
The important aim of research in the field of sericulture is improving the quality and the quantity of silk. This can be achieved only by an increase in the cocoon yield by using improved varieties of mulberry and also by supplementing the mulberry leaves with extra nutrient elements. In India, the possibility of giving an ideal food through artificial diets to silkworms at the mass level is remote. Therefore, one of the simplest yet effective method
to enrich the leaves is to supplement them with various known fortification agents. In recent years, several attempts have been made to fortify the mulberry leaves with nutrients such as carbohydrates (Ito, 1960; Kumararaj et al., 1972; Sengupta et al., 1972; and, Roychoudury et al., 1992), proteins and amino acids (Ito, 1978; Subburathinam and Krishnan 1998; and Alagumalai et al., 1999a and b), vitamins (Horie and Watanabe, 1980) and antibiotics (Alagumalai et al., 1991a and Dechu et al., 1997). Besides these, studies on the effects of hormones on the commercial characters of *B. mori* are also in progress. Prolactin was found to enhance the larval growth, reduce the larval duration and increase the fecundity of *B. mori* (Bhaskar et al., 1983 and Magadam et al., 1993). Insulin, thyroxine and adrenaline have resulted in a higher cocoon weight in eri silk AVorm (Padki, 1991 and Hemavathi and Bharathi, 2003).

The quality of the mulberry plant that serves as the sole source of nutrition for the monophagous silkworm, *li. mori*, has proved to be an appropriate means for improvement of seed and silk production in sericulture. The quality of the leaf has a great influence on the amount of food ingested. To boost the productivity of silk, improved quality of leaf of mulberry variety is to be used for the
silkworm rearing. It is a well known fact that the quality of the mulberry leaf has an intimate relationship with the nutritive value of the leaf (Takeuchi, 1959). The nutritional content of the leaf depends on the levels of moisture, protein, minerals, fat, crude fibre, sugar, starch content and other substances (Sinha and Jolly, 1971 and Agarwal et al., 1980). The biochemical substances in the leaves highly influence the growth and development of the insects (Krishnan and Chockalingam, 1981; and Krishnan et al., 1984).

Different varieties of mulberry exhibit differences in the nutritional quality of the leaves (Karasawa, 1957 and Hassanein and Shaarawy, 1962b). Similarly the differential effects of the mulberry varieties on silkworm growth was elucidated by Yadav and Goswami (1992), Sikdar (1993), Rupa et al. (1993) and Chenthilnayaki et al. (2004). Improvement of food value in mulberry is mainly determined by the quantity and the quality of proteins found in the leaves (Hirano, 1980). So, variations in the patterns of leaf protein in different varieties of mulberry leaves require elucidation.

Several workers have shown that different varieties of mulberry affect silkworm rearing differently.
Karasawa (1957), through rearing studies, established the nutritional status of six mulberry varieties and proved the nutritional superiority of KNG over Mysore-local, Goshyoerami, Kosen and Selection I varieties. Seki and Oshikane (1959) made similar observations and documented changes in the economic characters of cocoon when larvae were fed with different varieties of mulberry leaves. They further reported that some varieties were distinctly superior to others with regard to larval growth, success of cocoon crop and cocoon characters. On the basis of cocoon and shell weight, Hassanein and Shaarawy (1962a) established highly significant differences in the nutritional factors of The mulberry varieties and they ranked the six mulberry varieties in the order of Japanese, Selvarica, Moretlins, Rosa, Roumi and Lbu. Further the nutritional superiority of K$_2$ over Mysore-local was proved through silkworm rearing experiments (Narayanan et al., 1966 and Chawla, 1969). They demonstrated differences between different varieties of mulberry plants and their influence on larval growth and weight., Tayade and Javvale (1984) observed that the economic characters of hybrid silkworm cocoons were improved by feeding S$_4$ variety rather than Kanva -2, Kosen and I. M-2 varieties. By feeding experiments, Susheelamma et al. (1989) observed that ACC-143 and
ACC-203 varieties of mulberries were superior to other varieties of mulberry cultivars (Kanva 2 and Local). Differences in silk ratio in the cocoons (Pillai et al. 1981), cocoon performance of silkworm (Giridhar and Reddy, 1991) and silk gland volume (Giridhar et al., 1991) in different silkworm breeds due to different mulberry varieties indicate that different varieties of mulberry affect silkworm rearing in different ways.

