly higher in batches fed with higher moisture content leaves. Similarly, nutritional efficiency parameters like conversion efficiency of ingested and digested food into larvae, cocoon and shell were recorded significantly higher in batches fed with higher moisture content leaves. Higher moisture content leaves feeding leads to increased weight of silk gland (Rahmathulla, 2003). The lower water intake in the new silkworm race could be attributed to the reduction in the quantum of food intake (Aftab Ahamed *et al.*, 1998).

Aftab Ahamed *et al.* (1999) analyzed the food and dietary water intake and utilization by feeding tukra infected mulberry leaves to the new bivoltine silkworm *B. mori* during 4th and 5th instar. They reported that it caused shortening of the larval duration and significant increment in conversion rate, conversion efficiencies, water absorption efficiency, water retained in the body and water retention capacity. In continuation of this a significant increase in larval biomass, cocoon, pupal and shell weight followed by their efficiencies were noticed inspite of lesser wet food consumed. Food conversion into the body substance, conversion rate, dietary water intake and utilization were decreased when silkworm fed with white fly infected leaves (Aftab Ahamed *et al.*, 1999). Aftab Ahamed and Rachotaih (2000) studied the impact of powdery mildew and leaf spot diseased mulberry leaves feeding on consumption and conversion efficiency of silkworm and concluded that larval duration and dry food consumption was increased.

Kafian (1982) demonstrated that the evaluation of the strains must be made on the basis of food utilization efficiency at different feeding amount under favorable conditions for each sex. Ueda and Suzuki (1967) reported that with the increase in temperature (20 – 30°C) leaf silk conversion rate decreases. The physiological activities, food intake and economic parameters are influenced by body temperature of the silkworm (Anonymous, 1972). Sigematsu and Takeshita (1967) showed an increase in intake of mulberry leaves during late age with decrease in rearing temperature. Effects of various environmental factors on nutrional and water requirements of insects were studied (Hiratsuka, 1920; Legay, 1958; Kapil, 1963; Ito, 1967; Verma and Atwal, 1967; Scriber and Slansky, 1981; Delvi and Naik, 1984; Naik and Delvi, 1987; Mishra and Upadhaya, 1995; Rahmathulla and Geetha Devi, 2001). Muniraju *et al.* (1999) studied the effect of temperature on leaf-silk conversion in silkworm and reported that low temperature (26°C) throughout the rearing favoured higher silk conversion with better survival in bivoltine silkworm and 32°C during young age and 26°C during late age for multivoltine. Negative correlation for survival and cocoon yield was observed with increasing temperature up to 32°C and lethal beyond this temperature in case of bivoltine. Shen (1986) reported high efficiency of conversion in larvae reared at low temperature. Rahmathulla *et al.* (2002) analyzed the nutritional indices and nutritional efficiency parameters of 5th instar larvae of new bivoltine races (CSR2 × CSR4, CSR2 × CSR5 and CSR18 × CSR19) under different environmental condition. They demonstrated that the nutritional indices parameters like ingesta, digesta, approximate digestibility and reference ratio were superior under optimum temperature (23 – 25°C) and humidity conditions (65 – 70%). In adverse environmental conditions during 5th instar most of the nutritional efficiency parameters were higher than the control. During high temperature and low humidity conditions CSR18 × CSR19 race performed well. Most of the feed conversion efficiency parameters and ingesta and digesta required to produce one gram of cocoon and shell were higher in nutritional and environmental stress condition, This may be due to physiological adaptation of the larvae under different stress conditions (Rahmathulla *et al.*, 2004).

Aftab Ahamed *et al.* (2001) reported that administration of chloramphenicol resulted in increased conversion of food in to shell content, indicating its beneficial results of higher silk synthesis. They reported that food assimilated, assimilation rate, assimilation efficiency, food converted, conversion rate, and conversion efficiencies were significantly higher in the antibiotic treated silkworm batches, though the dry food consumed is on par with the carrier control. Significant decrement in dietary water loss through faeces and transpiration was reflected in higher water absorption efficiency and water retention efficiency in the silkworm larvae fed with antibiotic supplemented mulberry leaf.

Chronological variation in the consumption and utilization of food under diseased condition in insects was reported by Harper (1973), Ramakrishnan and Choudhary (1979). Nath *et al.* (1990) reported that food consumption in silkworm come down when infested with uzifly. Gururaj *et al.* (2001) reported that food consumption and assimilation decreased in BmNPV infected silkworm, to

Table 4. Nutritional parameters of mulberry silkworm under various feeding, environmental and nutritional conditions