IMPORTANCE OF PROTEIN IN NUTRITION

Among various supplementations tested, dietary protein is known to have a significant impact on silkworm growth and silk production (Subbarao et al., 1989; Zhang et al., 1991; and, Subburathinam and Krishnan, 1998) and also on the haemolymph protein concentrations (Horie and Watanabe, 1983) in silkworm, B. mori. The quality of dietary protein is an important determinant of herbivore insect feeding, growth, survival and population dynamics (Slansky and Scriber, 1985; Bernays and Barbehenn, 1987; Mattson and Scriber, 1987; Felton et al., 1992; and, Karowe and Martin, 1993). It has been established that a nutritionally unbalanced protein diet will reduce a herbivore’s growth rate by imposing a metabolic load (Krishnan, 1985 and Schroeder, 1986). So a balancee
protein diet is essential for the optimal growth of silkworm. Krishnasastri (1986) expounded that the protein available in mulberry leaf is one of the important factors determining the suitability of the leaves for feeding silkworms.

Several attempts have been made using proteins such as egg albumin, casein and soybean as dietary supplements on silkworm, *B. mori* (Sengupta *et al.*, 1972). In most previous studies soyabean was used as a component in the artificial diets (Ito *et al.*, 1975 and Horie and Watanabe, 1983).

SOY PRODUCTS IN SILKWORM NUTRITION

Soybean and its products are used as protein sources in silkworm diets (Ito *et al.*, 1975). Among the soybean products, soybean protein, soybeanmeal and defatted soybean meal are used commonly in feeds (Reinecke, 1985). Soybeans are rich in protein (38-42 percent) and contain other nutrients such as carbohydrates and lipids (Wolf and Cowane, 1971 and Smith and Circle, 1978). Ito *et al.* (1975) claimed that only minor differences exist in amino acid composition between mulberry leaves and soybeanmeal. The co-efficient of pattern between the two was calculated to be 0.925. Because of such similarity soy protein has been included in the feed of silkworms from time immemorial.
(Ito et al., 1975). Hence silkworm, B. mori has a long history of rearing on diets containing a variety of soybean products as indicated through the nutritional research conducted on defatted soybeanmeal and various other proteins (Ito and Arai, 1973). However, these studies were carried out using soy protein as a component in the artificial diet and not as supplement along with mulberry leaves. Mathavan et al. (1984) observed that a protein, in its hydrolyzed form, is more effective in enhancing silkworm growth than in the intact form.

PROTEIN SUPPLEMENTATION

It is important to emphasise the optimal level of dietary protein while discussing the effect of protein on insect nutrition because the dietary protein is effective only upto an optimal level, beyond which the larval growth is impeded considerably. The growth rate of Pseudosarcophaga affinis was poor on a diet containing 0.75 percent amino acid but improved much at 2-3 percent level. Nevertheless, it was relatively poor at 4 percent amino acid level but improved much at 2-3 percent level (House and Barlow, 1956). Maximum growth rate in the red flour beetle, Trifolium castaneam was observed at 8 percent protein level, while decreasing growth response was noticed
above this level (Medrano and Breassani, 1977). Larval growth of *B. mori* increased as the concentration of soybean meal in the diet was increased (Horie and Watanabe, 1983). The best growth was observed with 30 percent soybean meal, while a higher concentration of the nutrients resulted in the reduction of larval weight and heavy mortality.

It was reported by Brewer *et al.* (1985 and 1987) that the larval development of spruce budworm, *Choristoneura accidental is*, was optimum when the larvae were fed on a diet containing 2.4 percent protein. A higher or a lower concentration of protein in the diet resulted in a significant reduction of larval development.

In general the dietary efficiency of any nutrient in the diet increases with an increase in the level of supplement proteins, but excessive incorporation is found to be detrimental. Broadway and Duffey (1986) found that different dietary regimes resulted in significant differences in the larval weight gain. In a diet containing 1.2 per cent casein, the larvae of *S. exitus* attained optimal growth, whereas in a lower concentration of 0.6 percent casein, the larval growth and the development were delayed. Similarly, the larvae of *H. zea* grew fast with 1.2 percent casein, while
there was delay with a higher or a lower concentration of casein.

Bloom and Duffey (1990a) revealed that high and low levels of dietary protein (above five percent and below one percent) significantly reduced the gain in larval weight of *H. zea* and *S. exigua*. The dose response curves for the two species were similar, although *H. zea* was less sensitive to reduced dietary proteins than *S. exigua*. Bloem and Duffey (1990b), in another experiment, observed the toxicity of rutin in *H. zea* larvae, which varied significantly with varying levels of soy protein and casein in the diet. The growth rate of *Telogryllus commodus* increased linearly with increasing casein at low concentration and levelled off at higher casein levels (Burgess *et al.*, 1991). It has been reported that soybeanmeal accelerated the silkworm larval growth significantly up to a certain level, but inclusion of defatted soybeanmeal in the diet had a detrimental effect (Roychoudhury and Roychoudhury, 1995).

Although the majority of the literature on the nutritional value of insect food emphasise the importance of protein quantity (Mattson, 1980., and, Scriber, 1984), protein quality is also a crucial factor influencing the growth and the development of insects.
(Bernays and Woodhead, 1984). It is also inferred that the optimal dose differs from protein to protein and also between insects. Hence, determination of optimal dose becomes a must for such a study.

PROTEIN PROFILE STUDIES

In insects, haemolymph is the reservoir of amino acids, which, in turn, play a major role in moulting and reproduction. In silkworm, storage proteins are the major haemolymph proteins that are utilized for larval-pupal transformation, reproduction and adult development (Tojo et al., 1978 and Levenbook, 1985). In B.mori, storage proteins are of two types, SP1 and SP2 (Tojo et al., 1980). SP1 (82 kDa) is female specific. SP2 (76 kDa and 72 kDa), an arylphorin, is the most abundant protein in the haemolymph of both male and female and has 8.8 percent tyrosins and 9.7 percent phenylalanine. The concentration of SP1 in the case of female and that of SP2 in the case of both the sexes increases in the haemolymph during the fifth-instar and reaches a maximum before spinning.

Sekeris and Scheller (1977) reported that the storage proteins are synthesized by the larval fat body and secreted into the haemolymph. Riddiford and Hice (1985) state the synthesis of these storage proteins depends
feeding activity of the larvae. Protein in the haemolymph decreases during larval-pupal transformation, coinciding with their increase in the fat body cells. Tojo et al. (1980) confirmed the presence of storage proteins in the fat body at the time of pupation. For the purpose of tissue formation in the adult, the storage proteins are selectively taken from the haemolymph into the fat body and stored in the form of protein granules (Levenbook, 1985).

The increase in the levels of protein and amino acids in the haemolymph of *H. zea* and *S. exigui* with increased concentrations of dietary protein was observed in the studies of Bloem and Duffey (1990a). Inockuchi (1970) conducted studies on the effect of dietary amino acids on the concentration of protein in the haemolymph of silkworm larvae. The total haemolymph protein level in the silkworm larvae was closely associated with the level of essential amino acids in the artificial diet (Horie et al., 1971). In the silkworm larvae fed with artificial diet containing soybean, the concentration of protein in the haemolymph was enhanced with increasing concentration of dietary protein (Horie and Watanabe, 1983). The studies of Nagata and Kobayashi (1990) suggested that the protein in the diet influenced the accumulation of storage proteins SP1 and SP2 in the haemolymph of silkworm, *B. mori*. 
The study by Janarthanan et al. (1999) emphasised the importance of nutrition and hormone on the storage protein in silkworm, *B. mori*. Though the development of most insects is directly or indirectly controlled by hormones, it could also be partly regulated by food intake (Calvez, 1981). It is evident from the perusal of literature that the study of storage protein (SP1 and SP2) in the haemolymph is used as an important marker in evaluating the nutritional value of the supplementary protein.

**NUTRITIONAL INDICES**

It is clear from the literature survey that nutrients have a significant impact on various nutritional parameters, which is manifested in larval and pupal characters.