Race	Condition	Ingesta (g)	Digesta (g)	AD (%)	ECI cocoon (%)	ECD cocoon (%)	ECI shell (%)	ECD shell (%)	References
CSR2 × CSR5	High temperature	3.10	0.897	28.76	17.77	61.36	8.65	29.86	Rahmathulla *et al.*, 2002
	High humidity	4.47	1.360	30.42	17.50	57.54	8.64	28.43	
	Normal	4.38	1.412	32.23	17.67	54.83	9.58	29.74	
PM × NB18	Local variety	3.598	1.012	50.04	15.06	37.87	-	-	Prabhakar *et al.*, 2000
	M5	2.68	0.775	41.04	17.94	53.33	-	-	
	S54	2.72	0.875	43.39	17.83	40.75	-	-	
Shin - Asagiri	Medium quantity feeding	5.80	2.600	40.00	18.00	47.00	7.90	16.0	Singh and Ninagi, 1995
C146 × C137	Medium quantity feeding	5.30	2.500	48.10	17.00	46.50	8.00	17.50	
C145 × C140	Medium quantity feeding	4.80	1.700	35.00	16.20	43.00	8.80	25.00	
Daizo	Medium quantity feeding	1.80	0.800	34.25	16.50	44.00	4.20	11.20	
Nistari	Food deprivation	1.40	0.902	35.62	20.72	58.35	-	-	Nath *et al.*, 1990
	Control	1.96	1.270	33.66	14.61	46.26	-	-	
NB_4D_2	Mealy bug infected leaf feeding	2.61	1.260	51.9	21.0	-	-	-	Aftab ahamed *et al.*, 2000
	Contol	3.38	1.620	51.80	14.70	-	-	-	
L × NB_4D_2	*Coffea arabica* extract fortified leaf feeding	4.04	1.740	43.15	22.53	52.21	-	-	Jeyapaul *et al.*, 2003
	Alternantherna sessiles	3.64	1.361	37.50	22.69	60.51	-	-	
	Control	3.58	1.302	36.33	17.30	47.85	-	-	
PM × NB_4D_2	Fortification with Chloramphennicol	2.94	1.642	55.8	17.70	-	3.10	-	Aftabahamed *et al.*, 2002
	Control	2.98	1.331	44.60	16.40	-	2.80	-	
NB_4D_2 × KA	Summer	4.60	1.841	42.82	16.13	47.00	9.09	26.47	Anantharaman *et al.*, 1994
	Monsoon	4.18	1.771	42.68	19.02	52.77	10.11	28.03	
	Winter	4.42	1.921	44.31	17.64	40.17	09.17	21.17	

Values of food intake are expressed in gm/larva/5th instar.
AD; Approximate digestibility; ECI: Efficiency of conversion of ingested food; ECD: Efficiency of conversion of digested food.

an extent of 11 and 9% respectively. In BmNPV infected larvae approximate digestibility percentage significantly reduced from 120 hrs onwards. However, for the entire 5th instar period, there was no significant difference. ECI and ECD% were significantly less by about 40% in BmNPV infected larvae. Food conversion was also less by about 46% in BmNPV infected larvae. On the contrary, Food oxidation in the BmNPV infected larvae was significantly high (11%).

Jeyapaul *et al.* (2003) studied the impact of plant extracts on nutritional efficiency in mulberry silkworm. In their study it was recorded that food assimilated, assimilation rate, assimilation efficiency, food converted and conversion efficiencies were significantly higher in plants treated silkworm batches. *Coffea arabica* treated batches (1 : 25 concentration) recorded significantly higher feed conversion parameters.

Effect of thyroxine on food ingestion, digestion and the digestive enzymes was made on the fifth instar mulberry silkworm were studied (Hemavathi and Bharathi, 2003) Food ingested, digested, leaf ingestibility were higher in the thyroxine fed larvae. The enhanced digestibility, protease and lipase activities indicate higher enzyme synthesis corresponding to enhanced food intake.

Conclusion

The growth and development of silkworm is easily influenced by the quality and quantity of mulberry leaf as well as various environmental factors such as temperature, relative humidity, light and air current. Innumerable

researchers in India and abroad were undertaken studies on the various aspects of silkworm nutrition and concluded that dietary efficiency is of paramount importance in enhancing the silk productivity. But it is rather pertinent to note that in nutritional studies repeatability of results is very scare because of variability of many factors. To get consistent results in nutritional studies further more studies and methodologies are required to be standardized. Further, nutritional studies should be continued to work out dietary efficiency of new breeds to be released by various research organization.

It was felt and also it would be appropriate and suitable to screen the improved productive hybrids to understand the conversion efficiency of ingested mulberry leaf in to silk. Another important study need to be undertaken on feed conversion efficiency of a particular breed/hybrid by feeding leaves of different mulberry genotypes and its effect on food ingestion, digestion and conversion efficiency of breed under different feeding regime, environmental and climatological conditions.

Further rapid development of biotechnology will be open up vast vistas and spawn a revolution in sericulture In the future, the gene controlling the character of high leaf-silk conversion rate could be transplanted into some silkworm races and it consequently improve the leaf silk conversion rate of new race.

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