Naik and Delvi (1987) and Anantharaman et al. (1993) have reported on consumption and utilization of food by silkworm, *B. mori*. Waldbauer (1968) study on consumption, digestion and utilization of food in insects reflected the nutritional status of insects. Muthukrishnan et al. (1978) and Takano and Arai (1978) stated that moulting, synthesis of silk protein, body weight gain, cocoon productivity, silk production and seed production of silkworm depend on the quantitative and the qualitative variations of protein in the feed. Horie and
Watanabe (1983) also reported that the fifth instar larvae digested and absorbed over 60 percent of the ingested protein and 65 percent of the digested protein for the synthesis of silk protein.

The protein content of the food benefits the lepidopteron either directly or indirectly (Dhandapani and Balasubramanian, 1980), while, in diptera, the effect is not prominent (Sang, 1956 and Baker, 1975). It has also been pointed out that the dry matter ingested by the silkworm, *B. mori* declined gradually with an increase of soy protein level in the artificial diet (Horie and Watanabe, 1983). A significant negative relationship was observed between the percentage of dietary protein and the feeding rate. Similarly a negative relationship was observed between the dietary protein and the faecal ejection in the larvae of *H. zea* and *S. exigua* by Broadway and Duffey (1988). Zhang *et. al.* (1991) also reported a negative correlation between the consumption rate and the soy protein level of the artificial diet. His study also showed a negative correlation between the protein content of the diet and the faecal ejection of the experimental larvae.

Scriber and Slansky (1981) and Mattson and Scriber (1987) revealed a positive correlation between the food
utilization efficiency and growth rates of herbivorous insects on the one hand, and the protein content of the diet on the other. In southern armyworm, *S. eridania*, Karowe and Martin (1989) studied the extent to which growth and metabolic rates were affected by the quantity and the quality of protein in the diet.

The supplementation of thyroxine along with the mulberry leaves enhanced the efficiency of conversion of ingestion and digestion in *B. mori* (Hemavathi and Bharathi, 2003). *Atticus ricini*, when fed with a diet rich in protein, increased the percentage of digestibility, gross conversion efficiency and net conversion efficiency (Shaarawy et al., 1975). In the nymphs of *Schistocera gregaria*, Bernays and Woodhead (1984) observed an increase in the efficiency of conversion of ingested food to body substance due to the amino acid supplementation. Mathavan et al. (1984) observed increased gross and net conversion efficiencies in the silkworm supplemented with *Spirulina sp*.

**ECONOMIC CHARACTERS**

Improving the economic characters is the main objective of supplementing the silkworm with various nutrients. Shamachary et al. (1980) observed that the larval weight had a direct influence on the cocoon weight, shell
weight: and pupal weight in the silkworm, *B. mori*. Several attempts have been made, using various nutrients, to enhance the larval and cocoon characters of *B. mori*. Studies on mineral supplementation to the larvae of *B. mori* resulted in increased larval growth and cocoon weight (Loknuth *et al.*, 1986 and Subburathinam *et al.*, 1993). Enrichment of mulberry leaves with vitamins also enhanced the cocoon characters of *B. mori* (Chauhan and Singh, 1992). Fortification of mulberry leaves with extra nutrients such as glucose, glycine, egg albumin and molasses was found to increase the larval growth and improve the cocoon characteristics (Sengupta *et al.*, 1972 and Babu, 1994). Magcsh and Devaiah (1996) have inferred that a feed additive named sericare influenced the silk productivity of *B. mori*.

Above all, the dietary protein has a significant effect on the commercial characters of *B. mori*. Earlier studies proved that increasing the concentration of protein in the diet increased the silk production by accelerating the silkworm larval growth (Zhang *et al.*, 1991; and, Vanishree *et al.*, 1996). An increasing trend in the larval characters and cocoon characters was observed in *B. mori* led with artificial diets containing soyabean (Horie and 'Walanabe, 1983). Bhaskar *et al.* (1983) and
Mathavan et al. (1984) observed increased larval weight and decreased larval duration when the silkworms were fed on mulberry leaves fortified with prolactin and single cell protein (SCP) respectively. A positive correlation between the protein content of the diet and the larval weight of *H. zea* and *S. exigua* was noticed by Broadway and Duffey (1986). In 1988, Broadway and Duffey pointed out that the larval growth of *S. exigua* significantly varied with respect to dietary protein type.

An increasing trend in larval weight with the increasing levels of soy protein in the artificial diet was observed by Watanabe et al. (1990). Zhang et al. (1991) observed a positive relationship between soy protein content and silkworm larval weight and a negative relationship between the protein and the larval duration of the fifth instar of *B. mori*.

In the case of *B. mori*, the whole process of egg development is completed during the non-feeding pupal period. On emergence, the adults do not feed and they concentrate on depositing the eggs. Hence the pupal metabolism and the fecundity of *B. mori* depend entirely on the amount of energy stored during the larval period (Mathavan et al., 1984). The reports of Purohit et al. (1975),
Krishnaswami et al. (1978) and Mukherjee et al. (1983) stated that, in some species of insects including silkworm, *B. mori*, the nutritional condition during immature stages contributed much to the quantity of eggs laid by the adult.

The importance of the amino acid composition of the diet for reproduction in insects has been documented in the case of several species of aphids by Retnakaran and Beck (1968) and Emden (1973), adult mosquitoes by Briegel (1985), and, the larvae of the commercial silk moth, *B. mori*, by Horie and Inokuchi (1978). Horie and Watanabe (1983) and Rahaman et al. (1990) observed that *B. mori* reared on ascorbic acid enriched mulberry leaves produced more eggs than the untreated females.

The egg production and egg production efficiency were enhanced in the larvae of *Ceratitis capitate* when fed with different types of protein diets (Cangussu and Zucolota, 1992). The egg production and the egg weight in silkworm, *B. mori* were increased by the soy protein in the artificial diet (Zhang et al., 1991). In the case of *B. mori*, development of heavy females with more number of eggs resulted due to supplementation of amino acids (Kumarilalitha et al., 1992) and soy protein (Vanishree et al., 1996).
In insects, *Anthocaris cardamines* (Courtney, 1981), *Choristoneura famiferana* (Renwick and Radke, 1982) and *Colias philodice* and *C. interior* (Karowe, 1988), a positive and highly significant correlation between female pupal weight and fecundity was observed. In muga silkworm, *Antheraca mylita* (Ahsan et al., 1976), in oak tasar silkworm, *A. polyphenius* (Miller et al., 1982), in *A. proylei* (Rajendra and Bardaiyar, 1982; and, Rajendra et al., 1994), in eri silkworm, *P. riciri* (Rajendra and Prasad, 1987), in *Samiacynthia ricini* (Kotikal et al., 1989) and in silkworm, *B. mori* (Krishnaswami et al., 1978; Shamachary et al., 1980; Jayaswal et al., 1991; Subburathinam et al., 1991; and, Shaheen et al., 1992) correlation studies between cocoon weight, pupal weight, shell weight and fecundity have been well documented. Perusal of literature revealed the importance of the dietary protein on the economic characters of the silkworm, *B. mori*.

LAB TO LAND FIELD TRIAL

Though technological improvements made in the field of sericulture have earned India the second position among the raw silk producing countries in the world, the level of technology adoption is still low and far from satisfactory (Chikkanna et al., 1992). A large gap exists between the
researchers and the farmers. To bridge this yawning gap between the researchers and the farmers, the lab to land field trial appears to be a major step to motivate the sericultural farmers. The main aim of the lab to land field trial is to motivate the small and the marginal sericulturists to take up the improved technologies achieved by promoting close contacts with the researchers.

In an on-farm study, Roychoudhury et al. (1992) pointed out that the enrichment of mulberry leaves with sucrose and commercial sugar increased the effective rate of rearing (ERR), total crop yield, cocoon weight, shell weight and cocoon / shell ratio. They also showed an improved performance by the cost-benefit analysis.

On-farm trials done by Das et al. (1993a) indicated that the supplementation of sucrose in the selected fields showed an improvement in the cocoon production besides providing a high return to the farmers as compared to the control groups. Therefore technology transfer from lab to land is absolutely essential for getting better returns.